26 September 1975, Volume 189, Number 4208

SCIENCE

Energy Analysis and Public Policy

The energy unit measures environmental consequences, economic costs, material needs, and resource availability.

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Responsible development of energy resources and allocation of energy research and development monies requires an analysis of many social, economic, and environmental options. Technology assessment and the environmental impact statement have evolved as mechanisms through which options can be identified, analyzed, compared, and subjected to public scrutiny. Both mechanisms require the analyst to consider potential impacts ranging from those which can be rigorously quantified to those which are inherently nonquantifiable.

A major difficulty, one that exacerbates the uncertainty with which decision-makers are almost always confronted, is that different units are commonly used in measuring impacts. One of the most commonly used units is dollars. Economists often use sophisticated techniques to convert a broad range of "apples and oranges" impacts into dollars. Environmental impacts are typically treated as externalities and stated in dollar amounts. But this attempt to evaluate all, or even most, impacts in terms of dollars is being challenged. A growing number of ecologists and environmental interest groups argue that dollars are an inappropriate measure for some impacts and that economic estimates of impacts represent, at best, only a fraction of the true environmental costs or benefits.

An example of the inadequacy of dollars as an assessment measure is the mineral resource classification system, utilized within the Department of the Interior by the Bureau of Mines and the U.S. Geological Survey. In an attempt to provide realistic energy estimates, Interior's classification system subdivides resources according to two criteria: the extent of geological knowledge about the resource, and the economic feasibility of its recovery. Reserves generally refer to economically recoverable material in identified deposits, whereas resources include deposits that cannot be recovered due to economic and legal constraints (*1*). However, definition of reserves using an economic criterion carries an implicit bias. At best the criterion provides information on whether or not the costs of bringing the resource to the consumer are competitive with the costs for resources already in production; thus, the reserve estimates change every year and yield little insight into quantities available for the long term.

What is needed to improve the analysis of interrelations and trade offs among environmental consequences, economic costs, material requirements, and resource availability is a comprehensive but simplified set of consistent measures drawn from a single external conceptual system. The energy accounting procedures or net energy analysis utilized by Odum (*2*), Berry and Fels (*3*), Chapman (*4*), and Slesser (*5*) provide such a mechanism.

The remainder of this article is divided into three parts. (i) The concept of net energy is discussed, including a description of the means by which net energy is measured, its relationship to energy demand, material shortages, dollar costs, environmental stress, and reserve estimates; (ii) net energy analysis is demonstrated through an evaluation of geothermal energy development; and (iii) some observations are made concerning the uses and limitations of the technique in the public policy-making process.

Net Energy and Energy Subsidy

Net energy has been defined as the amount of energy that remains for consumer use after the costs of finding, producing, upgrading, and delivering the energy have been paid (*2*). In Fig. 1, these energy costs are conceptualized and illustrated as energy subsidies, or feedbacks of high-quality energy which serve to "open the valves" for development of more energy. Indications are that, as we extract more dilute, deeper, and dirtier energy sources, the energy subsidy required to extract and upgrade the new sources increases. Some portion of each year's new energy demand represents additional subsidies to energy extraction. Consequently, an increase in energy demand or consumption may not represent an increase in the amount of energy available to do work in the consuming sectors of society. The entire increase may be required to get the new energy. Note that this has not always been true, since technological advances sometimes compensate for any decrease in the quality of the resource. The introduction of solid state electronics into the electronics industry is a case in point. Electric power generation is another example. When efficiencies increased and fuel oil costs decreased (due to advances in drilling technology), there was a net energy increase. Whenever new technological capabilities increase the efficiency of performing the same task, net energy increases. These technological advances themselves require energy (for research and development); however, this energy investment has traditionally made large energy savings possible.

In Fig. 2, the relation between money and energy is illustrated in more detail and the external inputs or subsidies are divided into three types: direct energy, material, and environmental subsidies. The processed energy used for process heat, in transportation and in manufacturing materials, is a direct energy subsidy.

Material subsidies are less straightforward. They may include goods, services, capital, labor, and information. Material, labor, and capital requirements are most often measured in terms of economic costs. However, estimates of the energy values of

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these inputs can be made by evaluating the fuels needed for resource extraction, transportation, manufacturing, labor, services, and capital expenditures. From an analysis of the network of processes which contribute materials to manufacture a commodity, the inputs of the suppliers and of their suppliers can be identified. The energy required to manufacture each input can be obtained from a number of sources. Data in raw form are given in the *Input-Output Structure of the U.S. Economy*, and in the *Census of Manufacturers* (*6*). In addition, several documents now give energy cost data in a more usable form for selected materials (*3, 7, 8*).

