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NET ENERGY ANALYSIS OF NUCLEAR AND WIND POWER SYSTEMS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

By

GENE T. TYNER SR.

NORMAN, OKLAHOMA

1985

NET ENERGY ANALYSIS

OF

NUCLEAR AND WIND POWER SYSTEMS

A DISSERTATION

APPROVED FOR THE GRADUATE COLLEGE

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CHAPTER 1

INTRODUCTION

It is now commonplace to acknowledge that the era of an abundant fossil-fuel supply will soon draw to a close. Hubbert was among the first to suggest this likelihood, noting that 80 per cent of the fossil fuels of the Earth will have been consumed in a short period of time spanning about 300 years.[1] Following Hubbert, Fowler pointed out that petroleum mining in some parts of the United States (1976) was being energetically subsidized by petroleum mining in other parts. He also held that by about 1987 petroleum mining in the United States will be subsidized (energetically) by petroleum mining outside the United States.[2]

There is some dispute as to the number of years of supply of coal that will be available to us, but some, such as Merklein and Hardy, point out that the coal supply of the United States could be

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[1]M. King Hubbert, "The Energy Resources of the Earth," Science 109, (February 1949), pp.255-272.

[2]Richard G. Fowler, "The Longevity and Searchworthiness of Petroleum Resources," Energy 2 (1977), pp. 189-195. The term "energetically" was used by Fowler to refer to the amount of energy (petroleum in this case) that was being expended to find and fetch the petroleum. This notion is similar to Odum's net-energy concept.

reduced to sixty years at a 5 per cent growth rate.[1] The issues resurrected in this study seem to be related to the broad question: What are our energy choices as we run out of fossil fuels?

It has also been commonplace to reason that, as fossil fuels are depleted, sources of energy such as oil shale, solar, geothermal, wind, and nuclear fission and fusion that may have once been uneconomic will then be economic. Western society in general seems to be persuaded by this reasoning. For example, see Landsberg, Arrow, et al.[2]

Hubbert[3] and Fowler,[4] both looking at the problem in terms of physical yield versus physical effort, implicitly suggest that the traditional economic view is an inappropriate way to look at the problem of energy supply. Howard T. Odum joined this discussion noting that it takes a great deal of energy to acquire energy. The Odum school focuses on the idea that there must at all times be an independent source of energy which yields substantially more output-energy than required input-energy.[5] At the present time the current source of net energy is in certain fossil-fuel processes. The question is, What will be that independent net-energy source after the fossil fuels are gone?

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[1]Helmut A. Merklein and W. Carey Hardy, Energy Economics (Houston: Gulf Publishing Company, 1977), p. 205.

[2]Hans H. Landsberg and Kenneth J. Arrow, et al., Energy, The Next Twenty Years. (Cambridge, Mass.: Ballinger Publishing Co., 1979).

[3]M. King Hubbert, "Resources of the Earth," Idem.

[4] Richard G. Fowler, "Searchworthiness," Idem.

[5] Howard T. Odum, Energy Basis For Man and Nature, (New York: Wiley-Interscience, 1971).

The following main points of the Odum argument are extracted:

> . . . The true value of energy to society is the net energy,[1] which is that after the energy costs of getting and concentrating that energy are subtracted. . .
>
> Many calculations of energy reserves which are supposed to offer years of supply are as gross energy rather than net energy and thus may be of much shorter duration than often stated. . .
>
> Energy sources which are now marginal, being supported by hidden subsidies based on fossil fuel, become less economic when the hidden subsidy is removed. . .
>
> Increasing energy efficiency with new technology is not an energy solution, since most technological innovations are really diversions of cheap energy into hidden subsidies in the form of fancy, energy-expensive structures. . .
>
> Solar energy is very dilute and the inherent cost of concentrating solar energy into forms for human use has already been maximized by forests and food producing plants. Without energy subsidy there is no yield from the sun possible beyond the familiar yields from forestry and agriculture. . .
>
> Nuclear energy is now mainly subsidized with fossil fuels and barely yields net energy. . .

The Odum view has generally been ignored or allegedly refuted by the scientific community. As will be discussed in detail throughout this study, challengers (net-energy analysts) to the Odum school have chosen to use more narrow energy-accounting conventions than the Odum school used. Also, the challengers used preliminary engineering cost information as the basis of their net-energy estimates in their studies. Subsequent experience has shown that those earlier cost estimates, even in real terms, were seriously flawed.[2]

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[1] Howard T. Odum, "Energy, Ecology, and Economics," Whole Earth Epilog, (Baltimore: Penguin Books, 1974), pp. 469-473.

[2] Charles Komanoff, Power Plant Escalation: Nuclear and Coal, Regulation and Economics. (New York: Komanoff Energy Assoc., 1981).

Odum held that there was a close relationship between the economic cost of an energy-transformation entity and energy input to that entity. Other energy analysts, who are later identified in this study as mainstream energy analysts, adapted certain energy-accounting conventions for doing Energy Analysis and in the final analysis count as inputs only the direct use of fuels and the indirect energy embodied in physical materials as the basis of their energy analysis.[1] The more recent work of Robert Costanza, a former Odum student now at The Center For Wetlands Research at Louisiana State University, has convincingly argued for expanding the system boundary of accounting to include labor and government services as energy-input costs.[2]

In this study an argument is made that, not only should labor and government services be counted as energy costs, but likewise, interest (the rental cost of borrowed money) should also be included as an energy cost.

The models adapted in this study incorporate that expanded boundary and also reflect the most recent cost data and projections for nuclear power stations and wind machines -- data that were not available at the time of the earlier studies. Consequently, the conclusions reached in this study are even more pessimistic than those reached by Odum.

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[1]Direct consumption of energy refers to current consumption of fuels on-site; indirect refers to energy that is consumed at earlier stages of processes and is often called embodied energy.

[2]Robert Costanza, "Embodied Energy in Economic Evaluation." Science 210 (December 12, 1980): 1219-1224.

Purpose of this Study

The purpose of this study is to determine, by applying well-considered net-energy accounting models, whether two of the energy-transformation technologies, now held up as replacements for United States-depleting fossil fuels, are primary sources of energy, or do they require large energy subsidies for their existence. The two technologies analyzed in this study are nuclear-powered and wind-powered electricity-generating and distribution systems. A major question is answered: Will these technologies provide enough energy to replicate themselves (or viable substitutes) out of their own output-energy and leave energy for the rest of society to use, or are they merely round-about ways of consuming fossil-fuel sources that have high net energy?

Overview

This is an interdisciplinary study including economics. A brief summary of the methodology used by mainstream economics in dealing with resource shortages in general and energy in particular is included in chapter 2. It is held that mainstream economic approaches are intellectually tied to substitution reasoning which can be simply stated: As shortages of a particular good arise, prices will increase, triggering entreprenurial activity to increase the supply of the good or the supply of an acceptable substitute.

There is no limit specified in economic theory as to the extent that such substitution can occur. Therefore, such reasoning seems to rest on a dubious foundation with respect to energy and, perhaps, other critical resources such as metals, minerals, clean air, clean water, healthy topsoils, and a diversity of living species.

It will be argued that there is no functional substitute for energy, although it is acknowledged that our demand for energy services can change through efficiency, conservation, and lifestyle alteration.

In chapter 3 the concept of net energy is developed. A controversy developed between those having an Energy-Analysis perspective and some energy economists. It is the author's view that most of the controversy turns out to be more "territorial" than a scholarly effort by either side to bridge the wide perceptual gap that still persists between the two disciplines. At the height of the controversy both schools were jockeying for "favor at court" as to who would advise the government on energy-policy matters. The energy analysts perhaps weakened their case by getting involved in a discussion of energy theories of value. Economists with more than a hundred years of experience in debating value theory correctly dismissed the value-theory arguments of some energy analysts. Unfortunately, in so doing they have almost succeeded in dismissing a matter of vital significance; that replacement energy sources may not be as readily available as previously thought.

Odum was a major participant in that earlier debate between energy analysts and economists. It is author's opinion that the issues raised by Odum have temporarily fallen into disfavor as a result of three major reasons:

First, the economics profession, because of its prestigious position and sheer size, overwhelmed the discussion.

Second, the mainstream energy analysts, by choosing the narrower system-boundary definition along with the energy economists, succeeded in reducing future energy supply to a nonproblem. Many studies done by mainstream energy analysts found that most forthcoming energy-transformation technologies yielded substantial net energy. Therefore, future energy supply was not in jeapordy -- at least not in the near future.

Third, a glut of foreign fossil fuels occurring from 1983 through the present (1985) allayed earlier public perceptions of energy-supply problems and focused even scientific attention away from the issue. It is the author's opinion that the current excess supply is only temporary. It is the expected outcome of an extraordinary amount of mining effort, which has served only to hasten the depletion of these precious resources. The ultimate energy-supply problem remains much the same as described by Hubbert[1], Fowler[2], and Odum[3].

A critical discussion of the most prevalent methodologies being employed in Energy Analysis will be included in chapter 4. Most analysts, when counting the inputs needed to fabricate and operate energy-transformation systems, account only for the inputs of direct burning of fuels and indirect energies embodied in physical materials. Most energy analysts specifically exclude the energy embodied in goods and services consumed by workers, for example. Also, all costs related to such items as interest, taxes, profits, and professional fees are not a part of the Mainstream Energy Analysis accounting process. This failure constitutes a major weakness in Mainstream Energy Analysis methodology. A case will be made for including all economic costs as energy costs.

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[1]M. King Hubbert, "The Energy Resources of the Earth," Idem.

[2]Richard G. Fowler, "Searchworthiness," Idem.

[3]Howard T. Odum, Energy Basis for Man and Nature, Idem.

The close historical relationship between energy use and economic activity will be reviewed in chapter 5. The argument is made that all dollar outlays are proxy indicators for a set of prior energy outlays related to the construction and operation of energy-transformation entities. A case for a new and simplified Energy Analysis methodology will also be made. There has been a fairly stable relationship between energy consumption and real Gross National Product (GNP).[1] Annual Energy/GNP Ratios were calculated using 1972, 1979, and 1983 as base years for Gross National Product. For example, for 1979 the 37-year mean value is 35,791 Btu's per 1979 dollar of Gross National Product; i.e., it takes 35,791 Btu's/$1979 to produce each dollar's worth of real GNP ($1979). The years 1979 and 1982 were chosen because two valuable data sets for nuclear-power-plant costs expressed in 1979 and 1982 dollars, respectively, were available. Energy/GNP Ratios, using 1983 as a base year, were calculated because Wind Energy Conversion System costs were expressed in 1983 dollars. Calculations were made using the 37-year mean values, as well as the extreme high and low values of the respective coefficients. Coefficients were also calculated for the year 1972 to use in conjunction with the calculations in chapter 5 pertaining to feedback energy needed to obtain fossil fuels.

It will be argued that <u>every</u> dollar expended in the lifecycle of energy-transformation systems (development, operation, decommissioning, and disposal of related wastes) constitutes a proportional expenditure

[1]Cutler J. Cleveland, et al, "Energy and the U. S. Economy: A Biological Perspective," Science 189 (31 August 1984).

[2]Throughout the study real dollars means "corrected for inflation."

of energy and must be counted as an energy-input when determining the net energy to be expected from future energy-transformation technologies. The procedure is to determine the lifecycle cost of the transformation entity in uninflated dollars and to multiply the result times the chosen Energy/GNP coefficient.

It is argued that the failure to consider all monetary expenditures related to the existence of energy-transformation facilities has resulted in an overestimate of the amount of net energy that can be expected from certain technologies and incorrectly values their real benefit to society.

The methodology outlined in chapter 5 will be applied to two technologies: (1) large nuclear power stations and (2) Wind Energy Conversion Systems. Both of these technologies are somewhat well developed, have already undergone some scrutiny by mainstream energy analysts and economists, and are generally heralded as renewable energy technologies to replace the fossil fuels as they are depleted.

A brief resume of the results of crude net-energy calculations using selected time-series data for petroleum, natural gas, and coal is also included in chapter 5. This information was included to extend the arguments of Hubbert,[1] Fowler,[2] and Odum[3] that we are already involved in a situation where more and more feedback energy is needed each year to acquire fossil fuels. The phenomenon of continuing feedback energy

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[1]Richard G. Fowler, "Searchworthiness," Idem.

[2]M. King Hubbert, "Energy Resources," Idem.

[3]Howard T. Odum, "Energy, Ecology, and Economics," Idem.

is not specifically considered in this study, and to include it makes for more even less-favorable conclusions.

It appears that all prior energy analyses of nuclear and wind power have been made by drawing the system boundary around those technologies to include only the electricity-generating plant. It is contended that this constitutes an additional major specification error. Electric power is not useful until it reaches the industrial, commercial, and residential consumers. Since the capital cost of Other Plant is more than 150 per cent of the cost of Generating Plant, more than half of the energy-input costs have been unaccounted for in prior analyses.[1] The case will be made that these prior studies have been flawed accordingly.

Also, most prior energy analyses treated entities such as nuclear power stations and wind energy conversion machines as independent and disconnected entities from the larger system of which they are a part (i. e., the total electrical grid). In chapter 6 it is argued that this too represents a serious system-boundary specification error. Simply stated, one cannot give full credit for the performance of an individual entity when redundant systems are required to back up the primary systems when the primary systems are out of service for maintenance, accidents, or refueling. In this study the cost of redundancy is not allowed to escape the accounting process.

Typically, other energy analyses have assumed that electric power stations would produce electricity about 75 per cent of the time (24 hours per day, 365 days per year) over their lifecycles. Chapter 6

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[1]See appendix A.

also summarizes the results of a 30-year time-series analysis which shows that the electrical-utility system in the United States is becoming less efficient with the passage of time. The precise cause for this trend is not entirely established in this study, but preliminary analysis shows that it seems to be related to the introduction of nuclear power plants. In order to estimate the net-energy output to be expected from energy-transformation entities, it is necessary to have some idea of future system efficiency. It is shown that the United States electrical grid achieved a maximum total-system use of 57 per cent in 1956 and that the efficiency has steadily fallen to about 40 per cent in 1982. In the Base Case a 50 per cent Efficiency Factor was used for both the nuclear and wind studies in this study in order to be on the conservative side.

The methodology outlined in chapter 5,considering the constraints mentioned in chapter 6, will be applied to nuclear-powered electric systems in chapter 7. The results show that nuclear power stations are not likely to be sources of net energy but will require some sort of external energy subsidy. This is particularly evident in the Dynamic Net Energy Analysis. Various sensitivity analyses are done. As will be discussed in the chapter, the net-energy results are related to the real economic costs of carrying out the processes. Real economic costs, among other things, are related to the level of lifestyles of the human participants in the related processes. Therefore, the net-energy benefit of a particular technology could be improved by any arrangement that lowers costs, including lowering material lifestyles of the related human participants.

The methods of chapters 5 and 6 are also applied to wind-powered electricity-generating systems in chapter 8. These results show that these systems also require an external energy subsidy for their existence. The same comments above, with respect to economic cost and net-energy benefits, also apply to wind systems.

Chapter 9 relates the findings of chapters 7 and 8 to a limited set of broad issues that society is already facing. It is argued that most of the cited problems were made on the presumption that a continuing net-energy supply would not be constrained in a way that the findings of this study suggest. It is argued that the problems, as presented, will be exacerbated in an interacting manner, making them much more difficult to solve than originally thought. Chapter 9 will also include a discussion of certain broad policy issues that must be considered as we face a situation of continuing deterioration of energy-materials availability. These will include some of the organizational and ethical issues facing society in the light of the current study.

The final chapter provides an overall summary.

An Interdisciplinary Approach

The overview should confirm that this study was best carried out as a single-discipline study. In fact, past energy analyses have been done by systems biologists, engineers, economists, and physicists.

Most energy analyses use economic cost as a basis for estimating energy-input quantities. Therefore, reaching into the discipline of economics was necessary. However, the conclusions reached in this study, with respect to future energy supply, are contradictory to those reached by mainstream economic analyses. Chapter 2 is essentially a discussion of the way that Mainstream Economic Analysis deals with resource shortages. Chapter 3 deals with the controversy between some energy economists and energy analysts. It was necessary to gain support and guidance from fields outside of economics which provided the basis for including the disciplines of engineering, environmental science, and geography. If the methodology and conclusions of this study are ultimately accepted in the scientific community, then the broad philosophical and ethical issues involving the organization and management of human resources must be dealt with. This was the basis for including the disciplines of philosophy and organizational behavior. Much assistance was was received from a professor of physics, who formerly held the David Ross Boyd Chair at the University of Oklahoma.

Summary Comments

This study is related to the earlier works of Hubbert[1], Fowler,[2] Odum,[3] Costanza,[4] and Komanoff;[5] however, the author has been greatly influenced by Georgescu-Roegen,[6] and Daly.[7]

---

[1]M. King Hubbert, "Energy Resources," Idem.

[2]Richard G. Fowler, "Searchworthiness," Idem.

[3]Howard T.Odum, Energy Basis For Man And Nature, Idem.

[4]Robert Costanza, "Embodied Energy," Idem.

[5]Charles Komanoff, Power Plant Cost Escalation, Idem.

[6]Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process, (Cambridge, MA: Harvard University Press, 1971).

[7]Herman E. Daly, Economics, Ecology, Ethics: Toward A Steady-State Economy, (San Francisco: W. H. Freeman and Co., 1973).

The author's main concern is fourfold:

First, it is necessary to develop a rationale for the greatly expanded system boundary which includes the energy embodied in the wages paid to labor, the taxes paid to government, the interest paid to money lenders, and the profits paid to owners of money capital. In other words, Odum's original model, which shows flows of energy (fuel and energy embodied in goods and services) in one direction and flows of money in the opposite direction, is the underlying simple model for this study.

Second, to develop models for Net Energy Analysis of energy-transformation systems and to incorporate the latest costs and performance information of nuclear-powered and wind-powered systems into the models.

Third, to determine if nuclear-powered and wind-powered electricity-generating systems are independent sources of net energy; i.e., would they be able to replicate themselves out of their own energy and leave net energy to meet the needs and wants of society, or, are they merely roundabout ways of depleting the net-energy supplies of fossil fuels?

Fourth, to relate the findings of the study to some of the other broadly defined problems that society already faces.

CHAPTER 2

ECONOMIC ANALYSIS AND RESOURCE DEPLETION

Precis

Mainstream economists have not considered future energy supply to be a particular problem. A 1979 study by Resources for the Future will be discussed as representative of the prevailing economic viewpoint with respect to future energy supply.[1] Since this study comes to different conclusions, it seems necessary to comment on the methodology of economics with respect to shortages of resources in general and energy in particular.

It will be argued that there is a a major weakness in traditional economic theory which results in an overestimate of the amount of Earth resources, especially energy, which will be available for society's use. This problem is related to Georgescu-Roegen's[2] linkage of mainstream economics to the Newtonian world view and the failure of economists to include the implications of the Second Law of Thermodynamics (the entropy law) into economic theory. The argument will be made that the law of entropy places energy in a unique role in the

---

[1]Hans H. Landsberg and Kenneth J. Arrow, et al., Energy The Next Twenty Years. (Cambridge, MA: Ballinger Publishing Co., 1979), p. 237.

[2]Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process. (Cambridge, MA: Harvard University Press, 1976).

conduct of economic activity.[1] As noted by Fowler, it is the "Lifeblood of the economic body, integral, undivorceable, but nonetheless, vital."[2]

Mainstream Economics and Shortages

Modern economists are understandably wary of anyone who talks about impending disaster resulting from resource shortages. They often cite Jevons's 1865 forecast of doom in which he worried that England would run short of easily mined coal.[3]

However, there is probably little disagreement that the fossil fuels of the Earth must be considered as a finite stock. Hubbert holds that their geological transformation has been underway for the last 600 million years and that our current rate of depletion greatly exceeds the rate of formation.[4]

It will be argued that Mainstream Economic Analysis, as presently practiced, might be unable to anticipate the possibility of shortages of the so-called finite materials that are critical for carrying out the economic processes. Energy is considered to be one of the most critical resources for the sustenance of human civilization.

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[1] Ibid.

[2] Richard G. Fowler, Personal Communication, June, 1985, Norman, Oklahoma, Emeritus Professor of Physics, Univerisity of Oklahoma.

[3] W. Stanley Jevons, "The Coal Question," cited by Earl Cook: Man Energy and Society, (San Francisco: W. H. Freeman and Company, 1976), p. 428.

[4] M. King Hubbert, "The Energy Resources of the Earth," Science 109 (February 4, 1949): 63.

W. W. Rostow cites the assumptions that underlie the energy-economy models:[1]

> They start with four empirical and, as nearly as we know, correct assumptions.
>
> 1. There is no foreseeable physical limit on the U. S. Energy supply over, say, the next half century; that is, coal, shale, and advanced forms of nuclear power could supplant the probable decline in oil, natural gas, and uranium reserves, even without the large scale solar or fusion power.
>
> 2. The marginal (and average) cost of energy will rise; that is, for some time we can expect the real cost of replacing a unit of energy consumed to exceed its present average price. We do not know with confidence what the rise in the real price of energy will prove to be.
>
> 3. The total cost of energy in the U. S. economy as a proportion of GNP is relatively small, say, 5% in 1975. Therefore, even a quite substantial rise in the price of energy will yield only a modest damping in the rate of increase of real GNP, assuming GNP continues to rise regularly at rates not grossly dissimilar to those we have experienced since the end of the second world war.
>
> 4. We cannot estimate reliably, on the basis of past experience, what the price elasticity of demand for energy will prove to be in the face of a gross alteration of energy prices over a long period of time; nor can we estimate reliably long period changes in taste and in the income elasticity of demand for energy, as real income per capita rises; nor can we estimate reliably what the long-run elasticity of substitution of other factors of production for energy will prove to be. Therefore, in striking long-run demand-supply balances, considerable ranges are appropriate.

Rostow also criticizes the energy-economy models because "they fail to capture the major features of the energy problem confronted by the United States and the world economy -- now and over the decade or so ahead," although he holds to the substitution postulate in assumption "1" above.

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[1] W.W Rostow, "Energy and Full Employment," ed. Charles J. Hitch: Energy Conservation and Economic Growth, American Association For The Advancement Of Science, Selected Symposium 22, (Boulder: Westview Press, 1978), pp. 59-112.

Rostow's quote from Santayana seems appropriate for the discussion in this chapter:[1]

> There is a sort of poetic ineptitude in all human discourse when it tries to deal with natural and existing things. Practical men may not notice it, but in fact human discourse is intrinsically addressed not to natural existing things but to ideal essences, poetic or logical terms which thought may define and play with. When fortune or necessity diverts our attention from this congenial ideal sport to crude facts and pressing issues, we turn our frail poetic ideas into symbols for those terrible irruptive things. In that paper money of our own stamping, the legal tender of the mind, we are obliged to reckon all the movements and values of the world.

Although somewhat critical of the energy-economy models, Rostow goes on to presume that substitutions of alternative energy forms of nuclear, solar, and fusion power can be substituted for the depleting fossil fuels.

It is held that the economist's view of the future energy supply arises out of basic economic concepts of consumer and entreprenurial behavior involving the substitution of one good for another. For example, Samuelson notes:[2]

> **Substitution-effect:** The first factor explaining diminishing consumption when price rises is an obvious one. If the price of tea goes up while other prices do not, then tea has become relatively dearer. It pays, therefore, to **substitute** other goods for tea in order to maintain one's standard of living most cheaply. Thus tea becomes a relatively dearer source of stimulation than before, and less of it will be bought and more of coffee or cocoa.

That is reasonable enough as far as it goes. These preference notions accurately describe the behavior of consumers who want to make

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[1] W.W. Rostow, "Energy and Full Employment," ed. Charles J. Hitch: Energy Conservation and Economic Growth, American Association For The Advancement Of Science, Selected Symposium 22, (Boulder: Westview Press, 1978), pp. 59-112, citing Santayana without a citation included.

[2] Paul A. Samuelson, Economics, An Introductory Analysis, Sixth Edition, (New York: McGraw-Hill Book Company, 1964), p. 438.

choices among available alternatives before them. However, the majority of economists then goes on to implicitly assume that the possibilities for substitution are infinite.

The traditional economic model goes like this: When a commodity such as air is plentiful, its economic value is small or even free. When a desired commodity becomes scarce, it acquires economic value. Under appropriate economic conditions of demand for a commodity, entrepreneurs will seize an opportunity to make a profit and make that commodity (or acceptable substitutes) available to demanding consumers. If the commodity is continuously demanded, it will, therefore, be continuously supplied because of the profit motive. The economic value of a particular commodity may be reduced by substitutions in the exchange arena, e.g., coffee for tea, honey for sugar, and oats for wheat.

Hogan and Manne[1] are typical of mainstream economists who use this type of reasoning to argue that capital and labor can be substituted for energy. Recall from above that Rostow notes the dollar value of energy has been only about 5 per cent of total GNP. Accordingly, many economists have tended to minimize the importance of energy in the economy since it represents only a small proportion of economic value.

For Hogan and Manne, the energy situation is likened to an elephant-rabbit stew consisting of one rabbit (analogous to energy) and one elephant (analogous to the rest of the economy). Even if one added another rabbit or two to the pot, argue Hogan and Manne, "wouldn't it

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[1] Hogan, William W., and Alan S. Manne, "Energy-Economy Interactions: The Fable of the Elephant and the Rabbit?" ed. Robert S. Pindyck: The Structure Of Energy Markets, (Greenwich, CT: Ai Jai Press Inc., 1979), pp. 7-26.

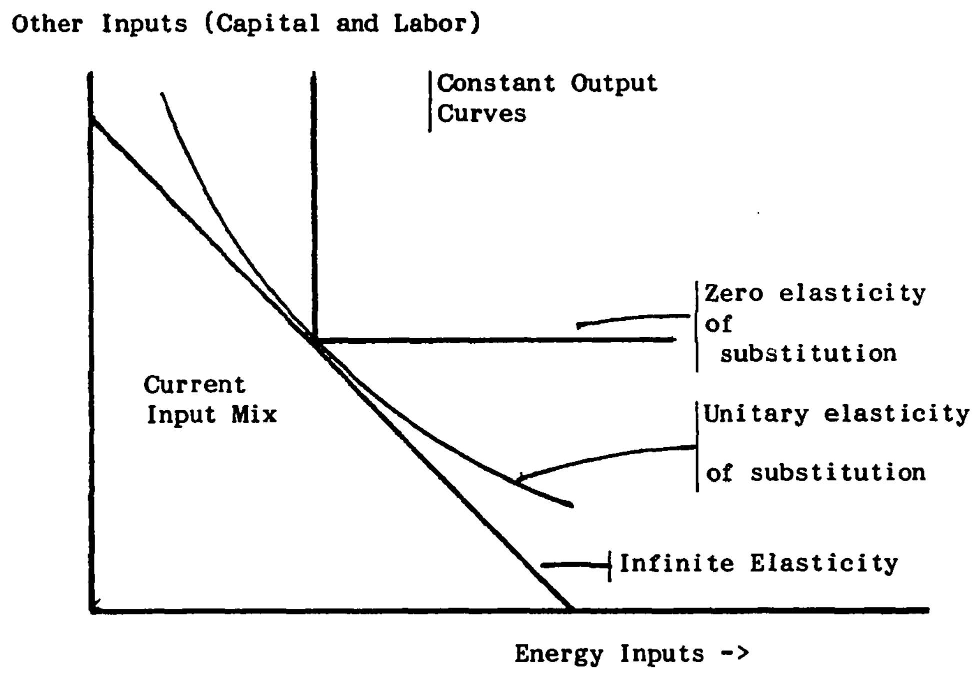
still taste a lot like elephant stew?"[1]

The indifference curve models, such as figure 2.1, familiar to economists, are used to illustrate the point by Hogan and Manne.[2]

Yes, rabbits and elephants may be somewhat functionally substitutable for each other in a stew, but if one extended the analogy to

Figure 2.1

THE ELASTICITY OF SUBSTITUTION CONCEPT



NOTE: In the above diagram a production process is implied. The manager can have the same amount of output by a range of combinations of inputs of either energy or capital and labor.

[1]Ibid.

[2]Ibid.

list the necessary ingredients for making the stew, he would notice that such a stew requires, not only an elephant, a rabbit, and probably some water, but also a pot and some firewood. Without the pot or the firewood there would be no stew, although one could have either rabbit or elephant stew or a combination of the both. One can substitute coal for the firewood, but one cannot substitute the rabbit for the fuel or the pot and still have cooked stew.

The assumption of infinite substitution cannot be applied to energy as a generic class of economic goods. Yes, coal can be substituted for firewood, petroleum for coal, and natural gas for petroleum, but can capital and labor be substituted for energy? It is argued that nothing substitutes for energy. When the system boundary is appropriately drawn, it can be understood that the existence of capital (buildings, machinery, tools, tractors) in society is possible only by consuming a proportional amount of energy at many stages of the economic process and which occurs over a long period of time.

Wanting to substitute capital for energy is asking for the proverbial free lunch. Costanza has succinctly put it this way: "It is easy to think you can get a free lunch by looking at only small parts of the system in isolation. When the whole system is analyzed, however, it becomes clear that all you can do is transfer the cost of your lunch to another segment of the system."[1]

The substitution model seems to provide a satisfactory explanation of consumer behavior in regard to ordinary goods and services as

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[1]Robert Costanza, "Embodied Energy and Economic Evaluation," Science 210 (12 December 1980): 1224.

long as they can be supplied or substitutes can be provided and as long as the availability of a particular class of commodity is not absolutely crucial for all activities to be carried out. But, if one grants that energy is vital for all economic processes, then the traditional economic model may have serious limitations in explaining economic behavior, leave many questions unanswered, and cast doubt on its dependability for guiding strategic social considerations, especially with respect to public-policy measures such as tax and subsidy policies for new energy-transformation technologies.

The economic literature is replete with statements and even predictions that, when the price of petroleum reaches a certain higher level, energy form "x" will be "economic."[1] For example, they say: . . ."at $30/lb., 2.1 thousand tons of uranium are recoverable, but at $50/lb., 2.9 thousand tons are recoverable."

Slesser noted that one of the most blatant errors was the prediction by some economists that oil shale would be economical when the price of oil reached $6/bbl.[2] It might be noted that the price of oil has increased to over $28/bbl., and the extraction of oil shale is still not economic. One wonders if oil shale will ever be economic as a fuel source; i.e., can it be the sole source of itself plus an adequate supply for society?

Such predictions seem to be made in a ceteris paribus vacuum. Many economists implicitly ignore the strong likelihood, barring radical technological breakthroughs, that, if the price of oil, coal, and other

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[1] Hans Landsberg, Arrow, et al., Next Twenty Years, Idem.

[2] Malcolm Slesser, Science, (15 April 1977): 259.

basic materials continues to rise, the price of everything needed to extract oil shale or uranium will rise correspondingly, including the price of machinery and labor needed in those extraction processes.

For example, uranium from Tennessee Shale (0.001 per cent) may always be quite difficult to extract in physical terms (energy, labor, and materials required), regardless of what happens to prices, unless the efficiency of the processes can be radically improved. The mining of uranium, oil shale, or any other mineral is constrained by the technical state-of-the-art and the availability of the needed resources, not the least of which is the amount of energy (direct and indirect) that is needed to drive the processes.

An example might illustrate the inadequacy of the infinite-substitution reasoning with respect to energy. Suppose there was a sudden interruption of oil imports. Probably the price of petroleum would increase substantially, well above the price levels which are to trigger the ushering in of petroleum substitutes. In such a scenario the money supply can be infinitely expanded, the interest rate can become negative 10 per cent, the most imaginative tax incentives can be offered, cost-plus-1000 per cent contracts can be offered, and dictators may decree action; but without a great deal of local energy to subsidize it, no alternative energy source would be forthcoming regardless of how much one may wish it to be.

It is generally accepted that depletion of petroleum will occur first and natural gas second. There is also widespread belief that the world has substantial reserves of coal, but about 80 per cent of the total coal resource ever available on Earth will be produced, roughly, in the 300-year period from years 2000 to 2300, say Merklein and Hardy, writing in 1978:[1]

> . . . The one major U. S. fossil fuel outside of hydrocarbons is coal, but even there our expectations are probably too high. At 1970 Production rates, U. S. coal reserves are good for 300 years. At a 3% growth rate, the reserve-life is only 85 years; at a 5% growth rate, it shrinks to 60 years. And, of course, such a growth rate becomes imperative if we switch to coal in our search for alternate energy--imperative, but not necessarily technically feasible, because of the ever-present capacity problem.

Most economists assume that we can always depend on higher prices and technological ingenuity to usher in replacement-energy sources. Many point to historical experience and recall how we formerly relied on firewood, whale oil, and coal. Then we substituted petroleum and natural gas which were both cheap and clean. The same reasoning holds that we must now temporarily shift either to coal or natural gas until nuclear fission and fusion become the dominant energy forms. Landsberg, Arrow, et al., in The Resources for the Future study seem representative of this position:[2]

> ARE WE RUNNING OUT OF ENERGY?
>
> **REALITY ONE: The world is not running out of energy.** The potential for energy resources of the United States and the world are so large that the ultimate physical exhaustion of energy in general is hardly a matter for present concern. In the long run of half a century or more, some of the more speculative forms of energy production, such as nuclear fusion and new applications of solar energy, will in all likelihood be capable of supplying essentially unlimited amounts of energy at costs that will probably be high, but easily manageable with the income levels of that time . . .

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[1] Helmut A. Merklein and W. Carey Hardy, Energy Resources, Idem. p. 205.

[2] Hans H. Landsberg and Kenneth Arrow, et al. Energy Next Twenty Years, Idem, p. 7.

. . . For this reason, it is incorrect and misleading to define the long-run energy problems in terms of a gap, or a shortfall, or shortage, as though there were some natural definition of energy needs and some physical supply limits preventing these needs from being met. The energy is there to be had, at a cost, in virtually whatever quantities may be demanded; and demand itself is a variable, depending on cost and availability of energy . . .[1]

The foregoing statement seems to rest more on assertion than fact. The authors admit, on the one hand, that nuclear fission and fusion are "speculative" forms of energy transformation. Yet they go on to assert the likelihood of their supplying "unlimited amounts of energy, albeit at high prices, but manageable with the incomes of the time."

The inference of this sort of reasoning is that all we need to do is throw enough money into the energy-development processes and out will come energy. Such propositions are made in complete isolation from the question of how much energy goes into the process of developing and operating such systems.

Energy -- Not Just Another Commodity

Except for geothermal energy, only the sun produces energy. Human systems can initiate various transformation processes, but energy is not produced on this globe. We mine the stocks of fossil fuels and uranium from the Earth and transform the free energy into more useful forms (heat or work) but always at a loss at each stage of the transformation process. Such is the irreversible nature of the Second Law of Thermodynamics (or the entropy law).

When energy was perceived as an abundant and easily obtainable

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[1]Ibid.

resource, we did not recognize that its availability was crucial to all earthly temporal activity. From the long perspective of geological time, it is generally agreed that most energy derives from the sun. Although energy from the sun is absorbed into the Earth, most of it is transferred back into the atmosphere where it drives the hydrological processes. Subsequently, nearly all is then radiated back into space. A minute fraction of the incident sunlight is captured in plant systems of the Earth where it is transferred by living systems through food chains and ultimately returned to space, as heat, or buried. The buried plant matter, which is slowly transformed into fossil fuels by geochemical processes, has provided our current stocks of coal, petroleum, and natural-gas resources.

Some thermal energy comes from the warm interior of the Earth through conduction, hot springs, and volcanoes. Tidal energy derives from the forces of gravity of the planetary system. A certain amount of heat is also seasonally stored in rocks, soils, oceans, lakes, rivers, pavements, and buildings.

Man has also harnessed the hydrological cycle, a solar-driven system, by such constructions as dams, waterwheels, and windmills. We have developed the technology to focus and store solar energy by the use of solar collectors and storage systems.