It should be noted, however, that procedures for energy accounting are currently not consistent, consequently the actual analysis is not as straightforward as my description might suggest. For example, some investigators do not give labor an energy value at all, others assign it the energy content of the food the worker eats, and still others assign to it the total energy consumed by each worker (as measured by the goods, services, and food he consumes). Capital depreciation is often not included, but some authors assign to it the energy cost of replacing the capital goods. Some of the procedures now in use for energy accounting are compared and demonstrated in a series of articles in *Energy Policy* (*4, 8*).

When all input requirements are analyzed, it becomes clear that energy limits the ability to obtain any input. This had led to the concept of energy as the ultimate limiting factor, which is to say: (i) that energy is the only commodity for which a substitute cannot be found, (ii) that potential energy is required to run every type of system, and (iii) that energy cannot be recycled without violating the second law of thermodynamics.

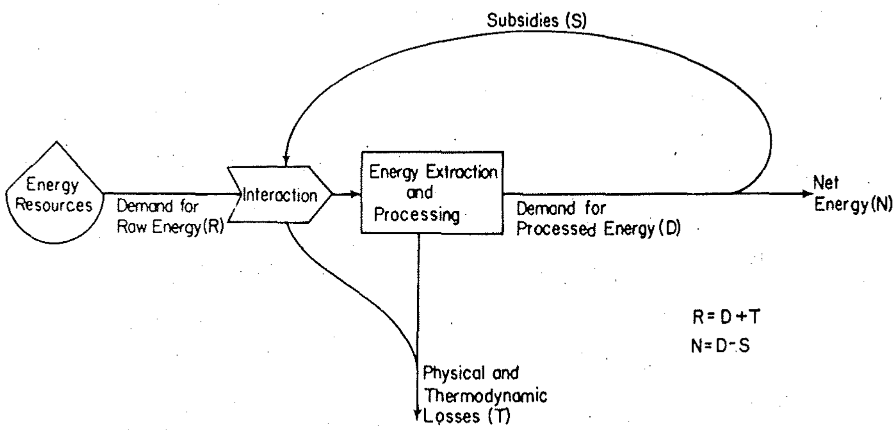

Fig. 1, Functional relationship among net energy, energy demand, and energy subsidy.

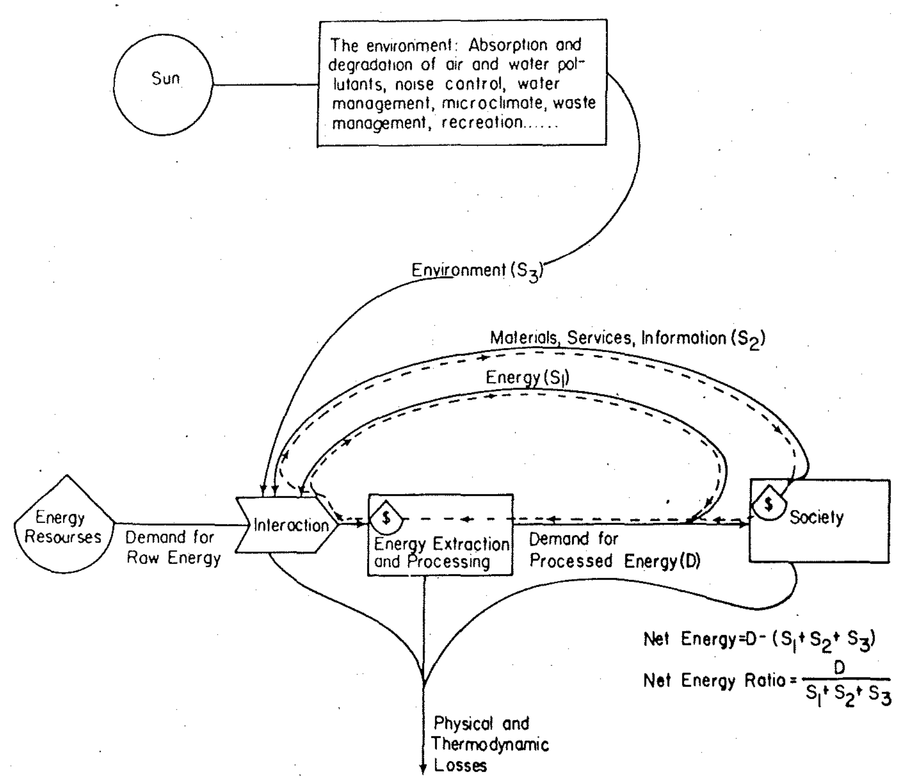

Fig. 2. Categorization of energy subsidy types and the countercurrent relation of dollar flow to energy flow. Solid lines represent energy flow and dashed lines represent dollar flow.