No good or service (including any capital good), however, is brought into a useful state except through the irreversible expenditure of energy and materials, both directly and indirectly. Even as one sits motionless in a deep state of meditation, the body is irreversibly burning food energy that came from food chains via the sun. The cantaloupe that sprang from last year's seed has collected sunlight for around ninety days, is harvested and consumed, and in twenty-four hours is a degraded pile of fertilizer. The calories of the cantaloupe and the related embodied energy of the whole agricultural and marketing process have been irreversibly dispersed. As one's pencil leaves graphite traces on the paper, that graphite for all practical purposes is irreversibly dispersed. Most of the original solar energy collected by what remains of the tree (wooden part of the pencil) is dispersed in the shavings of the pencil sharpener. All the energy used in making and operating the chain saw, the logging trucks, the saw mills, the depreciated capital equipment, the graphite mining, is proportionally gone -- radiated into space never to be available to humanity again.

The chair on which one sits, the lamp that lights the paper, and the room are all being unidirectionally degraded into a common soup of irretrievability, uniformity, and randomness. If one is lucky and expends the necessary energy on maintenance, one's house may last as long as a lifetime; a chair may need replacement in as few as ten years; the pencil may need replacement next week; the cantaloupe is already gone.

Economic Science and Entropy

Many economists also argue that there are no energy shortages, only improperly low prices. The idea is that higher prices and profits are supposed to bring forth entrepreneurial activity to provide more energy or viable substitutions. The fallacy here is the false premise, perhaps held unconsciously, that net energy can be created out of something else or by some sociotechnical invention or wish. The reasoning seems to be based on the First Law of Thermodynamics (or Newtonian mechanics) and ignores or fails to recognize the deadly implications of the Second Law of Thermodynamics. Odum's definition of entropy seems adequate:[1]

> . . . Entropy is a technical measure of the amount of disorder .. . is defined by the amount of heat involved in changing from a condition of maximum order of molecular motion at zero temperature (absolute zero) on the Kelvin scale to an observed condition containing heat. Entropy change is the ratio of change in calories of heat to the temperature in degrees, Kelvin. . .

The point has been made by Georgescu-Roegen that the study of Newtonian mechanics was a logical extension of Galileo's perception of the universe as a celestial machine that possessed the forces of motion which would keep things going infinitely; i.e., a body in motion tends to remain in motion, and so forth. The ideas of infinite substitution and perpetual motion seem to be intellectually related concepts.

The classical formulation of the first two laws of thermodynamics came as the result of Sadi Carnot's work in 1824 on the efficiency of steam engines.[2] The first law states that the energy of the universe remains constant; i.e., there is no gain or loss of energy in the universe. The second law states that the entropy at all times moves toward a maximum; or put another way, once energy is degraded (transformed), the heat is dispersed in nature to a point where recovery is not practical -- i.e., more energy is expended than recovered.

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[1]Howard T. Odum and Elizabeth C. Odum, Energy Basis For Man And Nature, (New York: McGraw-Hill Book Company, 1971), p. 1.

[2]Encylopedia Britannica, 20th ed. 22. v. "Thermodynamics," by A. W. Po. pp. 88.

Georgescu-Roegen comments on the close identification of economics and classical mechanics:[1]

> . . . The whole truth is that economics, in the way this discipline is now generally professed, is mechanistic in the same strong sense in which we generally believe only classical mechanics to be. In this sense Classical mechanics is mechanistic because it can neither account for the existence of enduring qualitative changes in nature nor accept this existence as an independent fact. Mechanics only knows locomation, and locomotion is both reversible and qualityless. The same drawback was built into modern economics by its founders, who on the testimony of Jevons and Walras, had no greater aspiration than to create an economic science after the exact pattern of mechanics. . .
>
> The intriguing ease with which Neoclassical economists left natural resources out of their own representation of the economic process may not be unrelated to Marx's dogma that everything in nature offers us is gratis. A more plausible explanation of this is that the no deposit, no return analogue befits the businessman's view of economic life . . .
>
> All in all, the wholesale attachment of almost every economist of the last one hundred years to the mechanistic dogma is still a historical puzzle. Once, it is true, physicists, mathematicians, and philosophers were one in singing the apeoheosis [sic] of mechanics as the highest triumph of human reason. But by the time Jevons and Walras began laying the cornerstones of modern economics, a spectacular revolution in physics had already brought the downfall of the mechanistic dogma both in the natural sciences and in philosophy. And the curious fact is that none of the architects of 'mechanics of utility and self-interest' and even none of the latter day model builders seem to have been aware at any time of this downfall. Otherwise, one could not understand why they have clung to the mechanistic framework with the fervor with which they have. Even an economist of Frank H. Knight's philosophical fineness not long ago referred to mechanics as the 'sister science of economics'.

In the context of the foregoing, it is argued that mainstream economists are intellectually disconnected from the implications of the entropy law. Most economists treat energy as an ordinary commodity.

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[1]Nicholas Georgescu-Roegen, The Entropy Law and the Economic-Process, (Cambridge, MA: Harvard University Press, 1971), pp. 1-3.

They assume that substitutions can always be found for ordinary commodities, and energy is considered to be just another commodity.

Although there is a wide range of evidence that the substitution postulate holds for a wide range of economic goods and services and even holds between various forms of energy under restricted conditions, it is argued that to expect that substitutes for depleting energy sources can be infinitely discovered is nothing more than a statement of technological faith and is dangerously misleading.

Chapman cites Skinner's interesting division of resources:[1]

> . . . The sum of materials won from the Earth numbers in the hundreds, but we can group resources into five broad groups: (i) food and clothing derived from plants; (ii) stone, cement, abrasives, and similar materials with special physical properties suitable for activities such as building, grinding and polishing; (iii) materials useful for their chemical properties, especially fertilizers to increase plant yields; (iv) metals and special minerals for machines and (iv) energy to run the machines. . .

It seems clear that Skinner and Chapman are pointing out that there are broad classifications of earth materials that have properties that place them in mutually exclusive functional categories and that intersubstitutions among the classifications are not easily made -- perhaps not at all.

Ayers, who does research in the area of materials balance, and Indira Nair, noted the following:[2]

> . . . It is clear that the laws of conservation -- of matter and energy, for example -- have implications for the use of

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[1] B. J. Skinner, "Earth Resources," ed. P. F. Chapman: Metal Resources And Energy, (London: Butterworths, 1983). p. 7. Proceedings Of The National Academy Of Sciences, USA 76 (1979) p. 4212.

[2] Robert U. Ayres and Indira Nair, "Thermodynamics and Economics," Physics Today (November, 1984) 62-71.

resources and for the generation and treatment of wastes. The law of the increase of entropy -- the second law of thermodynamics -- constrains economic processes to those that reduce available work, increasing the entropy of the Universe. . .

We hope to demonstrate that it has significant -- if not world-shaking implications for economic theory, especially as applied to resource, environment and technology policy. . .

It is clearly more realistic to regard the economy, like the earth itself, as an open system through which materials and energy continuously flow. The laws of thermodynamics now assert themselves.[1]

A broad issue under consideration in this study is related to Ayer's quote of Solow:[2]

If it is easy to substitute other factors for (exhaustible) natural resources, then there is, in principle, no problem. The world can, in effect, get along without natural resources. Exhaustion is an event, not a catastrophe ... If, on the other hand, output per unit of resources is effectively bounded -- cannot exceed some upper limit of productivity which is, in turn, not too far from where we are now -- the catastrophe is unavoidable. ... Fortunately, what little evidence there is suggests that there is quite a lot of substitutability between exhaustible resources and renewable or reproducible resources.

Only a few economists, such as Brown,[3] Ayers,[4] Daly,[5] and Mishan[6] have shown an expressed concern about future resource-supply problems.

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[1]Ibid: 71.

[2]Ibid: 71.

[3]Lester Brown, "Food Prospects: Shadow of Malthus," Challenge, (July-August 1980).

[4]Robert U. Ayers, "Thermodynamics and Economics," Idem.

[5]Herman EDaly, Economics Ecology Ethics: Essays Toward A Steady-State Economy (San Francisco: W. H. Freeman and Company, 1980).

[6]E. J. Mishan, "Growth and Anti-Growth, What Are The Issues?" Challenge (May/June, 1973): 28.

Other economists who have expressed concern about future supplies of resources include Baumol,[1] Georgescu-Roegen,[2] Schumacher,[3] Boulding,[4] and Kneese.[5]

Summary Remarks

With respect to future resource supply, especially energy, the prevailing world view is grounded in the perspectives of mainstream economics. The views of the economists cited above are generally ignored. Since the conclusions reached in this study seem contradictory to mainstream view, it seemed necessary to attempt to account for the differing conclusions.

The role that infinite-substitution reasoning plays in the method of economics in dealing with the depletion of finite materials in general and energy in particular was summarized.

Despite the fact that energy cost has accounted for approximately only 5 per cent of total national product in the past, it is the author's judgement that energy cannot be considered as an ordinary good for which other, so-called factors of production, such as capital and

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[1]William J. Baumol, Sue Blackman and Ann Batey, "Unprofitable Energy is Squandered Energy," Challenge (July-August, 1980).

[2]Nicholas Georgescu-Roegen, The Entropy Law, Idem.

[3]E. F. Schumacher, Small Is Beautiful: Economics As Though People Mattered (New York: Harper and Row Publishers, Inc., 1973).

[4]Kenneth Boulding, "The Economics of the Coming Spaceship Earth," ed. Henry Jarrett, Environmental Quality In A Growing Economy (Baltimore: Johns Hopkins University Press, 1966).

[5]Alan Kneese, and Ralph C. D'Arge, Economics And The Environment: A Materials Balance Approach. (Baltimore: Johns Hopkins Press, 1970).

labor, can be substituted. Energy must be thought of as a unique and indispensable aspect of nature. The basis of this view rests in the logic that neither capital[1] nor labor can be made available except through expenditure of energy. The capital involves the embodiment of energy through a complex web of processes. Labor, in like manner, is sustained by goods and services, all of which require an embodiment of energy. In other words, energy cannot be substituted for itself.

It is also held that, as the fossil fuels are depleted, energy cost will play a much more dominant cost role in real Gross National Product. However, the costs of other goods will rise also because energy is vital for their availability, and it might not be readily recognized that it is the growing energy shortage that is the driving force behind it all.

It is held that economic predictions of future energy supply are carelessly resting on assertions of faith in technical progress that is to bring forth mechanical systems that can be substituted for the depleting net-energy supplies of fossil fuels.

Mainstream economic theory, with its underlying premise of infinite substitution, does not seem to provide a framework for anticipating energy shortages in the future. If it is assumed that energy transformation is vital to all organized social activity, then it seems wise for energy (and perhaps other broad categories of resources such as those described by Skinner above) to be a major focus of attention when looking at future resource problems. Energy Analysis is an emerging

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[1]Note: The term capital is used throughout this study in the traditional economic sense to mean physical capital, i.e., buildings, machinery, and so forth, as opposed to other uses referring to money.

discipline with such a focus and will be critically reviewed in the following chapter.

CHAPTER 3

ENERGY ANALYSIS: INTRODUCTION AND HISTORY

Precis

In this chapter the concept of Energy Analysis will be discussed. The second section of the chapter summarizes the debate between energy analysts and economists on the role of Energy Analysis as a basis for national energy policy and technology assessment.

Concept of Energy Analysis

Some energy must always be expended to make energy available in a form that is valuable to human endeavor. Perhaps the most free potential energy is that provided by ecological systems and the hydrological cycle: air, wind, and rain. If we happen to be near a wild persimmon tree, the food energy may be used with little energy expenditure, but if the fruit must be fetched from a distance, it is another matter. One might starve to death walking to the tree.

Firewood was relatively easy to find when Earth's population was small, as little energy was needed to collect fallen twigs and branches. Some energy was needed to maintain the fires and coals and later to obtain the flint or other ignition systems. Man was able to get more firewood energy with the technologies of matches, axes, and saws, but considerable energy was needed to assemble these devices from the mining of the raw materials, fabrication of devices, transportation at many stages, and the ultimate disposition of the residuals from all the processes. Most of us who have kept track of the Trans-Alaska Pipeline need not be reminded that it takes a great amount of energy to locate, mine, transport, and transform the finite stocks of fossil fuels that have been accumulating in the past millions of years. It also takes a lot of energy to make the machinery available which uses those fuels. Additional energy must be expended to sequester or transform residual wastes from all processes, including energy transformation, before they can safely be re-entered into biological systems without harmful results.

Some substances, such as chemical and radiological wastes, may need sequestering and tending for thousands of years into the future, well beyond the usefulness of the transformation systems which produced them. Considering the historical stability of political systems, it may be arrogant to presume that our social structures are impregnable to change, that we can assure such safekeeping will actually be possible for, in some cases, a quarter million years or more, and that there will be sufficient energy on hand to carry out the safekeeping. Love Canal in New York and Times Beach in Missouri are dramatic reminders of our tendency to put things away and forget where we put them. Further, if energy is in critically short supply for consumption, one wonders whether energy would be diverted for safekeeping of dangerous depositories.

The concept of net energy is like the concept of net profit. One subtracts the total cost from total revenue to determine net profit.

Net energy is obtained by subtracting total input-energy from total output-energy. The central problem, hence, the greatest controversy, in Net Energy Analysis is how to prescribe the appropriate boundary around a system for accurate measurement of inputs.

At some time in the lifecycle of any oil or gas field or coal deposit, for example, it becomes apparent that the continued expenditure of energy for mining and processing of the remaining resource might very well be greater than the energy that would be available from the fuel that was being recovered, particularly if net energy is measured at the point of end use.[1]

Economic Analysis might fail to anticipate at what point this is occurring. In fact, it is possible for capitalists to earn short-run financial profits when the net-energy balance of the process under study is small or negative. By way of explanation, current human activity is subsidized by our past activity. That is to say, much of what we are producing today is from the tools and structures (economic capital) that were constructed when petroleum and natural gas were much easier to obtain. Entrepreneurs in a competitive market tend to set prices and create profit on the basis of short-run opportunity rather than on the basis of long-run replacement costs. This is particularly true for depletable resources.[2]

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[1]Measurements have often been at the well site or mine mouth and have not included subsequent refining and other processing costs such as transportation, for example.

[2]A substantial amount of our infrastructure and standing capital was probably constructed when oil was cheap (e.g.,$1.50/bbl.) All currently produced stuff is enjoying this benefit. Oil miners may profit from their activities but may not be providing net energy.

Someday, in the relatively near future, we may finally realize that continued efforts to extract petroleum, natural gas, and coal from the Earth will result in negative net energy from those efforts. Fossil fuel will still be in the ground, but an external energy subsidy will be required for its retrieval. This was Fowler's 1977 position, stating that the U. S. petroleum reserves should be reserved for chemical feedstock purposes rather than used as fuel.[1]

It is questioned whether efforts to obtain the less-concentrated ores such as oil shale and tar sands will yield net energy or whether such activities will be merely roundabout ways of using up the current stocks of net energy. Similar conclusions have been reached by Merklein and Hardy who note that "shale oil is, and will remain for a long time, a white elephant . . . Tar sands are a pipe dream . . ." [2]

Energy Analysis is a relatively new discipline that has grown out of the apparent uneasiness that some scientists have had with less specialized Economic Analysis.

Gilliland writes:[3]

> Net Energy Analysis 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. . . . 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. . . . 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

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[1]Richard G. Fowler, The Longevity And Searchworthiness Of Petroleum Resources, Idem: 189.

[2]Helmut A. Merklein, et. al., Energy Economics, Idem: 204.

[3]Martha W. Gilliland, "Energy Analysis and Public Policy," Science, 189 (September 1975): 1051.

subsidies to energy extraction. Consequently, increase in the amount of energy available to do work in the consuming sectors of society. The entire increase may be to get the new energy. . .

The measurements are in units of energy, such as Btu's, joules, or kilowatt-hours. Most energy analysts use some technique for converting monetary data to energy units.

Debate Between Economists and Energy Analysts

Gilliland's 1975 article initiated a heated debate among some economists and energy analysts. In that paper she was critical of Economic Analysis, saying:[1]

> . . . 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.

In that paper she encouraged the substitution of Energy Analysis for Economic Analysis for the following reason:[2]

> . . . Energy Analysis of alternative energy supply technologies can provide more information of a less conflicting nature to policymakers. 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.

Huettner, an economist, responded to Gilliland's paper, expressing concern that Energy Analysis might replace Economic Analysis in national policy matters with respect to energy. Huettner writes:[3]

> Of deeper concern, however, are criticisms that seek an alternative framework to guide decision-making or to value inputs

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[1]Ibid.

[2]Ibid: 1056.

[3]David A. Huettner, "Net Energy Analysis: An Economic Assessment," Science, 192 (9 April 1976): 101.

and outputs. While no net energy advocate has to my knowledge, explicitly favored that it replace traditional economic analysis, the use of net energy accounting to value inputs and outputs and to guide decision making has far-reaching implication, particularly for the allocation of resources . . .

. . . More than just the appropriate selection of the numeraire is implied, however; prices are formulated as if energy were the only relevant resource constraint, and the relative scarcity of non-energy inputs becomes a factor only if it leads to a change in the energy content of these inputs. In essence, all non-energy resources are viewed as transformed energy, and in this one-commodity world all derivative products are priced according to their energy content.

In 1977, Slesser responded to Huettner, first critizing Huettner's throwing together all energy analysts into one school of thought. He distinguished between two approaches to Energy Analysis:[1]

. . . Net Energy Analysis does not use "net energy accounting to value inputs and outputs"; it uses gross energy accounting nor does Huettner distinguish betwen the two schools of energy analysis: that of Odum, to which Gilliland ... appears to be an adherent, and that which, broadly speaking, supports the conventions from the workshop on energy anlysis methodology convened by the International Federation of Institutes for Advanced Study (IFIAS) in Sweden in 1974. . .The former school places an energy value on the sun and on labor. The latter group regards the sun as a free good and argues that, since the objective of the economy is to furnish people with their needs, to count the energy for life support of labor is to double-count. This group treats energy analysis as the "determination of the energy (resource) sequestered in the process of making a good or service within the framework of an agreed set of conventions. . .