Project Independence identified many kinds of constraints or limiting factors on development of energy resources—shortages of steel, draglines, drilling rigs, certain catalysts, water, and certain types of manpower were discussed. In fact, however, all of these have a common denominator, energy. With ample energy, all materials can be produced or substitute materials found. For example, seawater can be desalinated and pumped to the arid West for oil shale and coal development, synthetic substitutes for catalysts can be made, and ash and radioactive waste can be rocketed into the solar system. The sulfur can be taken out of the coal either before combustion, during combustion, or with stack gas cleaning technologies; we can drill to 30,000 feet (9000 meters) for natural gas, extract the oil from oil shale and reclaim the land, and recover additional oil from old oil reservoirs using advanced recovery techniques. However, all of these material needs and advanced processes require energy; thus energy itself is an important limiting factor to increasing energy supply.

The environment also subsidizes energy development, because it provides direct services to man. Woodwell (*9*) refers to these as the "public service functions of nature." For example, terrestrial ecosystems purify the air by absorbing and recycling air pollutants; similarly, aquatic ecosystems purify the water. Through soil stabilization and evapotranspiration, ecosystems maintain the hydrologic cycle and the quantity of water supplies. They also control the diversity of plant and animal populations, provide recreational opportunity, and produce useful products such as food and lumber. Recently, pollution has increased to levels beyond the absorptive capability of the ecosystem, thereby causing changes in the ecosystem (usually toward less productivity). When changes are significant, society pays to mitigate the ecosystem damage through "environmental technology," that is, stack gas cleaners and advanced waste water treatment plants.

Dollar evaluations of impacts may account for the cost of the environmental technology or the cost of crop damage, but the energy value of the environmental subsidy is much larger since the ecosystems deal with lower levels of pollution and provide many other services without cost. Schumacher (*10*) argues that "production depends heavily on the capital provided by nature in the form of air, water, and resources," and that "we treat this capital as income, and value it at nothing." A dollar evaluation based on the cost of controlling pollution, providing water, recreation, and other services where no ecosystems exist at all might come closer to measuring the total environmental subsidy.

Thus purely natural ecosystems, as well as agricultural systems such as North Dakota's wheatlands and Montana's cattlelands, have high energy value for man. Their value will be lost for some time while coal is stripped from the subsurface. Western oil shale and coal resources are located in water-scarce regions and their exploitation consumes large quantities of water. If a decision is made to allocate water to western energy development, many agricultural users may not only be denied water but the quality of what is available may be reduced. Until vegetation is reestablished, runoff will be much greater than on grass-covered soils. These losses in natural value must be included as lost subsidies in net energy calculations. They represent losses to society that are partially paid for with expensive technology and sometimes compensated for by direct payment to those receiving the damages, as is now being considered for the coastal states adjacent to outer continental shelf oil and gas development.

The energy value of environmental subsidies is generally evaluated by calculating the losses in photosynthetic activity (as reflected in reduced gross primary productivity) caused by land disruption or ecosystem change (*11*). Gross primary productivity is a measure of the amount of sunlight captured and concentrated by plants and, consequently, is a measure of the work the ecosystem does. Additional measures may also be important, such as the work the sun does by inducing a heat gradient within the ecosystem (measured by the Carnot ratio), and the work done by the kinetic energy of the wind or tides (in the case of a coastal system) coming from outside the system. If the heat gradient within the ecosystem or wind flow through it were changed by the development, these changes would also affect the net energy calculation.