Odum, founder of what Slesser terms the "net-energy school," also responded to Huettner:[2]

. . . Net energy calculations are one of the by-products of doing general energy analysis, in which all flows believed to be important--including flows of money--are diagramed. Each is then evaluated in energy terms, first in degraded heat equivalents, then

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[1]Malcolm Slesser, "Letters to the Editor, Energy Analysis," Science, 196 (10 April 1977): 259.

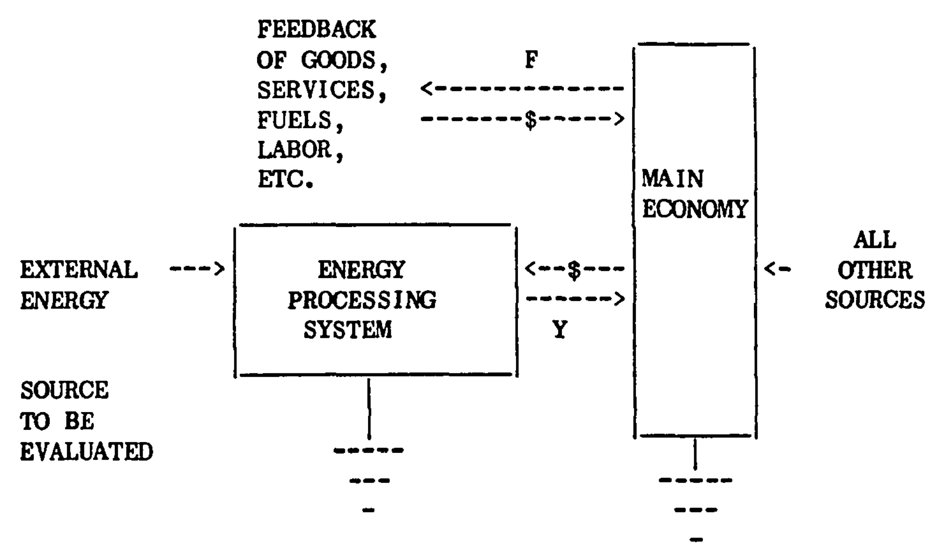
[2]Howard T. Odum "Letters to the Editor, Energy Analysis," Science, 196 (10 April 1977): 262.

in coal equivalents. Net energy is calculated to evaluate the contribution to the economy of an externality, such as fuel, minerals, environmental interaction, sun, wind, land, and so forth. Since money flows only within closed loops of the economy, one cannot evaluate in dollars whether an inflow from an external energy source or an environmental interaction is economic. The value of money overall is proportional to the energy inflows from outside.

The requirement for net energy calculation was represented to us by those writing Public Law 93-577 (the Non-Nuclear Energy Research and Development Act of 1974) with the simple diagram . . .[1] . . . Net Energy was defined as the difference between the yield Y and the feedback F, where both are expressed in equivalent energy

Figure 3.1

ODUM MODEL



Notes: F = feedback of energy-embodied goods and services
Y = GNP, (energy embodied goods and services)

Source: Howard T. Odum, "Letter to the Editor," Science 196 (10 April 1977): 260.

[1]Ibid.

units (of the same quality and energy cost. Calculating the yield ratio (Y/F) helps to estimate the fraction of the economy that must be returned to the processing of energy. For example, a yield of 6 for 1 returned seems to be characteristic of the main primary energy sources available to The United States with the price of foreign oil at $12 per barrel. The yield from nuclear plants is not as high. Proposed alternative energy technologies, such as solar heating, oil shale, solar cells, and low-velocity windmill generators have very poor yields. Net energy calculations cut through confusion in showing which proposed primary energy sources are poor.[1]

Slesser argued that the reason that Energy Analysis reaches different conclusions from those reached by Economic Analysis is that markets are imperfect.[2] Huettner's point is that, even if markets are free or perfect, analysts employing Energy Analysis will reach far different conclusions from those reached by analysts employing Economic Analysis and that, regardless of which school of Energy Analysis is used, "When in Italy, all roads lead to Rome.[3] By this, Huettner means that those holding an Energy Analysis perspective seem to view the world from a different perspective than that of economists. In this study the author holds that integrating the implications of the entropy law into one's perspective changes the perspective substantially.

Georgescu-Roegen entered this exchange, concerned with what he terms the "energetic dogma," typified by "one of the earliest propounders, Fred Cottrell . . . who argued that all that mankind needs is to obtain 'net energy'."[4] Georgescu-Roegen would seem to be on the side

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[1]Ibid.

[2]Malcolm Slesser, "Letter to the Editor," Science Idem: 259.

[3]David A. Huettner, "Letter to the Editor," Science Idem: 262.

[4]Nicholas Georgescu-Roegen, "Energy Analysis and Economic Evaluation," Southern Economic Journal, (April 1979): 1023-1058.

of energy analysts who share his concern with the implications of the entropy law on the economic process, but he turns against them, believing that "matter matters," as well as energy. Quite correctly, he argues against those who feel that, given enough energy, anything is possible. Second, he takes issue with those energy analysts who would substitute Energy Analysis for Economic Analysis as the basis for major policy considerations. Although fundamentally holding that "the entropy law is the taproot of economic scarcity," he also holds the following position:[1]

> . . . It would be a great mistake to think that it [the economic process] can be represented by a vast system of thermodynamic equations . . . The entropic process moves through an intricate web of anthropomorphic categories, of utility and labor, above all. Its true product is not a physical flow of dissipated matter and energy, but the enjoyment of life. . .

Georgescu-Roegen addresses Huettner's challenge to the energy analysts in the series in Science, noting:[2]

> Huettner followed the fallacious practice in standard economics of ignoring the essential differences between flows -- the material elements that are changed by a production process -- and funds--the agents that perform the change. As a result, his price equations had exactly the same form as his equations for presumed energy equivalents.

Huettner, in an unpublished article, said:[3]

> . . . Georgescu-Roegen .. . has argued, quite brilliantly, that matter matters, that energy analysis is not the rational basis for economic evaluation, that economic choice is a purely economic matter and not a physico-chemical one, and that our present approach to technology assessment requires a thorough reorientation.

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[1]Ibid.

[2]Ibid.

[3]David A. Huettner, "Energy Analysis and Economic Evaluation: Comment, Unpublished Article, University of Oklahoma.

However, Huettner doubts that Georgescu-Roegen's flow-fund analysis is likely to settle the issue and that the purpose of his [Huettner's] article was to show why Energy Analysis gives a different answer from Economic Analysis.[1]

In that series of exchanges in Science, Slesser calls for humility on all sides.[2]

Energy Analysis is not likely to take the place of Economic Analysis. However, perhaps there is room for collaboration and integration of aspects of Energy Analysis considerations into economic models. At least it seems paramount that economists must answer the charges of Georgescu-Roegen of the "mechanistic" connection and must integrate the implications of the entropy law into their thinking.

Economists may also find that the viewpoints brought forth by Energy Analysis may add a new dimension to their understanding of the social processes. Energy analysts, on the other hand, would benefit from the notion that choices and preferences of consumers, entrepreneurs, and politicians are principally psychocultural, although ultimately constrained by physical reality. Economists, however, need to catch on to the notion that the ultimate limits of the economic system are, at some point, constrained by certain physical realities.

New information about physico-chemical limitations is also likely to measureably influence tastes and preferences of consumers, entrepreneurs, politicians, and economists. Energy analysts and economists such as Georgescu-Roegen are correctly arguing that the entropy

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[1]Ibid.

[2]Malcolm Slesser, "Letter to the Editor," Idem: 259.

law is pervasive and that the mainstream economist's way of thinking about energy supply and the supply of other resources is seriously at fault.

It is held that most mainstream economists, using infinite-substitution reasoning, would argue that the price mechanism will provide the most reliable clues of resource availability both in the short run and in the long run.

It is argued that the failure to include the implications of the law of entropy into their method may have led mainstream economists into a dangerous intellectual trap (the trap of infinite-substitution reasoning) and may, consequently, place human civilization in deep peril.

The arguments of Georgescu-Roegen are currently being defended, among others, by Daly[1] against those of Burness, et al.[2]

Summary

The concept of Energy Analysis was introduced. The debate that broke out between economists and energy analysts was summarized. Energy analysts aroused the ire of some energy economists by pushing for the acceptance of an energy theory of value. Some economists were concerned that, not only might the government seek council from other than economists on energy policy, but more importantly, the conclusions of the energy analysts were likely to be different from conclusions reached by economists. The Odum net energy model, which will be used as the con-

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[1]Herman E. Daly, "Thermodynamics and Economic Concepts as Related to Resource-Use Policies, A response," Land Economics (forthcoming) 1985.

[2]Stuart Burness, et al, "Thermodynamic and Economic Concepts as Related to Resource-Use Policies," Land Economics, 56 (February 1985).

ceptual basis for drawing the system boundary around energy-transformation entities in this study, was introduced and shown as figure 3.1.

It is agreed, with Huettner, that Energy Analysis will lead to different conclusions from those reached by mainstream economists based on the infinite-substitution model. The conclusions reached in this study are no exception.

The differences in perspective, however, are fundamental. It is argued that energy is a unique aspect of nature for which there is no substitute. It is unique because of the laws of thermodynamics, especially the second law. Georgescu-Roegen has eloquently argued that mainstream economics is intellectually disconnected from the implications of the Second Law of Thermodynamics. It was argued that the failure of most economists to come to grips with this issue, not only intellectually misleads them, but since their influence is globally pervasive, also places civilization in deep peril accordingly.

CHAPTER 4

A CRITICAL VIEW OF STANDARD ENERGY ANALYSIS

Precis

There is a major and a minor methodology in Energy Analysis. The dominant school characaterized in this study as Standard Energy Analysis (SEA) includes writers such as Chapman,[1] Herendeen and Bullard,[2] and the likes.

The other far less-influential school is closely associated with students of Howard T. Odum,[3] a systems biologist at the University of Florida, and the more recent work of Costanza[4]. This author's position is closely related to that of Odum. The problem of system boundary will be discussed at some length. A critical discussion of the current state-of-the-art in Standard Energy Analysis and suggestions for a relatively simple net-energy method will conclude the chapter.

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[1] P. F. Chapman, G. Leach, and Malcolm Slesser, "The Energy Cost of Fuels," Energy Policy, 2 (September 1974): 231-243.

[2] Robert A. Herendeen and Clark W. Bullard, III, "The Energy Cost of Goods and Services," 1963 and 1967, CAC Document No. 140, (Urbana, IL: [1967].

[3] Howard T. Odum, Energy Basis For Man And Nature, Idem.

[4] Robert Costanza, "Embodied Energy," Idem.

A Critical Discussion Of Standard Energy Analysis

Diversities in methodology in Energy Analysis led to a number of conferences and the ultimate adoption of a standardized set of "conventions" so that analysts could better communicate among themselves. The International Federation of Institutes for Advanced Study (IFIAS) conducted the first conference in Guldsmedshyttan, Sweden, in August of 1974. A second IFIAS conference, a goal of which was to bring together economists and energy analysts, was held in 1975 at Lidingo, Sweden. Apparently, this was not very successful. An additional conference was organized by The Institute of Energy Studies at Stanford in August, 1975.[1]

Rich sources of background information are also contained in Hannon,[2] Herendeen,[3] and Webb and Pierce,[4] among others.

Three Standard-Energy-Analysis techniques are described by Chapman, a leading writer in the field. The following is a summary of his review:

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[1]Energy Accounting As A Policy Tool, Subcommittee on Energy Research, Development and Demonstration, of the Committee on Science and Technology, U. S. House of Representatives, 94th Congress, Second Session, by the Environment and Natural Resources Division, Congressional Research Service, U. S. Government Printing Office, [1976].

[2]Bruce M. Hannon, "An Energy Theory of Value," Annals Of The American Academy Of Political and Social Science 410 (1973).

[3]Robert A. Herendeen and Clark W. Bullard III, "Energy Cost of Goods and Services," CAC Document No. 140, Center for Advanced Computation, University of Illinois, Urbana-Champaign, [1974].

[4]Michael Webb and David Pearce "The Economics of Energy Analysis," Energy Policy, 3 (December 1975): 332-344.

1. Statistical Analysis. In this technique, Census of Production data are used to estimate energy per unit of output. These data are coupled with data on industrial output and allow an estimate to be made of the energy cost per unit of output.[1]

2. Input-Output Analysis. This technique involves the use of national Input/Output (I/O) tables. Monetary values are transformed mathematically to energy values to show the amount of energy embodied in each component of the I/O table. It is based on the matrix approach developed by Leontief for use in economics.[2]

3. Process Analysis. The following is quoted from Chapman:[3]

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

Historically, we have recorded a great deal of financial data on physical materials and energies rather than on the physical quantities of materials by volume and weight. Most of the various techniques have been developed to translate the financial data to physical (energy and materials) data. For example, the Input/Output calculations of Bullard, showing the number of Btu's embodied in each dollar's worth of each item in the United States Standard Industrial Classification Code, show that 33,938 Btu's were required to produce each dollar's worth of

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[1]P.F.Chapman, "Energy Costs: a review of methods," Energy Policy (June 1975): 95-96.

[2]Wassily Leontief, The Structure Of The American Economy, (New York: Oxford University Press, 1941), pp. 1919-1939.

[3]P. F. Chapman, "Energy Costs:" Idem.

cigarettes and 517,502 Btu's to produce each dollar's worth of cement.[1]

Standard analysis has been used in the United States, the United Kingdom, and other countries in Europe. Regardless of the subset used (input-output or process), these methods require an accounting (as inputs) only for the direct use of fuels and the indirect energies embodied in the physical materials. For example, Bullard notes the following in a footnote:[2]

> As a first approximation, we could multiply the dollar cost of the power plant (88 million* at 1970 prices...) by the average intensity for all goods and services in 1970 (68,690 Btu/$). This coefficient is simply the ratio of total U.S. energy use to gross national product in 1970 . . .Wages and taxes are excluded to be compatible with system boundary of the I-O model which corresponds to GNP. Using this convention, energy to produce items bought with wages are charged to the wage earner, not the employer.

It should be noted that Bullard uses the word convention, and it is argued that such a practice is valid as a convention only, a misleading one at that. It constitutes a major specification error in describing the boundary that should be abstractly drawn around an energy-transformation system in order to do accurate Energy Analysis. Note that Bullard explicitly excludes wages and taxes "to be compatible with system boundary."[2]

What is left is an accounting for the direct use of fuels and the indirect energy embodied in physical materials only. Wages and taxes are monies paid to workers and governments, respectively, who buy actual goods and services with those monies. None of these goods or

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[1]Clark W. Bullard III, Peter S. Penner and David A. Pilati, Net-Energy Analysis: Handbook For Combining Process and Input-output Analysis, Energy Research Group University of Ill, [1976], p. 22.

[2]Ibid.

services is brought into the economic arena except through the use of energy and materials.[1]

The practice of excluding wages and taxes reflects a somewhat incomplete understanding of National Income and Product Accounting. Gross National Product (GNP) is a measure of the monetary value of the total physical product of the economy, usually in annual quantities. National Income (NI) measures the money payments to the factors of production involved in producing the physical goods and services. These factor payments include wages, tax dividends, interest, and profits.[2]

The two economic accounts (Product and Income) are somewhat mirror images of one another, and the sums of the two accounts are equal amounts. The apparent logic used by Herendeen and Bullard is that counting wages would involve a double counting because wages and other factor payments appear in the Income accounts, whereas fuels and physical materials appear only in the Product accounts. If economists followed such a practice, a microeconomic analysis would not be possible.

Argument for Expanded System Boundary

It is argued that Energy Analysis is analogous to a micro-economic analysis. In microeconomics one deals with the firm or

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[1]Direct refers to fuels and electricity actually consumed on site of the entity being evaluated, and indirect refers to those consumed in the web of industrial processes before they are brought to the facility under evaluation.

[2]Richard G. Lipsey, et al. Economics, 7th ed., (New York: Harper & Row, Publishers, 1984), pp. 504-511.

industry, while in Energy Analysis, one deals with an energy-transformation entity or system (for example, a nuclear power plant.)

In an earlier proposition it was held that, in order for anything to be made useful for human consumption, some amount of energy must be expended. The amount of energy involved is out of a complicated network of prior expenditures (money/energy). Therefore, it follows that any payment of money is representative of some real amount of goods or services. Hence, when money crosses the company fence (the system boundary), outbound, then the company expects real goods and services to travel in the opposite direction across the same system boundary, inbound. Therefore, all money payments are proportional to energy flows. All financial payments made by a company, say, an electric-utility company, are for actual goods and services that are made available only through a real set of prior energy expenditures. Recall from above that wages, interest, taxes, and so forth (so-called factor payments) are not counted as energy costs in Standard Energy Analysis. A Robinsoe Crusoe-type example may help in understanding the author's reasoning as to why they must be included.

Suppose that the Army Corps of Engineers (Corps) is designated the responsible agency to construct a nuclear power system on a remote island. The system boundary is drawn around the island. Suppose further that the remote island has its own uranium source. Assume that the Corps has complete technical capability to move to the island with all of the equipment needed to construct a complete facility. Also let us assume that the amount of energy embodied in all that equipment and material taken to the island is known.

Standard analysis procedure includes only the energy embodied in the physical materials and any direct use of fuels/electricity as inputs. Normally, they do not count the wages paid to the members of the Corps or the interest, taxes, and so forth related to the project.

Now suppose that, instead of paying the members of the Corps a salary, everything that workers and their families need for living (food, clothing, shelter, entertainment, education, health care, retirement, and so forth) is furnished in kind . Since standard analysts normally count the energy embodied in physical materials and fuels, they would be remiss if they did not count the energy embodied in those goods and services consumed by the workers, although they would fail to count them when money payments are involved.