In summing the various types of energy subsidies, all energy measures must be of the same quality. Energy forms are the same quality if they are equivalent in their ability to do work. For example, a calorie of electricity can do more work than a calorie of coal or oil and both can do more work than a calorie of sunlight. Energy quality is calculated by evaluating the energy used in converting from one energy form to another, that is, by evaluating the amount of one type of energy required to develop another. In the conversion of coal to electricity, physical and thermodynamic losses occur and auxiliary energy is used within the process and in maintaining the industry structure. The ratio of energy delivered to the sum of the losses plus the auxiliary energy is the quality conversion factor for coal to electricity. As such, 3½ units of energy in the form of coal are equivalent to 1 unit of electricity in their potential to do work (*12*). Most people are familiar with quality differences between electricity and coal, but there are similar differences among other energy forms. For example, petroleum is approximately 2000 times more concentrated than the sun's energy, 20 times more concentrated than photosynthetic energy (sugar), and 40 times more concentrated than wind energy (*12*). Since electricity is 3.5 times more concentrated than petroleum, it requires 7000 calories of sunlight to produce 1 calorie of electricity (2000×3.5). Higher quality energy can do work that was not possible at all with the original energy forms; electronic communication is not possible without electricity; and, as defined here, information is the highest quality energy form, since it requires large amounts of time and energy (for research teams, educational institutions, and libraries) to develop. In order to obtain the total energy subsidy for a process, all types of subsidies must first be converted to the same quality.

Money and Energy

Figure 2 shows the flow of money in the opposite direction to the flow of energy, indicating that the mining and processing sectors pay society for material and information, and society pays the processing sector for high-quality energy. The ratio of the two countercurrent flows (money and energy) is the price of the material (dollars per kilocalorie) or energy expended per dollar cost (kilocalories per dollar). The average price, or energy expended per dollar, for any given year is the ratio of total U.S. energy consumption to gross national product (GNP) for that year. In real dollars, this ratio was 21,200 in 1963; in 1970 it was 17,300 and in 1972 it was 15,800 (*13*). With the use of this ratio it is possible to convert dollar cost into energy subsidy. However, this represents average dollar to energy conversions for the entire economy, so that only an approximate energy value for a wide mixture of goods and services can be obtained. In addition, the dollar costs may include hidden institutional subsidies (that is, tax depletion allowance), or represent some regulated price rather than true costs. For specific sectors of the economy such as primary metals, mining, and petroleum refining, more accurate dollar to energy conversions can be estimated. Kylstra (*13*) calculated that in 1963 the primary metal sector used 28,665 kilocalories per dollar while the mining sector used 22,050 kilocalories per dollar. Up to date, dollar to energy conversions are needed if net energy analyses rely on costs. In principle, however, it is possible to account for all the energy subsidies directly without relying on cost and dollar to energy conversions. The important point is that a conversion and functional relation between the flow of money and the flow of energy exists, with the ratio of energy to money decreasing as one progresses within the economy from the fuel processing and primary raw materials processing sectors through manufacturing and energy conversion processes and finally to the consumer, who receives the smallest amount of energy for his dollar.

Figure 2 indicates that there is no money flow associated with either environmental subsidies or raw energy flow. We do not pay nature for each acre of land taken out of biological production, nor do we pay nature for the millions of years of work it did in making coal or oil. We pay industry to mitigate the environmental losses through environmental technology and to extract and upgrade the coal and oil. As indicated in Fig. 2, money circulates in the economy, but the sun and the raw coal, oil, gas, and uranium drive that circulation.

Economic Feasibility versus Energy Feasibility

Economic feasibility studies done in the past for extraction of oil from oil shale concluded that it was economically unsound, that is, large monetary expenditures were required. In terms of Fig. 2, this also means that large energy expenditures (labor, materials, water, and capital structure) were required. The amount of energy in the feedback loops for oil shale development was larger than for other energy sources, and that is what made it uneconomic. Recent economic studies conclude that extraction of oil from oil shale may be economically feasible, although the amount of energy in the feedback loops has not changed. The change is in the fact that other energy sources now require the same amount of subsidy; thus, oil shale now appears to be competitive. The net amount of energy which will go to society has not changed either, but where U.S. Geological Survey reserve estimates previously indicated zero, they now will show some economically feasible quantity. The true reserve to society is probably neither number. Net energy estimates will not change with changing dollar values. They

Table 1. Energy flow from the wellhead to the consumer for a 100-megawatt geothermal power plant at 80 percent load factor for 30 years.

Resource flow	Steam-driven turbines	
	Dry steam reservoir* (10^{12} kcal)	Wet steam reservoir–two-stage flashed† (10^{12} kcal)
At wellhead	116.0	164.2
Input to power plant	115.0	154.4
Steam ejector use	4.7	Unknown
Total generated as electricity	18.7	19.0
Auxiliary power use	0.6	0.9
Net output of electricity	18.1	18.1
Delivered to consumer as electricity‡	16.5	16.5

*Based on the Geysers, California (*20*). †Based on a 6 percent energy loss from the wellhead to the power plant and 11 percent efficiency from the wellhead to the transmission line (*21*). ‡Transmission and distribution loss of 9 percent.

will, in fact, remain constant with time unless technological advances in conversion efficiencies occur. Thus, the economic costs may measure the relative amount of energy in the subsidy (assuming hidden dollars in the form of depletion allowances are somehow negated), but they do not provide information on when the subsidy exceeds the output.