A dollar can be viewed as a ticket with rights to have energy-embodied goods and services. The holding of the money is an institutional entitlement of the holder to have those energy-embodied goods and services, either now or later. This same logic applies to all money payments, for example, interest, taxes, and professional fees for appearances before regulatory commissions (the Nuclear Regulatory Commission, public utility commissions, and legislative committees at the federal, state, and local levels), made by any energy entity.

Equipment operators, engineers, and architects involved in the construction of energy-transformation facilities who receive wages, as well as the bankers who lend the money, expect that the money they receive will be of an acceptable exchange value, entitling them, at some time, to energy-embodied fuels, goods, and services of an expected quality and quantity. They expect that their tickets will be redeemable in energy-embodied goods and services.

Standard analysts do not deal with the energy costs of using the infrastructure or the commons. In economics, taxes are payments for the use of the infrastructure or commons.[1] A recent study by Pat Choate suggests that an additional $3 trillion will have to be set aside for infrastructure repair over the next few years in order to keep the highways, bridges, sewers, water-treatment systems, etc., from falling apart. Choate's study suggests that we are not paying as we go for depreciation of the infrastructure or the commons by current taxes.[2] To that extent, we are understating the energy-inputs that might be appropriate, even in the current study.

This phenomenon may also account for the apparent decline in the ratio of GNP to energy consumption over time (see appendix A). We are allowing the infrastructure to deteriorate and environmental resources to be degraded. Industries escape much of the cost for their use of the commons, including environmental resources. These resources include clean air, clean water, and healthy topsoils, which are, not only being depleted in quantity, but degraded in quality by industrial pollution. This degradation will require substantial energy-materials resources to be fed back to clean up waste sites, and polluted water and restore polluted and degraded agricultural areas -- if this is possible.

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[1]Garrett Hardin, "The Tragedy of the Commons," Science 162 (December 15, 1968): 1243-1248. As used by Hardin, the commons is the common property of the body politic.

[2]Pat Choate and Susan Walker, America In Ruins: The Decaying Infrastructure, (Durham, NC: Duke Press Paperbacks, 1983).

On Double Counting

As noted earlier, standard analysts argue that counting wages and salaries results in double counting. The following reasoning is brought to this debate:

Gross National Product is a comprehensive measure of the nation's total annual production of commodities and services. The Bureau of Economic Analysis, U. S. Department of Commerce, defines Gross National Product in the following manner:[1]

> . . . is the market value of the goods and services produced by the labor and property supplied by residents of the United States, before deduction of depreciation charges and other allowances for business and institutional consumption of capital goods. Other business products used up by business are deducted. Gross national product comprises the purchase of goods and services by consumers and government, gross private domestic investment (including the change in business inventories), and net exports (exports less imports). Beginning 1960, the estimates include data for Alaska and Hawaii. . .

Only the end products of a year's economic activity are included. For example, the value of wheat sold in the economy is not included in the accounting for GNP -- only the final product "bread" is included to avoid double counting.

It has been argued that to include labor costs as an energy cost in standard analysis would be to double count. Presumably the reasoning is that we have two totals: (1) a Product total and (2) an Income total, the one nearly a mirror image of the other. Bullard has argued that, in order to be consistent with GNP accounting, the energy-embodied goods consumed as a result of the purchases of laborers with labor

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[1]United States Department of Commerce, Bureau of Economic Analysis, Business Statistics, in Explanatory Notes, following page 181.

incomes must be charged to the laborer and not counted as an energy-input to the energy-transformation entity.[1]

The author holds this to be incorrect. Spending wage income buys goods and services that are accounted for out of the Product side of the accounts. These goods and services are purchased in retail markets, and they will be worn out, usually by the purchaser (exchanges of used merchandise are irrelevant). The goods are consumed once only, and they are counted once. It is a matter of consequence, however, as to whether such consumption of energy-embodied goods and services should be charged as an energy-input to the energy-transformation entity.

Reference the Bureau of Economic Analysis definition of GNP above. It should be noted that the GNP is the dollar value of the end product of goods and services annually produced in the economy. It should also be noted, however, that the value of the end product is the summation of all the "values added" at each stage of the production and distribution process. In other words, each intermediate good is a subset of the finished commodity or service. Therefore, a money expenditure for an intermediate good, such as a wholesale purchase or a purchase of raw materials, which is not really counted directly as a part of GNP, _is_ ultimately included because it is physically included and accounted for financially as a subset of the final good or service.

For example, a farmer might get $4 for a bushel of wheat at the grain elevator; the commodity broker may get $5 from the flour-milling company; the flour miller may get $6 from the baking company; the

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[1]Clark W. Bullard III. et al. Net Energy Analysis: Handbook, Idem. p. 22.

baking company may get $10 from the supermarket for the baked loaves of bread; the supermarket may get $20 for the loaves of bread -- all made from the one bushel of wheat. The main point is that the $4 paid to the farmer for the bushel of wheat is included in the $20 in costs to the final consumer.

However, if one is analyzing income and expenses of the farmer who produced the wheat, there is, in this microeconomic sense, no a double counting of anything. The $4.00 received for the wheat is counted as part of farm income, and the $3.99 that the farmer spent on producing the wheat is not a double counting of expenses when we analyze his profit situation. If we want to know the profit and loss of a farm, we must look at all of the related receipts and expenditures.

Likewise, the system boundary for an energy-transformation entity, must coincide precisely with the economic boundary. It is in this same sense that the Odum net-energy model, which shows energy flowing in one direction and money flowing in the opposite, describes what goes on in energy flows (fig. 3-1). It is my conclusion that, if money is flowing (payments are being made), it is for goods and services, all of which require an energy expenditure for their being.

Everything is ultimately accounted for in the Gross National Product. For example, every dollar expenditure involved in the construction and operation of an electricity-generating system ultimately ends in some year's worth of GNP (or National Income). For example, interest income on a construction loan is included in current GNP; the wage income for construction workers is shown currently as the income is received; current purchases of goods and services are shown in the GNP;

income is received; current purchases of goods and services are shown in the GNP; the utility's purchase of fuel is reflected in the price of electricity (about 50 per cent of the current price of electricity from coal-fired and natural gas-fired plants); electrical sales to residential customers is a line-item in GNP accounting; electrical sales to industrial and commercial customers ultimately make their way into some future year's GNP via the prices of all final products. Little really escapes the net.

Apparently some energy analysts and economists have overlooked these dynamic considerations. I argue that there is no double counting in the Odum model, as described in figure 3.1. Money flows across the company fence, outbound, and energy-embodied goods and services flow in the opposite direction to the company. It is an inescapable condition. Money outlays for the construction and operation of energy-transformation entities crudely measure the amount of energy being used as inputs. The trick, of course, is to adequately define the relationship between the flows of energy and the flows of money.

A Model Of The Discrepancy

A model should clarify what I hold to be a serious error in Standard Energy Analysis methodology, (i.e., the failure to count all dollar outlays by an energy-transformation entity as energy outlays). Perhaps this model and the accompanying reasoning will also assist in clarifying what the Odum school has not yet successfully made clear in its work.

The traditional economic model is usually illustrated in most textbooks showing the two basic sectors as the business sector and the households sector. People live in households and travel to the business sector for a part of their day for which they are paid a wage. Workers use the money earned as wages to purchase real goods and services from the business sector.

In figure 4.1 note that no particular set of workers is identified with a particular sector of the economy. The underlying

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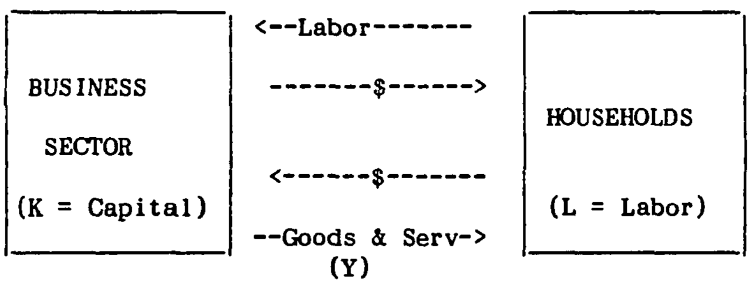
Figure 4.1

SIMPLE ECONOMIC MODEL



Note: The model is: $Y = f(K,L,)$, where Y = GNP.

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assumption of any economic model is that the factors of Production, Labor (L), and Capital (K) (machines, structures, and so forth) are functionally substitutable for one another.

The adapted convention of Standard Energy Analysis is that to count wages as an energy cost would be to double count. Standard Energy Analysis does count as inputs the direct use of fuels and the energy embodied in physical materials. Since machines are physical materials, they would naturally be counted as energy-inputs.

Standard Energy Analysis correctly counts the energy embodied in physical Capital (K). If Labor (L) is functionally substitutable for Capital (K), then how can one logically avoid counting the energy cost of the functional substitution? Therein lies the fallacy of the reasoning. The energy embodied in machines is always correctly counted as an energy input by standard energy analysts. There is no logical reasoning for omitting the energy embodied in the goods and services purchased by workers. The goods and services are the incentives necessary to attract the workers and are, therefore, an inherent cost of doing business. The same analysis applies to interest, taxes, profits, and professional services.

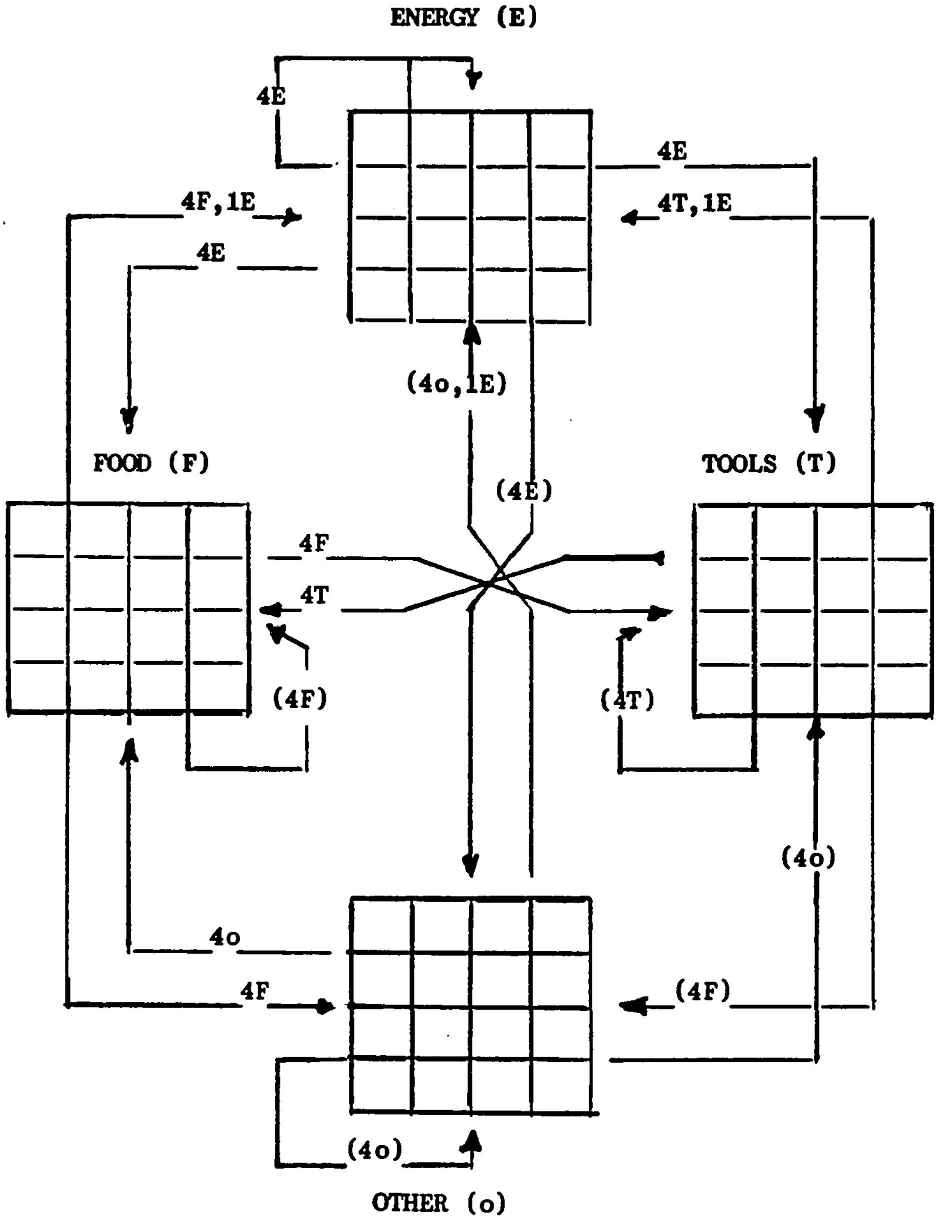
Let us assume that the community under study is an isolated, self-sufficient community. The only terrestrial energy source available is a nearby coal mine. The community economy is divided into four sectors and each sector annually requires exactly four energy units to carry out its activities. Further, it is assumed that the farmland is optimally used for maximum output and that there is no room for expansion. Only sixteen families can be supported from the land. Further, there is no opportunity for exchange with outside economies.

The four-sector Robinsoe Crusoe model (figure 4.2) is introduced for further clarification:

1. Energy. The sector initially requires four families to mine sixteen units of coal energy annually, the exact amount needed for the annual production of the total economy. Four of these units are used by each of the sectors, including four units for coal mining.

Figure 4-2

ROBINSOE CRUSOE CONCEPTUAL MODEL



2. Tools. The second sector, which annually requires the effort of four families, is responsible to provide tools needed by all of the other sectors, requires four energy units to carry out tool-making processes.

3. Food. This sector, which also requires the effort of four families, is responsible for all farming activities, including including the provision of food, fibre, and timber for lumber for the Food Sector and all of the other four sectors. It also requires four energy units to carry out its activities.

4. Other. This sector is responsible for providing housing, furniture, etc., to fill its own needs and the needs of all the other families. The sector also uses four energy units annually to carry out these activities.

Energy and Tools are considered intermediate goods. Food and Other are considered final goods, and their value would be counted in GNP. The model in figure 4.2 shows the interrelationship between the sectors.

In this hypothetical situation, What is the energy cost of mining coal, or how much net energy can the coal-producing families provide? The following is presented:

Using Standard Energy Analysis the energy-inputs would be as follows:

(4 units direct) + (1 unit indirect from Tools) = 5. The Output/Input Ratio would be 16/5, or 320 per cent.

This result is reached by counting only the direct fuels consumed and the indirect energy involved in the physical materials needed in the construction and operation of the energy-transformation entity. The end-use goods and services (Food and Other) consumed by workers who operate the coal mine are not included in this procedure.

Net Energy Analysis presents a different picture:

A close examination of the model shows that energy-embodied goods are also being returned to the energy sector from the other two sectors in the form of Food and Other consumer items. The following shows what these inputs are:

(4 units internal) + (1 unit from Tools) + (1 unit from Food) + (1 unit from Other) = 7.

The Output/Input Ratio is 16/7, or 228.6 per cent -- not 320 per cent, as shown in Standard Energy Analysis.

If the logic of the foregoing is upheld, one can see that Standard Energy Analysis counts only a part of the energy-inputs involved in the example. Odum is correct in holding that money flows in one direction and energy (fuel and energy-embodied goods and services) flows in the other (see figure 3.1). The problem is to identify the nature of that relationship.

Summary

The methodology being practiced by Standard Energy Analysis was questioned. It was argued that the practice of counting as energy-inputs only the energy in fuels and electricity and the energy embodied in physical materials used "on site" at the energy-transformation entity is an incorrect procedure. The Standard Energy Analysis method excludes the energy embodied in goods and services consumed by persons associated with labor, government, and financial services.

It was argued that the Odum model, which shows money and energy flowing in opposite directions, is the correct model for Energy Analysis. Although Standard Energy Analyses may have been slightly useful for making relative comparisons between various forms of energy transformation, it is not the appropriate model for understanding whether various energy-transformation entities are independent sources of energy. It is held that the Odum model is the correct one for such an understanding.

CHAPTER 5

A SIMPLIFIED NET ENERGY METHODOLOGY

Precis

In chapter 4 the case was made that mainstream energy analysts, in their adoption of a set of conventions, are thereby trapped in what is believed to be a conceptual error in defining the appropriate system boundary for Energy Analysis. This trap results from the practice of counting as energy-inputs only the direct consumption of fuels and the indirect embodied energy in physical materials. These analysts, like many economists, have seriously underrated the problems of future energy supply.

The Odum net-energy model (see figure 3.1) is a much more realistic framework than that used in Standard Energy Analyses. The Odum model shows money flowing in one direction and energy-embodied goods and services flowing in the other. When an energy-transformation entity pays out constant dollars for a system, those dollar quantities are proportional to the energy needed as inputs for the sustenance of such a transformation activity. Standard Energy Analysis models exclude items that must be included. The system boundary must be expanded to account for the embodied energy in the goods and services that are consumed by workers, government, and by those who receive interest income for renting out their money.

The case will be made that there is a proportionality between energy consumption and the production of goods and services. Costanza[1] provides a rich background for the Net Energy Analysis method that is used in this study. A summary of his important contribution is included in this chapter. His position supports my adoption of an average ratio of annual energy consumption and annual Gross National Product as a basis for making net-energy calculations.

A case will be made for a methodology to estimate the net energy available from future energy-transformation technologies which incorporates the expanded boundary. Using time-series data of annual energy use and real GNP (1947 to 1983), it will be shown how an Energy/GNP coefficient was calculated. This coefficient will be used in estimating the input-energy needed to sustain energy-transformation entities.

The general procedure for estimating the net-energy inputs will be outlined. Briefly, the procedure is to determine the lifecycle economic cost of the energy-transformation system and multiply that cost times an Energy/GNP coefficient. In dynamic analysis, these costs are apportioned between those that are incurred before the plant begins to operate and those costs that are incurred as the plant operates.