Economically, geothermal energy development now appears to be a viable option. Present average investment costs for geothermal power are \$250 per installed kilowatt. However, as high salinity brines, lower temperature fluids, and hot dry rock sources are exploited, these investment costs are expected to rise to \$500 per kilowatt in constant 1973 dollars. The cost rise is a result of the low quality (that is, deeper, more dilute, dirtier) nature of these new geothermal reservoirs. They will yield no more energy to society in the future than they would now. The reason we are not exploiting them now is that they require more subsidy (energy feedback) than competing sources do.

These examples emphasize the importance of answering the question: how much of the projected new energy demand for 1985, 1990, and later will be expended to increase or maintain net amounts of energy and thus the real GNP, and how much is simply the energy subsidy required to obtain and upgrade the new dilute energy sources? Estimates of net reserves require answers to questions such as: at what combination of depth, energy content, and sulfur content does coal cost more energy to extract, clean up, and process than it yields? Any coal with better characteristics than this "cutoff" combination is part of the reserve. At what depth onshore and offshore will oil and natural gas be net yielders? How much heat or chemicals can be pumped into an oil reservoir for secondary or tertiary recovery before more energy is being pumped in than is in the oil when it gets to the consumer? What is the "cutoff" combination of heat content, mineral content, and depth which makes a geothermal reservoir a net yielder? The reserve is the amount that exists with better characteristics than the cutoff characteristics. It is this net amount which will allow the United States to grow economically. Any amount below the net amount will be required just to maintain the present state. Within the net reserve category, some energy development will require less subsidy than others, thus some will be more economic to extract and process than others.

Geothermal Energy Reserves

It has been argued that, since geothermal energy is the natural heat of the earth, the geothermal resource is all of the heat in the earth's crust above the mean surface temperature or above 15°C. Since this heat is diffuse, a geothermal reservoir is said to occur whenever the heat flow from depth is one and one-half to five times the worldwide average of 1.5×10^{-6} calories per square centimeter per second. In addition, it has been postulated that geothermal energy from dry hot rock systems is almost limitless, since drilling 5.5 to 7.5 kilometers under a typical earth temperature gradient of 25°C per kilometer would yield the required 150°C to 200°C for geothermal power. On this basis, Rex and Howell (*14*) estimate that 40,000,000 megawatt centuries of electricity (megawatts of capacity with a projected life of a century) are available by exploiting hot dry rock at less than 10.5 kilometers.

On the other hand, the volcanic area being investigated for hot dry rock in the Jemez Mountains in New Mexico has a temperature gradient of 180°C per kilometer, which is 7.2 times the normal temperature gradient of the earth. A temperature of 200°C can be reached within 1.2 kilometers. This system could be a net energy producer.

Ideally, the question which should be addressed is: What combination of technological efficiencies, heat flow, and depth yields net energy? Unfortunately, data are not yet available to do accurate total net reserve calculations. Systematic and consistent compilations of the energy per kilogram required for all types of goods and services, and the kilograms of raw and manufactured materials required for every major piece of equipment are needed. Thus, the analysis below is presented both as a methodology for others to use and develop, and as a preliminary step in the evaluation of geothermal net energy reserves. Two power cycles using energy from two types of geothermal reservoirs were considered: a dry steam reservoir with steam driving the turbine, and a wet steam reservoir with two-stage flashed steam driving the turbine. As more data become available, the comparison will be extended to include binary systems and total flow impulse turbines using heat from wet steam reservoirs and from hot dry rock reservoirs.

Table 1 gives the physical and thermodynamic losses of energy as it is transformed from the enthalpy (heat content) in the steam or hot water at the wellhead to electricity delivered to the consumer. Output is based on a 100-megawatt (net) capacity power plant operating at 80 percent load factor for 30 years. Each system delivers 16.5×10^{12} kilocalories (electric) to the consumer in 30 years. Wellhead-to-consumer efficiency including electric transmission losses for the dry steam system was 14.2 percent, and for the wet steam system was 10 percent.