Also, in this chapter the results of order-of-magnitude net-energy calculations of fossil-fuel acquisition in the United States will be shown. The calculations are based on well-head and mine-mouth prices of fossil fuels and, therefore, do not consider the energy costs of refining, transportation, marketing, and so forth. As a conse-

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[1] Robert E. Costanza, "Embodied Energy," Science, Idem.

quence, the estimated net energy available from these fuels is substantially overstated. Nevertheless, the trend shows a marked increase over time in the amount of energy that is being fed back into the energy-acquisition process.

Background

How to choose the appropriate time frame for measuring the depletion of a particular amount of energy is a difficult problem. We are always using out of our past accumulations of knowledge, infrastructure, capital, and so forth. Today, oil wells are being drilled with equipment that may have been made in steel mills and foundaries that may have been constructed more than fifty years ago. Those steel mills are likely to have been constructed using the canals, for example, that were constructed a hundred or so years ago.

Even more complex to ponder is the consideration that those canals were constructed using virgin lumber that was grown in energetically rich, highly productive, biological circumstances, characteristic of early settlement days, that are not likely to be duplicated again, ever.

From the earliest time that man began to inhabit the North American continent in population size that would take a noticeable toll on the depletion of its rich resources, we have transformed these solar-embodied energy resources and mineral resources into stocks of equipment and structures (economic capital) that last for a period of time. The entropic process, however, reduces all such structures and the low-entropy materials first to debris and ultimately into randomness and disorder.

The lush virgin forests, rich in wildlife (concentrated proteins) for the easy taking of humans, have been constantly and ever increasingly exploited and reduced in size and quality. The topsoils in forests, plains, and bottomlands are being eroded at frightening rates,[1] leaving succeeding generations with less of this kind of resource to use. We build up stocks of man-made capital (factories, dwellings, canals, rails, highways, airports, steel mills), but these crumble into ruin too quickly. They are not renewable except to the extent that the supplies of needed energy and materials are renewable.

We have been accumulating, at high rates and for some time -- probably since the the beginning of the industrial era in the United States -- a fund of economic capital created out of stocks of natural resources. It is asserted that we accumulate these capital funds in spurts. Depending on economic conditions, we tend to live out of these accumulated funds of capital[2] for periods of time unaware that we may be consuming capital rather than living out of current income. We may be tempted to say that, not only are we doing better, but we have discovered the free lunch. This mind set led to the claim of some to hold that nuclear-powered electricity would be "too cheap to meter."

With the nuclear power industry currently in economic disarray, the promoters of nuclear-fusion power are speculating that this technology will provide us with an infinite energy supply. Promoters appear

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[1]Desertification In The United States: Status And Issues, Working Draft Review, U. S. Department of Interior, undated, received in 1980 preliminary to a series of conferences held throughout the United States in 1980, pp.25-60.

[2]Capital is meant to mean structures, such as factories, steel mills, machinery, and so forth, rather than money.

to be somewhat oblivious to the fact that all of the money (hence, energy) being spent on fusion development, as well as that to be spent on each new system, must be subtracted from the hoped-for energy-output.

A Money-Energy Proportionality Argument

The argument, which says that all money outlays are for real energy-embodied goods and services, to the best of my knowledge, originates with Odum.[1]

Costanza, of the Odum net-energy school, showed that there is a tight relationship between constant-dollar money expenditures and the consumption of energy. Following Odum, Costanza revived the 1933 argument made by Frederick Soddy that "the flow of energy should be the primary concern of economists."[2] Costanza also argued:[3]

> . . .Most proposals to increase energy efficiency via technology are ultimately based on the assumption of the mutual independence of primary factors of production; that is, capital, labor, natural resources, and government services . . . are the conventional primary factors . . . free from indirect energy costs?" [emphasis added].

Costanza cites Georgescu-Roegen:[3]

> . . . On paper one can write a production function any way one likes, without regard to dimensions or to other physical constraints . . . In actuality, the increase of capital implies an additional depletion of resources.

Costanza then goes on to make the case that the primary factors

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[1]Howard T. Odum, Energy Basis for Man and Nature, Idem.

[2]Frederick Soddy, Wealth, Virtual Wealth and Debt, The Solution of the Economic Problem, (New York: Dutton, 1933), Quoted by: Robert Costanza, "Embodied Energy," Idem, p. 1219.

[3]Nicholas Georgescu-Roegen, in Scarcity and Growth Reconsidered ed. V. K. Smith, Ed. (New York: Johns Hopkins Press, 1979), cited in R. Costanza, "Embodied Energy," Idem, p. 1220.

(capital, labor, and resources) are not independent, but quite interdependent, e.g., that the availability of capital is dependent on the availability of energy. Costanza modifies the 90-sector input-output model used by the Energy Resources Group at the University of Illinois noting:[1]

> . . . The modifications to include labor and government in the model require expanding the transactions matrix (x) to include two more sectors, households and government . . .

He took the results of the changed input-output model and put the energy intensities into regression format. The calculated energy intensities were multiplied by the sector's total output and used as the independent variable. Total output was used as the dependent variable. It will be noted in table 5.1 that the results of the regression coefficients improve significantly when labor and government services are included as

Table 5.1

COSTANZA REGRESSION ANALYSIS RESULTS[1]

	Including Energy Sectors			Excluding Energy Sectors		
Alter.	r^2	F	Signif. of F-test	r^2	F	Signif. of F-test
A	.0210	1.89	0.1729	.5539	100.57	0.0001
B	.0629	5.90	0.1710	.2042	20.78	0.0001
C	.7809	313.73	0.0001	.9907	8633.95	0.0001
D	.8535	512.74	0.0001	.9454	1401.31	0.0001

Explanation:
A - excludes labor, government and solar as inputs
B - includes labor and government
C - includes labor and government
D - includes labor, government, and solar

[1]Costanza, "Embodied Energy," Idem: 1220.

endogenous variables. Costanza notes the following:[1]

> The results indicate a significant relationship between embodied energy and dollar output when labor and government are included as endogenous sectors (Alternatives C and D). Several problems still exist, but the trend is clear. As more of the indirect energy costs are taken into account, the ratio of embodied energy to dollars becomes more nearly constant from sector to sector. The primary input sectors (Sectors 1 to 7) are the important exceptions to this rule. One interpretation . . . is that their direct and indirect production costs in energy terms are much less than the energy embodied in their outputs, the difference being the amount brought into the economy from the outside.

Costanza raises the following major issue:[2]

> . . . Several authors [citing Lovins,[3] and Stobaugh and Yergin[4]] have suggested that "decoupling" energy and GNP is possible and would allow the economy to continue to grow while decreasing energy consumption. . . . If the sector to sector differences in embodied energy intensities implied in these calculations were real, then it might be possible to simply shift production from high-intensity sectors to low energy intensity sectors to lower energy use without sacrificing economic activity. This conclusion would follow from the underlying assumption that the currently defined primary factors are independent. But because it takes available energy to produce labor and government services, capital and other natural resources, the assumption of independence is not warranted. . . . The possibility for large changes in energy efficiency is small since, all things considered, total energy efficiency is fairly constant from sector to sector. Any reductions in direct energy consumption are offset by increases in indirect energy consumption through increased use of labor, land, or capital

Costanza concludes with the following:[5]

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[1]Ibid: 1222

[2]Ibid: 1223

[3]Amory Lovins, Soft Energy Paths: Toward a Durable Peace, (Cambridge, MA: Ballinger, 1977).

[4]Robert Stobaugh and Daniel Yergin, Energy Futures: Report of The Energy Project at the Harvard Business School, (New York: Random House, 1979).

[5]Costanza, "Embodied Energy," Idem: 1224

> What does all this imply for national policy? The most important implication is that the physical dimensions of economic activity are not separable from limitations of energy supply. The universally appealing notion of unlimited economic growth with reduced energy consumption must be put firmly to rest beside the equally appealing but impossible idea of perpetual motion. It is easy to think you can get a "free lunch" by looking only at small parts of the system in isolation. When the whole system is analyzed, however, it becomes clear that all you can do is transfer the cost of your lunch to another segment of the system. . . .[1]

This writer has not studied the net-energy aspects of various efficiency improvements or various conservation alternatives; but this matter will have a high priority in future research plans.

First, in support of the conservationists, including Sant,[2] they are correctly making the case that energy conservation and efficiency improvements, rather than investment in central electricity-generating systems, provide a net benefit to society. Central power stations simply cost too much when compared to conservation and efficiency improvements. This author generally supports this position.

In a 90-year analysis, Cleveland, et al[3], showed additional evidence for the tight relationship between fuel use and economic production. In the author's opinion, the Cleveland study provides a further basis for the practice used in this study of applying a 37-year mean value for the Energy/GNP coefficient to the Lifecycle Cost of energy-transformation entities.[1] Using a 90-year mean-value coefficient would have yielded less-favorable net-energy results.

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[1]Ibid

[2]Roger W. Sant, The Least Cost Strategy: Minimizing The Costs Through Conservation, (Arlington: Mellon Institute, 1978).

[1]Cutler J. Cleveland, Robert Costanza, Charles A. S. Hall, and Robert Kaufmann, "Energy and the U.S. Economy: A Biophysical Perspective," Science 225 (31 August 1984): 890-897.

The larger question being addressed by Costanza and by this author does not involve the relative merits of various technological recipes. Both of us are relating to a larger issue. Yes, the current generation can have a higher standard of living by making the most efficient use of the resources it chooses to deplete. However, neither energy nor Earth resources are conserved for future generations, for example, if money is spent on a conservation gadget (resulting in a savings) and the difference is spent on other goods and services. This is because none of the other goods and services could have been made available, except through a set of energy-materials depletions in another part of the economy. Yes, the individual has made the most efficient use of his income by investing in conservation and efficiency-improvement technology, but he has not forestalled the rate of energy-materials depletion unless he does not consume either the central-power-station output or the conservation gadget. Almost facetiously, true conservation would occur when one takes the cash and burns it in a high-efficiency stove or puts it in a compost pile to serve his garden.

It seems appropriate to close this section with the following quote from Georgescu-Roegen who concludes the following:[1]

> If we abstract from other causes that may knell the death bell of the human species, it is clear that natural resources represent the limitative factor as concerns the life span of that species. Man's existence is now irrevocably tied to the use of exosomatic instruments and hence to the use of natural resources just as it is tied to the use of his lungs and of air in breathing, for example. We need no elaborated argument to see that the maximum of life quantity requires the minimum rate of natural resources depletion. By using these resources too quickly, man throws away

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[1]Nicholas Goergescu-Roegen, The Entropy Law, Idem, p.21.

that part of solar energy that will still be reaching the earth for a long time after he has departed. And everything man has done during the last two hundred years puts him in the position of a fantastic spendthrift. There can be no doubt about it: any use of the natural resources for the satisfaction of nonvital needs means smaller quantity of life in the future. If we understand well the problem, the best use of our iron resources is to produce plows or harrows as they are needed, not Rolls Royces, not even agricultural tractors.

Net Energy Procedures

The arguments developed in chapter 4 and the discussion in the foregoing section provide the underlying philosophy for the net-energy procedures devised for this study. The reasoning provides a firm basis for the argument that there is a proportionality between the **real** monetary cost of economic goods and services and the energy that is required to make them available.

To determine the net energy to be expected from an energy-transformation entity, the general procedure is to subtract estimated total input-energy from estimated total output-energy. The first step is to consider how the boundary is to be drawn around the system that is to be measured. In this study the net-energy boundary will match the economic boundary.

Output-energy can be estimated by comparing engineering estimates of future performance with actual experience and making a judgement as to expectations about future trends.

Measurement of the input-energy is another matter and the source of greatest controversy. The general procedure will be to: (1) determine the lifecycle real economic cost of the energy-transformation entity to be studied, (2) determine an appropriate Energy/GNP Ratio, (3) multiply total cost times the Energy/GNP Ratio to obtain estimated static input-energy, and (4) compare input-energy with output-energy.

All economic costs for nuclear-powered electricity-generating plants were based on the data developed by Komanoff.[1] Variable data for the wind-system models were from questionnaire information and accompanying brochures. The estimate for the transmission and distributions system cost for both nuclear and wind is estimated as a percentage of the generating cost and is explained in chapters 7 and 8.

Annual data (1947 - 1983) for energy consumption and Gross National Product (GNP) were collected. The nominal (or current) GNP numbers were divided by the respective implicit price deflators with the base year of 1979 for nuclear and 1972 for wind. Annual real GNP was then divided into annual physical energy use (Btu's) to determine the energy/GNP coefficient for each year. The detailed calculations are shown in appendix A and a summary is shown in table 5.2.

Three separate sets of Energy/GNP Ratios were derived using Gross National Product information for the years 1979, 1982, and 1983. The nuclear cost estimates were expressed in 1979 and 1982 dollars and the wind data were expressed in 1983 dollars. Calculations were made for each year from 1947 to 1983 and mean values were calculated for each set. The net-energy estimates were made using lowest-value, mean-value, and highest-value Energy/GNP Ratios for nuclear power systems and wind systems.

Appendix A shows data comparing annual Gross National Product and annual energy consumption from 1947 to 1983. Table 5.2, which follows, is an excerpt of that data for selected years.

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[1]Charles E. Komanoff, Power Plant Cost, Idem.

Table 5.2

ENERGY/GNP RATIOS SELECTED YEARS

(A) YEAR	(B) BTU'S Btu's Consumed	(C) Nominal GNP	(D) Energy/GNP Ratio (1979=100)	(E) Energy/GNP Ratio (1982=100)	(F) Energy/GNP Ratio (1983=100)
1947	3.305e16	2.313e11	43461	34324	34141
1950	3.362e16	2.848e11	38752	30605	30443
1955	3.917e16	3.980e11	36728	29007	28853
1960	4.375e16	5.070e11	36264	28828	28675
1965	5.262e16	6.910e11	34635	27597	27452
1970	6.636e16	9.930e11	37364	28889	30236
1975	7.048e16	1.054e12	35030	27665	27519
1979	7.884e16	2.418e12	32605	25750	25614
1980	7.590e16	2.632e12	31484	24865	24733
1981	7.394e16	2.954e12	29886	23603	23478
1982	7.082e16	3.073e12	29181	23046	22924
1983	7.045e16	3.305e12	27134	21436	21324
	37-year mean values:		35791	28266	28116

Notes: See appendix A for detailed information.
A Quad refers to a quadrillion (1.10e15) btu's of energy.
Notation "e15," for example, means the decimal point is actually 15 places to the right of where it is shown.

For example, column D, table 5.2 shows that the 37-year mean-value Energy/GNP Ratio is 35,791 Btu's per 1979 dollar of Gross National Product, i.e., it has on average taken about 35,791 Btu's to produce each 1979 dollar's worth of real GNP. A scan of the Energy/GNP Ratios will show an apparent decrease in the value of those ratios since 1950.

Cleveland, et al, however, show that this trend disappears when differences in energy quality are taken into account.[1]

For the static energy-input number, total economic cost is multiplied times the selected Energy/GNP Ratio, i.e., for example, 35,791 Btu's/$1979, 28,266 Btu's/$1982, or 28,116 Btu's/$1983. Static net energy for a single entity is a matter of subtracting estimated total input-energy from estimated total output-energy. The Output/Input Ratio is found by dividing estimated output-energy by estimated input-energy. Static Net Energy Analysis gives the total Output/Input Ratio for a single entity over its entire construction, operation, and decommissioning cycle.

Dynamic analysis shows the accumulated Output/Input Ratio, total net energy, and average annual net energy to be expected from an entire system (a group of single entities) at points in time. This procedure takes into consideration plants under construction and those that are being retired. For dynamic analysis, it is necessary to separate the costs between those incurred before the plant is completed and those that are incurred over the lifecycle of the plant after it begins to operate. A computer model was developed which will show the accumulated net energy (positive or negative) for any selected year. Dynamic analyses were calculated for 50 and 100 years involving varying rates of construction, expected lifecycles, cost ranges, performance capabilities, and so forth.

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[1] Cutler Cleveland, et. al. "Energy and the U.S. Economy: A Biophysical Perspective," Science 225 (31 August 1984): 890-897.

Estimated Net Energy, Fossil Fuel Mining

The energy estimates that are being made in this study involve speculation about energy considerations more than a hundred years into the future. It seemed important to have additional support as to whether the productivity of the energy-acquisition process was improving or deteriorating.[1] The substudy shows the trend of the amount of energy that was fed back into the process of acquiring fossil fuels from 1949 to 1983. Table 5.3 shows the results of that inquiry. Detailed information is contained in appendix A.

Earlier, it was mentioned that one of my major concerns was the looming possibility that we may be facing a situation where more and more effort (energy) may be required in the energy-acquisition process, leaving less and less available energy for other purposes.

Order-of-magnitude calculations were made to estimate the amount of feedback energy that is required in the process of acquiring energy in the United States. Table 5.3 shows the amount of net energy that we have realized from 1949 to 1983 from the mining of petroleum, natural gas, and coal. It will be seen that net-energy consumption (costs at the well head and mine mouth) increased from approximately 28 quads in 1949 to about 51 quads in 1982.

Total output-energy data and economic-cost data for each fuel are from Energy Information Agency data.[2] Input-energy information was obtained by: (1) calculating an average Energy/GNP coefficient

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[1] Productivity refers to the amount of yield versus the amount effort.

[2] U.S. Department of Energy, Energy Information Agency, 1983 Annual Energy Review, table 4. Washington, D. C. [1984], p. 11.

Table 5.3

NET ENERGY FROM FOSSIL FUEL PRODUCTION IN U.S.
1949-1983

(A) YEAR	(B) VALUE FOSSIL	(C) FEEDBACK ENERGY	(D) BTU FOSSIL PRODUCED	(E) NET ENERGY FOSSILS	(F) PER CENT FEEDBACK
1949	1.363e10	8.285e14	2.859e16	2.776e16	2.8
1950	1.473e10	8.954e14	3.230e16	3.140e16	2.7
1951	1.549e10	9.416e14	3.550e16	3.455e16	2.6
1952	1.505e10	9.148e14	3.447e16	3.355e16	2.6
1953	1.586e10	9.641e14	3.475e16	3.378e16	2.7
1954	1.524e10	9.264e14	3.309e16	3.216e16	2.7
1955	1.630e10	9.908e14	3.676e16	3.576e16	2.6
1956	1.724e10	1.048e15	3.890e16	3.785e16	2.6
1957	1.811e10	1.100e15	3.921e16	3.810e16	2.8
1958	1.617e10	9.829e14	3.632e16	3.533e16	2.6
1959	1.628e10	9.896e14	3.796e16	3.697e16	2.6
1960	1.625e10	9.878e14	3.836e16	3.737e16	2.5
1961	1.647e10	1.001e15	3.871e16	3.770e16	2.5
1962	1.681e10	1.021e15	4.009e16	3.906e16	2.5
1963	1.720e10	1.045e15	4.228e16	4.123e16	2.4
1964	1.721e10	1.046e15	4.392e16	4.287e16	2.3
1965	1.747e10	1.061e15	4.529e16	4.422e16	2.3
1966	1.809e10	1.099e15	4.797e16	4.687e16	2.2
1967	1.879e10	1.142e15	5.035e16	4.920e16	2.2
1968	1.869e10	1.136e15	5.193e16	5.079e16	2.1
1969	1.930e10	1.173e15	5.381e16	5.263e16	2.1
1970	2.064e10	1.254e15	5.660e16	5.534e16	2.2
1971	2.048e10	1.244e15	5.440e16	5.315e16	2.2
1972	2.055e10	1.249e15	5.628e16	5.503e16	2.2
1973	2.185e10	1.328e15	5.561e16	5.428e16	2.3
1974	3.301e10	2.006e15	5.379e16	5.178e16	3.7
1975	3.574e10	2.172e15	5.230e16	5.012e16	4.1
1976	3.712e10	2.256e15	5.259e16	5.033e16	4.2
1977	3.949e10	2.400e15	5.270e16	5.029e16	4.5
1978	4.073e10	2.475e15	5.278e16	5.030e16	4.6
1979	5.015e10	3.048e15	5.586e16	5.281e16	5.4
1980	6.738e10	4.095e15	5.670e16	5.260e16	7.2
1981	8.221e10	4.997e15	5.618e16	5.118e16	8.8
1982	7.647e10	4.648e15	5.516e16	5.051e16	8.4
1983	6.832e10	4.153e15	5.195e16	4.779e16	7.9

Source: See appendix A for detailed calculations.
All values are for $1972 = 100. An Energy/GNP coefficient of 60,789 Btu/$($1972= 100) was used to calculate Energy Input numbers.
Numbers pertain to fossil-fuel production, (i.e. mining) in the United States, not energy consumption in the United States.

($1972=100) and (2) multiplying the Energy/GNP coefficient times the constant-dollar value for each fuel for each year. Net energy was found by subtracting input-energy from output-energy.

Column E shows the amount of energy that is being fed back into the process of mining fossil fuels, measured at the well head and the mine mouth, respectively. Column F shows the per cent of feedback energy. It will be noted in table 5.3 that the per cent of feedback energy has been steadily increasing since 1949 from 2.8 per cent to a peak of 8.8 per cent in 1981 and declining in 1982 and 1983. However, table A-3 of appendix A, shows that the amount of energy being fed back into the petroleum industry reached 17 per cent in 1981 (appendix A.)

It should be noted that all of these calculations are based on prices at the well head for petroleum and natural gas and prices at the mine mouth for coal. Additional transportation, refining, and marketing energies are actually involved; therefore, the numbers shown in table 5.3 and appendix A are robust accordingly.

Additional Supporting Information

Hall and Cleveland, noted the following:

> For the past 30 years the number of barrels of oil found per foot of drilling effort in the American domestic petroleum industry for any given year can be explained as a secular decrease of about two percent per year and combined with an inverse function of drilling effort. Extrapolation of energy costs and gains from petroleum drilling and extraction indicated that drilling for domestic petroleum could cease to be a net source of energy by about 2004 at low dilling rates and 2000 at high drilling rates, and that the net yield will be less at the high drilling rate.[1]

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[1]Charles. A. S. Hall and Cutler Cleveland, "Yield Per Effort and Net Energy Analysis of the American Petroleum Industry," Science 211 (1981): 576.

Chapman, using Standard Energy Analysis, but including energy-costs beyond the well head, noted the following:[1]

> . . . The five energy, or fuel, industries -- coal mining, oil refining, , coke, gas and electricity production -- jointly consume more than 30% of the total energy input to the UK. . . . The fuel industries themselves are the largest consuming sector. . . .

Wallace E. Tyner cites Fremont, who "showed that national income per capita and total commercial energy consumption per capita are closely related," and Darmstadter, having studied all 153 countries in existence at that time, concluded the following:[2]

> the higher a nation's income on the current international scale, the higher, in general, its level of energy consumption; as its GNP rises over time, so does its energy conumption -- in close, even if not proportionate, conformity.[1]

Tyner also found a close relationship between per-capita commercial energy consumption and per-capita income in the economy of India.

Summary

The background section provided a historical perspective of the development of capital structures as it relates to energy-materials depletion in the United States.

The money-energy proportionality argument was developed drawing support from Odum, Costanza, Georgescu-Roegen, Cleveland, et al, and others. Costanza in 1980 and Cleveland, et al in 1984, provide the strong arguments for this view. Costanza shows that the factors of production (Land, Labor, Capital and Resources) are not independent, but

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[1]P. F. Chapman, et al., "The Energy Cost of Fuels," Energy Policy (September 1974), p. 231.

[2]Wallace E. Tyner, Energy Resources and Economic Development In India, (London/Boston: Martinus Nijhoff Social Sciences Division, 1978), pp. 1-5.

quite interdependent, i.e., that capital and labor cannot be substituted for energy and materials. Costanza and Cleveland, et al, argue against those who see the possibility of decoupling energy consumption and economic output. The possibility of a declining resource base, especially energy, raises important ethical issues with respect to social justice and inter-generational considerations and will be further discussed in chapter 9.

An overview, with underlying rationale, was provided for the net-energy procedures that will be followed in making net-energy analyses of both nuclear-powered and wind-powered generating systems in chapters 7 and 8 respectively. The general procedure that will be followed in this study is to determine the real lifecycle economic cost of nuclear-power and wind-power systems and multiply those costs times a selected Energy/GNP Ratio. Net-energy calculations will be made using the highest, mean value, and lowest value Energy/GNP Ratios for the appropriate tables shown in appendix A, and summarized in Table 5.2.

Table 5.2, based on the total data base in appendix A, shows energy consumption, real gross national product, and Energy/GNP Ratios for selected years.

Table 5.3 shows the results of order-of-magnitude calculations that were made to crudely estimate the trend of the amount of energy that was being fed back into the process of mining fossil fuels. The system boundary (economic boundary) encompasses those economic costs that were incurred at the well head and mine mouth. The energy costs of transportation, refining, marketing, and so forth, were not included. As a result, the net-energy quantities are overstated accordingly. The foregoing adds a robust quality to the conclusions of the study.

Additional supporting information for the money-energy proportionality argument was included. Chapman shows that about 30 per cent of the energy in the United Kingdom is being used in the processing of energy. His calculations included processing costs beyond the well head, and the mine mouth.

CHAPTER 6

UNITED STATES ELECTRIC UTILITY SYSTEM ENVIRONMENT

Precis

The purpose of including the information presented in this chapter is to show how the capability of any energy-transformation entity to deliver energy to society is constrained by the efficiency of the larger system of which it is a part; that is, the net-energy capability of a transformation system is limited by any inefficiency that is present, for whatever reason, in the larger system. Stated another way, it is not legitimate to claim an efficiency level for an isolated system when back-up systems are required to insure that the system meets the needs of society.

Most net-energy analyses up to this time have been made using Standard Energy Analysis procedures, and most have been for single isolated entities, such as one nuclear-powered plant or one wind machine. Most calculations have been so-called bus-bar calculations, meaning that the system boundary was drawn to exclude the electrical transmission and distribution grid system. It is held that energy is not useful until it is delivered to the energy consumers (industrial, commercial, and residential). Therefore, it is necessary to include, as an energy-input cost, the energy cost of transmission and distribution of the electricity-generating system. Overhead costs were also included based on the money-porportionality argument of chapter 5.

Since the net-energy estimates that are made in chapter 7 for nuclear systems and chapter 8 for wind systems project several years into the future, it is important to have some idea as to the trend in efficiency of the total system.

Further, it seems necessary to inquire into the effect on system efficiency of the introduction of large generating systems, particularly large nuclear systems.

Selected data about the United States electricity-generating system are discussed in the first part of this chapter. The data show the total electrical Generating Capacity of the United States from 1952 to 1982 and the corresponding electrical sales made by large, privately-owned United States utilities. The amount of nuclear Generating Capacity is shown for the same period. The data will indicate that, as nuclear plants are introduced into the system, the efficient use of the total system correspondingly declines. It is also shown that these United States utilities may have been able to generate the same amount of electricity without the construction of any nuclear power plants if they had maintained the level of efficiency they were achieving in 1959.

Decline in U S. Utility System Efficiency

The data in columns B, C, and E of table 6.1 are taken from Energy Information Administration documents. Data are for total generating system of the United States. Derivition of columns D, F, and G are explained at the bottom of table 6.1. Column E (i.e., maximum, continuous) shows the amount of electricity that could be generated if

Table 6.1

ELECTRICITY-GENERATING SYSTEM EFFICIENCY
United States

(A) Year	(B) Total Capacity (KW)	(C) Nuclear Capacity (KW)	(D) Col. B x 8760 (kWh)	(E) Total Net. Gen. (kWh)	(F) Effic. Factor	(G) Nuclear Fraction
1952	8.220e07	0.00	7.200e11	3.990e11	0.5541	0.0000
1953	9.140e07	0.00	8.006e11	4.430e11	0.5532	0.0000
1954	1.026e08	0.00	8.987e11	4.720e11	0.5251	0.0000
1955	1.145e08	0.00	1.003e12	5.470e11	0.5453	0.0000
1956	1.207e08	0.00	1.057e12	6.010e11	0.5684	0.0000
1957	1.291e08	1.00e05	1.130e12	6.320e11	0.5588	0.0007
1958	1.420e08	1.00e05	1.243e12	6.450e11	0.5185	0.0007
1959	1.560e08	1.00e05	1.366e12	7.100e11	0.5195	0.0006
1960	1.680e08	3.00e05	1.471e12	7.560e11	0.5136	0.0017
1961	1.807e08	4.00e05	1.582e12	7.940e11	0.5016	0.0022
1962	1.911e08	7.00e05	1.674e12	8.550e11	0.5107	0.0036
1963	2.105e08	7.00e05	1.843e12	9.170e11	0.4972	0.0033
1964	2.223e08	9.00e05	1.947e12	9.840e11	0.5053	0.0040
1965	2.361e08	9.00e05	2.068e12	1.055e12	0.5100	0.0038
1966	2.478e08	1.90e06	2.170e12	1.144e12	0.5270	0.0076
1967	2.693e08	2.90e06	2.359e12	1.214e12	0.5146	0.0107
1968	2.911e08	2.80e06	2.550e12	1.329e12	0.5211	0.0096
1969	3.133e08	4.00e06	2.744e12	1.442e12	0.5254	0.0127
1970	3.416e08	6.50e06	2.992e12	1.532e12	0.5119	0.0190
1971	3.689e08	8.70e06	3.231e12	1.613e12	0.4991	0.0235
1972	3.986e08	1.53e07	3.491e12	1.750e12	0.5011	0.0383
1973	4.424e08	2.29e07	3.875e12	1.856e12	0.4789	0.0517
1974	4.759e08	3.17e07	4.169e12	1.864e12	0.4472	0.0665
1975	5.082e08	3.33e07	4.452e12	1.917e12	0.4307	0.0655
1976	5.309e08	4.23e07	4.651e12	2.037e12	0.4380	0.0796
1977	5.602e08	4.60e07	4.907e12	2.124e12	0.4328	0.0821
1978	5.791e08	4.96e07	5.073e12	2.206e12	0.4348	0.0856
1979	5.982e08	4.93e07	5.241e12	2.247e12	0.4287	0.0824
1980	6.135e08	5.11e07	5.374e12	2.286e12	0.4254	0.0832
1981	6.348e08	5.55e07	5.560e12	2.294e12	0.4126	0.0874
1982	6.501e08	5.96e07	5.694e12	2.241e12	0.3935	0.0916
1983	6.581e08	6.28e07	5.765e12	2.310e12	0.4006	0.0954

Col. B - Total Generating Capacity of United States
Col. C - Total nuclear-powered generating capacity, U. S.
Col. D - Total capacity multiplied times 8760 hours.
Col. E - Total reported net generation, kilowatt hours.
Col. F - Column E divided by column D.
Col. G - Column C divided by column B.
Notation "e12," for example means decimal point is 13 places right.
Source (Col. C, D & F): Energy Information Administration (EIA), Annual Energy Review, Department of Energy.
KW - Means kilowatts of generating capacity.
kWh - Means kilowatt-hours.

all of the system could have been operated continuously, without interruption. The numbers in column E (maximum-continuous kilowatt hours) are obtained by multiplying column C (total Generating Capacity) times 8760 hours (total number of hours in a 365-day year). The potential maximum, continuous kilowatt-hours are then compared to reported Total Net Generation (kilowatt hours).[2] Total Net Generation (column E) is divided by maximum-continuous, kilowatt hours (col. D) to obtain the total system Efficiency Factor. The Efficiency Factor is an estimate of the surplus, or backup, Generating Capacity. A steady decrease in Efficiency Factor Ratios will be noticed in Column F, beginning in 1957 (.5684 to 1) through 1983 (.4006 to 1). Column G. shows the Nuclear Installed Capacaity as a ratio of the Total Generating Capacity.

Once a system is constructed, it has incurred a fixed cost that is distributed over its anticipated life -- say, 25 years. Regardless of the per cent of time that the system has operated, it probably will need to be abandoned at the end of its calendar life because of age-deterioration. However, a system that delivers 99 per cent of its maximum potential, ceteris paribus, would be considered a more efficient

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[1]Department of Energy, Energy Information Agency, Financial Statistics of Selected Electric Utilities 1983, [February 1985]. Also, see Annual Energy Review, [1985].

[2]Ibid.

[3]The numbers in column G are not to be confused with the way utility engineers calculate Capacity Factors. Capacity Factor measures a single plant's electrical generation as a percentage of its maximum possible generation divided by product of 8760 and design electrical rating. Efficiency Factor is introduced to account for backup capacity. Efficiency Factor accounts for total kilowatt hours that could have been generated if all of the capacity could have been used all of the time, versus the actual electricity generated.

process than one that delivered only 40 per cent of its maximum potential. Certainly, the net-energy measurement must compare the total energy-input (total-system cost) to total energy-output (sales).

Many economic analyses and energy analyses of electricity-generating systems have been made based on relatively high Capacity Factors. Usually these are expressed for single power plants, in isolation. They do not take into consideration the redundancy that must be available to meet, not only the "down time" from various operational problems, but also the varying demand situations (i.e., seasonal, time-of-day, and so forth). In a crude way, the ratios in column G are a useful measurement of total-system efficiency, and they also show the decline in efficiency over time.

Table 6.2 is an extension of table 6.1. Columns B and C are the same information shown in table 6.1. Column D shows total Generating Capacity minus Installed Nuclear Capacity. Column E shows the amount of electricity that could have been generated by Column D capacity if the total system had been operated a 52 per cent Efficiency Factor that was being achieved in 1959. Column F shows the surpluses and shortages of electricity that would have been encountered by maintaining such a system, maintaining a 52 per cent Efficiency Factor after 1957.

It will be noted that electricity demand for the United States could have been met (except for the 7 years with minuses) without building any of the nuclear capacity, by using the non-nuclear Generating Capacity, and operating it at a 52 per cent Efficiency Factor. The shortage years could have been met by slightly increased efficiency in those shortage years.

Table 6.2

ELECTRICITY-GENERATING POTENTIAL WITHOUT NUCLEAR CAPACITY
From Maintaining a 52 Per Cent Efficiency Factor

(A) Year	(B) Total Capacity (KW)	(C) Nuclear Capacity (KW)	(D) Col. B- Col. C (KW)	(E) (D)x8760 x .52 (kWh)	(F) Actual Net.Gen. (kWh)	(G) Surplus Elec. (kWh)
1952	8.220e07	0.00	8.220e07		3.53e11	
1953	9.140e07	0.00	9.140e07		4.43e11	
1954	1.026e08	0.00	1.026e08		4.72e11	
1955	1.145e08	0.00	1.145e08		5.47e11	
1956	1.207e08	0.00	1.207e08		6.01e11	
1957	1.291e08	1.00e05	1.290e08	5.87e11	6.32e11	-4.43e10
1958	1.420e08	1.00e05	1.419e08	6.46e11	6.45e11	1.38e09
1959	1.560e08	1.00e05	1.559e08	7.10e11	7.10e11	1.55e08
1960	1.680e08	3.00e05	1.677e08	7.63e11	7.56e11	7.90e09
1961	1.807e08	4.00e05	1.803e08	8.21e11	7.94e11	2.73e10
1962	1.911e08	7.00e05	1.904e08	8.67e11	8.55e11	1.23e10
1963	2.105e08	7.00e05	2.098e08	9.55e11	9.17e11	3.86e10
1964	2.223e08	9.00e05	2.214e08	1.00e12	9.84e11	2.45e10
1965	2.361e08	9.00e05	2.352e08	1.07e12	1.05e12	1.63e10
1966	2.478e08	1.90e06	2.459e08	1.12e12	1.14e12	-2.38e10
1967	2.693e08	2.90e06	2.664e08	1.21e12	1.21e12	-4.94e08
1968	2.911e08	2.80e06	2.883e08	1.31e12	1.32e12	-1.57e10
1969	3.133e08	4.00e06	3.093e08	1.40e12	1.44e12	-3.30e10
1970	3.416e08	6.50e06	3.351e08	1.52e12	1.53e12	-5.55e09
1971	3.689e08	8.70e06	3.602e08	1.64e12	1.61e12	2.77e10
1972	3.986e08	1.53e07	3.833e08	1.74e12	1.75e12	-3.99e09
1973	4.424e08	2.29e07	4.195e08	1.91e12	1.85e12	5.46e10
1974	4.759e08	3.17e07	4.442e08	2.02e12	1.86e12	1.58e11
1975	5.082e08	3.33e07	4.479e08	7.98e11	1.92e12	2.43e11
1976	5.309e08	4.23e07	4.886e08	2.22e12	2.03e12	1.88e11
1977	5.602e08	4.60e07	5.142e08	2.34e12	2.12e12	2.17e11
1978	5.791e08	4.96e07	5.295e08	2.41e12	2.20e12	2.05e11
1979	5.982e08	4.93e07	5.489e08	2.50e12	2.24e12	2.53e11
1980	6.135e08	5.11e07	5.624e08	2.56e12	2.28e12	2.75e11
1981	6.348e08	5.55e07	5.793e08	2.63e12	2.29e12	3.44e11
1982	6.501e08	5.96e07	5.905e08	2.68e12	2.24e12	4.48e11
1983	6.581e08	6.28e07	5.953e08	2.71e12	2.31e12	4.01e11
				Total, column G:		1.45e12

Columns B, C, and F from EIA Annual Energy Report, 1984.
Column D = Column C subtracted from column B.
Column E = Column D x 8760 hours/yr x .52 Efficiency Factor.
Column G = shows annual surplus or shortage (-).
The notation "e06," for example means decimal point is 6 places right.
Note: Column F shows the amount of electricity that could have been generated if the United States Utility system had not built any nuclear plants. A slight increase in the Efficiency Factor for the years with minuses might have met the demand, in the aggregate.
KW - Means kilowatts of generating capacity.
kWh - Means kilowatt hours.