Table 2 lists energy, material, and environmental subsidies for developing and operating a 100-megawatt geothermal power system for 30 years. Details of the calculations are given in the notes. The exploration value assumes that one out of four land areas acquired will be drilled, that one out of four exploratory wells drilled will be completed for testing, and that one out of four of these completed wells will locate a field of commercial size (*15*). As geothermal sites become more difficult to locate, the exploration subsidy will increase, reducing the overall net energy. The extraction subsidy is based on a drilling time of 40 days per well and 20 days for cementing. It would increase as deeper reservoirs are tapped. The subsidy from the environment (measured as a stress on it) includes the reduction in gross primary productivity caused by the land requirements of the geothermal field. The geothermal field is assumed to be located in a forested area such as northern California where the Geysers field occurs.

The sum of all subsidies is about 4600×10^{9} kilocalories for a dry steam field and 5400×10^9 kilocalories for a brine-type field using a two-stage flashed steam-driven turbine. The total delivered energy from the 100-megawatt power plant was $16{,}500 \times 10^9$ kilocalories (electric) or $57{,}750 \times 10^9$ kilocalories (equivalent to petroleum in quality) over 30 years at 80 percent load factor. Thus, the ratio of energy delivered to energy subsidy was about 12.6 : 1 for the dry steam field and 10.7 : 1 for the brine system. The environmental subsidy was low in each case. However, neither the health effects of sulfur emissions nor the biogeological effect of subsidence or induced earthquakes on the landscape have been evaluated. In addition, one could argue that indirect environmental subsidies for extracting the metals used in the materials and for manufacturing those materials should also be included. If we view our economic system as one driven by the sun and raw fuels as in Fig. 2, then we should include these indirect environmental subsidies just as we have included the indirect energy and material subsidies. Calculating from data given by Kylstra (*13*), I estimate that, for every kilocalorie of fossil fuel subsidy, there is an additional 0.3 kilocalorie (equivalent to petroleum in quality) of subsidy from nature. To my knowledge, no investigators have included this indirect environmental subsidy in net energy calculations.

The largest uncertainty in the numerical values given in Table 2 occurs where dollar costs were converted to energy units. These were the energy for exploration, for maintenance materials in the power plant, and for operating the field, power plant, and distribution system. These values could vary as much as 25 percent and that variance would cause the total energy subsidy to vary by 17 percent.

There are a number of configurations for geothermal power systems, each of which would result in a different ratio. For example, the electric power generation step requires the highest subsidy; thus it may be more net energy efficient to produce and utilize steam directly for space heating or industrial process heat. However, this requires that the users be located in close proximity to the geothermal field. Electricity is high-quality energy so that the price of producing it as measured by the energy subsidies will always be high. Some combination of depth and enthalpy of the geothermal fluid represents the point where as much energy is required to extract it as is produced. This will vary slightly for each type of proposed electric power generation facility (steam turbines, impulse turbines, and heat exchangers). The geothermal reserves should be defined in terms of their net energy ratios, that is, the ratio of delivered energy to energy subsidy.

Net Energy Ratios

The net energy ratio, as defined above and in Fig. 2, does not include physical and thermodynamic losses directly, but is the ratio of delivered energy to the energy value of material, environmental, and processed energy subsidies. The physical and thermodynamic losses are included only in the sense that increased efficiencies would reduce the losses and increase the delivered energy value. There have been several attempts to calculate these net energy ratios for other energy systems. Ballantine (*16*) calculated that the ratio of energy delivered as electricity from Northern Great Plains coal (based on 4700 kilocalories per kilogram) to energy subsidy is 4 : 1. Based on a 1000-megawatt light water nuclear reactor, Lem (*17*) calculated the maximum ratio of delivered electricity to energy subsidy as 9 : 1. Oregon's Office of Energy Planning (*18*) calculated ratios of 60 : 1 for domestic natural gas, 7 : 1 for high-Btu (British thermal unit) gas from coal, and 2.8 : 1 for oil from oil shale (all nonelectric uses). Although all of these ratios represent delivered energy to subsidy and all are expressed in equivalent energy qualities, in each case data were incomplete, so that precise comparisons are not possible.

When the price of oil increased, its net energy ratio decreased, resulting in inflation. Imported oil at $2 per barrel has a net energy ratio of 30 to 1, while at $11 per barrel the ratio is 6 to 1 (*16*). The real GNP cannot increase unless the economy is driven by energy sources that require little energy to extract. The purely economic calculations obscure this fact since they include the effects of government policy in subsidizing some resources (that is, nuclear) and not others. Government energy policy in areas such as outer continental shelf leases for oil, onshore leases for coal and geothermal sources, and tax depletion allowances could be made on the basis of which resources have the highest ratio of delivered energy to energy subsidy. And the U.S. Geological Survey could aid policy makers by calculating reserves on this basis as well as their economical recovery. The economics of the reserve estimate will track the net energy ratio.

Net Energy and Public Policy Decisions

Energy analysis has already captured the attention of persons searching for better policy analysis tools. Section 5 of the Non-Nuclear Energy Research and Development Act of 1974 (PL 93-577) states, as one of the governing principles for researching and demonstrating new energy resources, that "the potential for production of net energy by the proposed technology at the stage of commercial application shall be analyzed and considered in evaluating proposals." In response to this

Table 2. Energy subsidies required for the development and operation of a 100-megawatt geothermal power system for 30 years. All values are equivalent to petroleum in energy quality.

Subsidy types	Dry steam reservoir* (10^9 kcal)	Wet steam reservoir† (10^9 kcal)
Exploration (*22*)	50	50
Extraction and separation (*23*)		
Fuel	135	150
Construction and maintenance materials	135	150
Transport of materials	5	6
Steam transport (*24*)		
Construction and maintenance materials	25	35
Transport of materials	3	4
Construction‡ and operation of the steam field (*25*)	140	185
Conversion to electricity		
Construction materials (*26*)	570	1140
Maintenance materials (*27*)	25	35
Transport of materials (*28*)	70	140
Construction‡ and operation of the power plant (*29*)	160	215
Transmission and distribution (*30*)		
Construction and maintenance materials	2,800	2,800
Construction‡ and operation of the transmission lines	400	400
Environment (*31*)		
Field site	35	50
Transmission corridor	35	35
Total subsidy	4,588	5,395
Total energy delivered to consumer§	57,750	57,750
Net energy ratio		
Delivered energy to subsidy	12.6 : 1	10.7 : 1

*Steam-driven turbine. †Two-stage flashed steam-driven turbine. ‡Excluding materials. §16,500 kilocalories (electric) × 3.5 is 57,750 kilocalories of petroleum equivalents.

legislation, there are several government agencies involved in standardizing energy analysis procedures, and in performing some calculations. The Office of Energy Policy of the National Science Foundation (NSF) brought together energy accounting researchers at a workshop in August 1975. The objective of that workshop was to compare and standardize procedures and determine specific policy applications for the analyses. The Energy Research and Development Administration (ERDA) has stated that it plans to integrate evaluations of the net energy contribution of technologies into the national plan for setting energy research needs and priorities (*19*). ERDA's Office of Planning and Analysis is expected to have funding responsibility for these studies. In addition, the Department of the Interior's Office of Research and Development has contracted for energy analysis of several technologies. As a result of the legislation and agency interest, there is a probability that net energy analysis may come into widespread use. It has the potential to improve the input into the decision-making process.

The data and information provided to policy-makers are almost always incomplete and conflicting. Energy analysis may not eliminate the incompleteness, but it can reduce the conflicting nature of the inputs. I have shown the special role that energy plays in driving the flow of money, in allowing for the extraction, manufacture, and transportation of materials, and in allowing for substitution of different materials for ones in short supply. Since energy is the one commodity present in all processes and since there is no substitute for it, using energy as the physical measure of environmental and social impacts, of material, capital, and manpower requirements, and of reserve quantities reduces the need to compare or add "apples and oranges." In energy analysis, many environmental and social costs and benefits are internalized directly. For example, the energy value of the environment is the amount of the sun's energy used by the ecosystem in providing services and products, just as the value of a manufactured commodity is the amount of fossil fuel used by the machines in making the product. The use of the energy unit makes the two comparable.

Dollar evaluations do not usually internalize environmental costs, such as air pollution, or social costs, such as government subsidies in the form of regulations, taxes, or research. In addition, dollar evaluations often obscure the larger scale effects of an action because the dollar costs and benefits accrue to different people at different times. Dollar evaluations also change with time due to the changing value of money and assumptions concerning, for example, the discount rate. For a specific technology, such as the present nuclear fuel cycle and its supporting techniques, the energy evaluation will not change with time.

Energy analysis of alternative energy supply technologies can provide more information of a less conflicting nature to policy-makers. Assuming that more and better information improves the quality of decisions, then energy analysis can improve government policies in areas such as managing public energy lands, regulating gas, oil, and utility rates, providing tax incentives, and establishing research emphasis.

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21. A. L. Austin, G. H. Higgens, J. H. Howard, *The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits* (Lawrence Livermore Laboratory, Livermore, California, 1973), pp. 1–37; Federal Energy Administration, *Project Independence Blueprint-Geothermal Energy* (U.S. Government Printing Office, Washington, D.C., 1974), p. E1–E5.
22. Cost is estimated as $32 per kilowatt; 15,800 kilocalories per dollar; 100,000 kilowatts.
23. Fuel includes that for drill engines, mud pumps, cement pumps, and chemical injection; drilling depth in dry steam field of 1.8 kilometers and in the brine field of 1.4 kilometers for production wells and 0.45 kilometers for reinjection wells; 20 wells per 100 megawatt dry steam plant and 26 production wells, plus 13 reinjection wells per 100 megawatt brine plant; each production well lasts 10 years; drill engines operate 530 hours per kilometer drilled, cement pumps operate 270 hours per kilometer drilled, mud pumps operate 280 hours per kilometer drilled; all engines are 450 kilowatts and require 2030 kilocalories per kilowatt hour. Construction and maintenance materials include well completion materials and drilling equipment. For the dry steam field: 60 wells; 103,500 kilograms casing per well; 78,800 kilograms of cement per well; 2 valves per well; one steam separator. For the brine system: 78 production wells; 26 reinjection wells; 85,300 kilograms of casing per production well; 33,300 kilograms of casing per reinjection well; 59,000 kilograms of cement per production well; 18,200 kilograms of cement per reinjection well; three valves and three separators per production well; 16,600 kilocalories per kilogram of steel; 3400 kilocalories per kilogram of cement. Over the 30-year life, 4 derricks, 8 drill engines, 16 mud pumps, 8 cement pumps, 2 blowout preventers, 8 chemical injection pumps, and 20 drill bits per well are consumed. Transport: 3200 kilometers from the Midwest to California; 0.7 kilocalories per kilogram per kilometer.
24. All wells are located 0.8 kilometer from the power plant; for the dry steam system, 700,000 kilograms of steel for steam lines; for the brine system, 950,000 kilograms of steel for production and reinjection well steam lines; all replaced 100 percent in 30 years; 16,600 kilocalories per kilogram of steel. Transport: 3200 kilometers from the Midwest to California; 0.7 kilocalories per kilogram per kilometer.
25. For labor, taxes, rents, interest, in constructing and operating the field over 30 years: $22 million at the dry steam field; $29 million at the brine field; 6400 kilocalories per dollar.
26. Construction materials for dry steam turbine-generator: in 10^3 kilograms; aluminum, 45.4; copper, 91; concrete, 22,700; steel, 8720; stainless steel, 118; steel forgings, 76.3; other nonferrous metals, 54.5. Energy content: in 10^3 kilocalories per kilogram; Al, 21; Cu 31; concrete 3.4; steel, 16.6; stainless steel, 22; steel forgoings, 28; other nonferrous metals, 20. Fabrication of the turbine-generator: 31.8×10^6 kilogram materials; 9500 kilocalories per kilogram. For a brine power plant, the turbine is twice as large to accommodate lower pressure and temperature steam.
27. Over 30 years, $2.5 million for materials is needed for repairs at dry steam field power plant; $3.3 million at the brine field; 10,000 kilocalories per dollar.
28. Dry steam, 31.8×10^6 kilograms; brine, 63.6×10^6 kilograms; 3200 kilometers; 0.7 kilocalories per kilogram-kilometer.
29. For labor, taxes, rents, interest: $2.5 million for construction, $23 million for operation over 30 years at the dry steam power plant; $3.3 million for construction, $30 million for operation over 30 years at the brine power plant; 6400 kilocalories per dollar.
30. For transmission and distribution, 7.7 mills per kilowatt hour cost; 55 percent for materials at 10,000 kilocalories per dollar, 5 percent for fuel at 240,000 kilocalories per dollar, and 40 percent for operating at 6400 kilocalories per dollar.
31. Dry steam field: 40 hectares for direct use for well site pads, work areas, steam lines, and power plant plus 360 hectares indirect use. Brine field: 60 hectares for direct use plus 540 hectares for indirect use. In 1970, 400,000 megawatts of capacity withdrew 1.6 million hectares of land for transmission lines; therefore, 100 megawatts withdraws 400 hectares, of which 20 percent is direct use. Forest productivity in northern California is 5000 kilocalories per square meter per year. Direct use eliminates productivity; indirect use reduces it by half for 60 years, 30 years during field use and 30 years for ecosystem recovery. Energy quality conversion factor is 1/20.

32. I thank I. White, D. Kash, and R. Rycroft for evaluating the manuscript. This article is the result of research carried out within the Science and Public Policy Program under NSF grant No. SIA 74-17866.