Figure 6.1 shows the scatterplot of data points, with accompanying linear-regression information, of the time-series data shown in table 6.1. Values for both variables are taken from table 6.1. Nuclear capacity, as a per cent of Total Generating Capacity, is plotted on the horizontal axis. The total-system Efficiency Factor values plotted against the vertical axis. It will be seen that there is a fairly good correlation in the data by the r^2 value of 0.867976.

Further, it seemed necessary to determine if the aggregate data of table 6.1 could be confirmed by a utility-by-utility analysis. Although the results shown in figure 6.2 require further analysis, the tentative results suggest that there is some correlation between the introduction of nuclear facilities and declining utility efficiency, using the cross-sectional data. The following reasoning is shown:

For each individual utility:

Let x = the nuclear fraction, and

Let 1-x = the non-nuclear fraction,

Leg C = total Generating Capacity.

Derive f = Nuclear Duty Cycle.

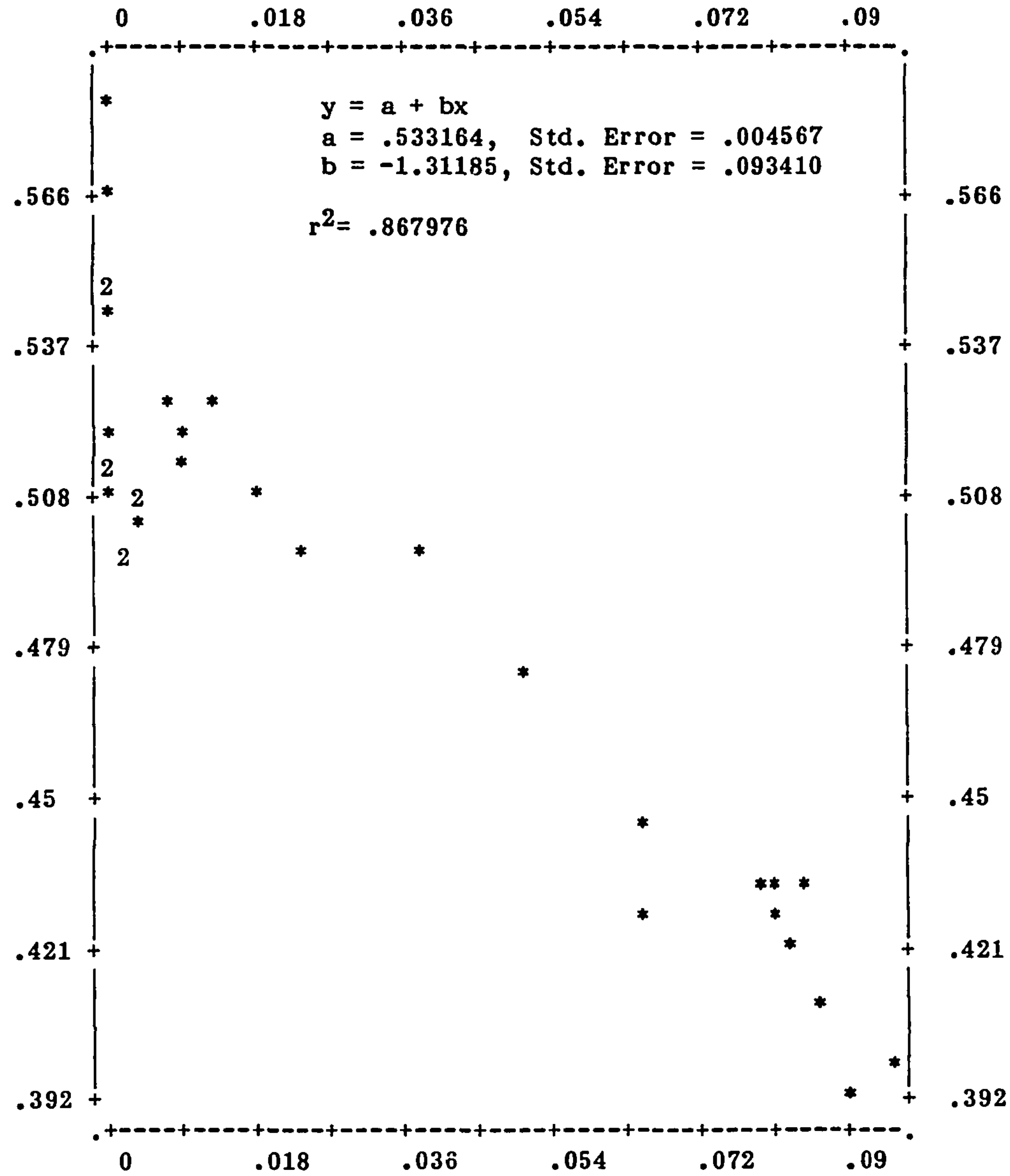
Then the overall efficiency, $$e = \frac{f(xC) + (1-x)C(1-f)}{C} \qquad (1)$$

Which results in $$f = \frac{1-e-x}{1-2x} \qquad (2)$$

The resulting values of "f" versus the values of "e" (for cross-sectional data for 101 large, United States, privately-owned utilties) are shown in appendix D and plotted in figure 6.2. Only those utilities

Figure 6.1

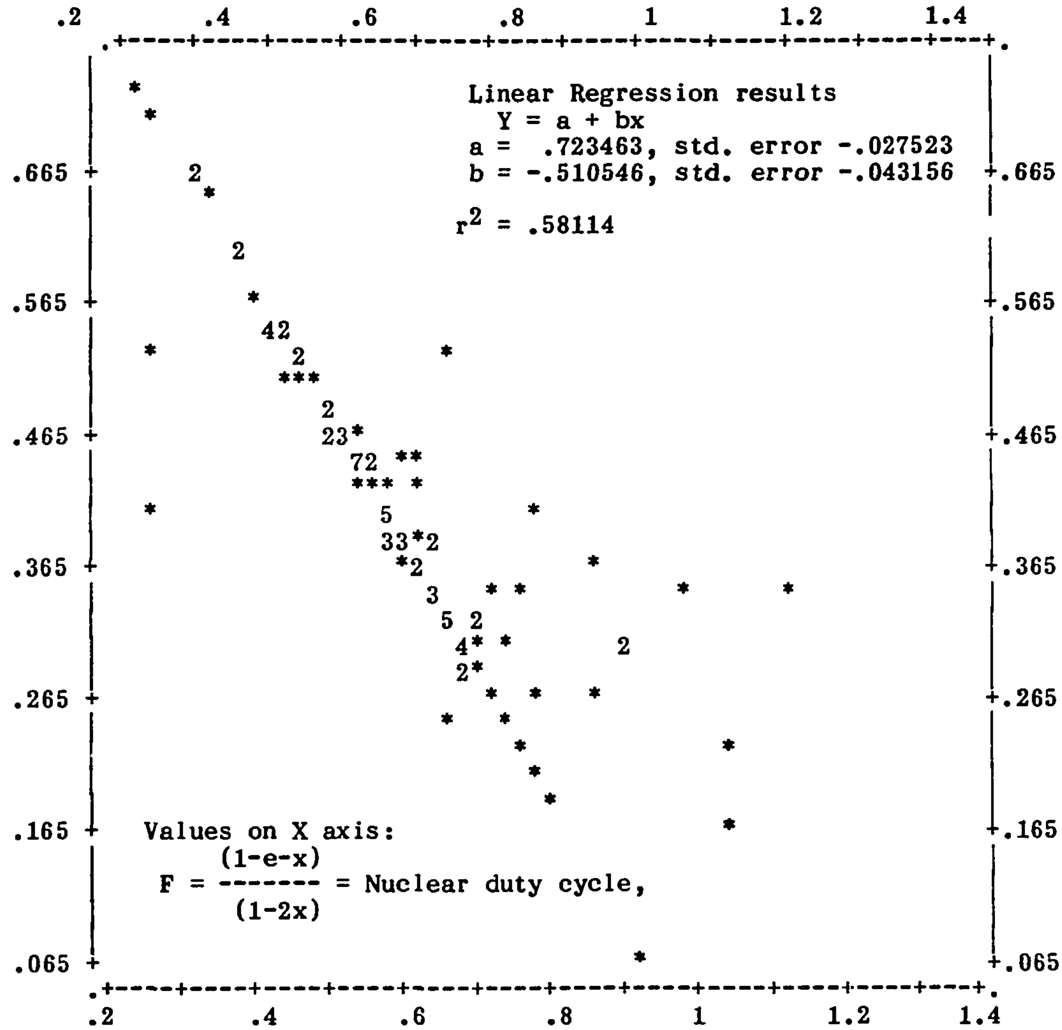
CAPACITY RATIO VS TOTAL EFFICIENCY
Vertical: Efficiency Factor:
Horizontal:Per Cent Nuclear Capacity



Notes: 32 data points. Integers on chart indicate number of obser-vatations at that location.
Plots are from time-series data shown in table 6.1.
Micro-computer statistical program used: The Statistician.

Figure 6.2

SCATTERPLOT: NUCLEAR DUTY-CYCLE VS UTILITY EFFICIENCY
Cross-Sectional Data, 1982
101 Large United States Privately-Owned Utilities
Vertical Axis: Efficiency Factor of Each Utility



Notes: See appendix A for basic information. Integers on chart indicate number of data points at that spot. 101 data points.
e = Efficiency Factor of each utility.
x = per cent of Installed Capacity as nuclear.
Source: appendix A and Financial Statistics of Selected Utilties 1983, Energy Information Agency, Department of Energy.

having total generating capacity greater than 1000 megawatts were selected for analysis. The linear-regression-analysis results are shown in the upper-right-hand corner of figure 6.2.

Although other factors, such as "off-system" sales and purchases, lifestyles (to include the greater use of seasonal air conditioning), and a miscalculation of future demand by the utility companies, must play a role in the declining Efficiency Factors, over time, there is a suggestion in the foregoing analysis that at about half of the declining efficiency is related to the introduction of large nuclear systems.

The findings seem reasonable. These large systems require that large blocks of backup generating capability must be on hand when these large plants are shut down. It seems reasonable that the recognition of generic safety problems may require the generic shutdown of large blocks of nuclear systems having those generic characteristics in order to avoid the risk of catastrophic accidents.

Part of the reason for the increase in electrical sales can be attributed to falling "real" prices of electricity during a large part of the period. This led to uses of electricity that were later found to be too costly by utility customers. The utility companies apparently presumed that the annual growth rate in demand of 7 to 8 per cent would continue indefinitely as they continued to expend their Generating Capacity, despite warnings from conservationists[1] that impending higher

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[1] Amory B. Lovins, "Electric Utility Investments: Excelsior or Confetti," Unpublished Invited Remarks the E.F. Hutton Fixed-Income Research Conference on Public and Invester-Owned Electric Utilities, held at the Hotel Pierre, New York, NY, (8 March 1979), p.4.

prices would depress demand.

Despite industry's promotional efforts to the contrary, there is a growing awareness that electricity is a high-quality form of energy and its use should be reserved for performing high-quality tasks such as running computers, communications systems, electric motors, and arc welders. Using electricity for space heating, in most cases, is an inappropriate use of electricity. As Lovins[1] says:

> It [electric space heating] is equivalent to paying about $130 for a barrel of oil . . . because it takes from three to five Btu's of fossil fuel to generate enough electricity to provide one Btu of heat from an electrical resistance heating system . . . It's like using a chain saw to cut butter.

Part of the reason for the declining efficiency is probably due to excess Generating Capacity which arose as a result of the declining demand (from the projected growth rates).

A major problem is to choose the appropriate Efficiency Factor to use for Net Energy Analysis. For example, nuclear power plants are sometimes credited for individually achieving from 50 per cent to 80 per cent Capacity Factors. However, it must be kept in mind that nuclear plants are scheduled as so-called base-load plants, and the utility companies schedule them for operation as much of the time as possible. "Standby" capacity must be on hand to meet the peak requirements of fluctuating demand schedules. Therefore, it seems reasonable to conclude that the "real" operating efficiency of a sub-set is constrained by the operating efficiency of the set.

Perhaps an analogy will assist in understanding the reasoning. A situation is recalled where an Air Force general found it individually

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[1]Ibid.

rewarding to be transported around in a relatively fast (for its time) experimental transport plane. Unfortunately, since the faster plane was unique, there were no spare parts, technical bulletins, or maintenance skills for it at locations that the general wanted to go. A more standard, but slower, version of transport aircraft was, therefore, kept loaded with spare parts and manuals, with flight crews and mechanics kept on "standby" to follow the ego-maniacal general around the country whenever the faster plane broke down.

The foregoing analogy provides the context for my argument that neither nuclear power plants nor wind machines can be credited with the high Efficiency Factors (usually referred to as Capacity Factors) that can be achieved by looking at the performance of the transformation system in isolation. For example, while some nuclear power plants may be "base-load" operated at 80 per cent Capacity Factors, their real system efficiency is constrained by the operating efficiency of the larger system of which they are a part. Tables 6.1 and 6.2 reflect the amount of of standby capacity that is on hand for "peak demand."[1]

Wind Energy Conversion Systems (WECS) are plagued with the same problem. Promoters of wind machines market their products on the basis that the owners and operators of wind systems can use as much of their electricity as they need locally and sell the surplus to the nearby utility company. If the machine is connected to the utility

[1]There is a level of demand for electricity that is relatively continuous which is called "base-load" demand. Demand fluctuates above this "base-load" varying with the time of day and season of the year. Plants with high fixed costs and low variable costs are usually dedicated to meeting the "base-load." Additional Generating Capacity must be on hand to meet the fluctuating demand conditions.

electrical grid, the Public Utilities Regulatory Policy Act (PURPA) mandates that utilities must purchase surplus electricity at the host utility's avoided cost. Viewed in isolation this might be perceived as a more efficient use of the energy supplied by the wind system, but the operating efficiency of the wind system is now actually constrained by the overall operating efficiency of the electrical grid into which it is feeding its surplus electrical power. If that grid is only 40 per cent efficient, then that becomes the efficiency constraint on the wind system.

Brittle Power

In a broader context, Lovins[1] has argued that our whole energy system is highly vulnerable to a high level of disruption without very much effort (i.e., sabotage). Large, central power stations are especially vulnerable to interruption by almost anyone wanting to make mischief. Central power stations are connected to complicated transmission and distribution networks. Only a few plants need to be interrupted for large segments of the utility grid to be disabled. Maintaining control of the system (voltage and frequency without damaging power surges) is a very complicated process and requires the communications and control systems over vast areas to be functional. The communications and control systems require power for their availability, and the process can degrade precipitously without power.

Lovins[1] makes the case that small, decentralized energy systems (such as wind-powered electricity-generating systems) are far more

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[1]Amory B. Lovins, Brittle Power. Andover, MA: Brickhouse Publishing Company, 1982.

resilient (less vulnerable). They can be disconnected from the utility grid and continue to supply power to a local area. They could also be positioned to provide power for the backup communications and control systems.

If the system boundary were expanded to account for energy costs of the security measures needed to overcome the vulnerability of large central power stations, especially large, nuclear-powered generating systems, the net energy benefits would be relatively smaller for nuclear systems and relatively larger for wind systems.

Summary

In summary, information shown in this chapter illustrates the declining efficient use of the United States electrical systems over the past twenty-five years. It was noted that there has been a decrease in Efficiency Factors as total Generating Capacity was expanded, and there is some evidence that the decline is related to the introduction of large nuclear plants into the system. This phenomenon bears further investigation as more nuclear plants come on line. Although the conclusions of this study do not rest on the tentative findings in this chapter, the preliminary results show that there is some correlation between increased use of nuclear power and declining overall efficiency of the United States utility system.

The argument was made that the efficiency of any particular generating system is constrained by the overall efficient operation of the total system of which the individual generators are a part. When making net-energy analyses of energy-transformation systems, the efficiency of the total system should be considered. The efficiency of the total United States electrical system, as defined above, has fallen from approximately 57 per cent in 1956 to 40 per cent in 1983. For the Base-Case, in the analyses of nuclear and wind systems, a conservative 50 per cent Efficiency Factor will be used. Considering the findings of this chapter, the conclusions of the analyses are robust accordingly.

Since wind systems are being interconnected to the utility grid, they are not insulated from the efficiency problems being experienced by large utility systems.

The vulnerability of large energy systems to disruption by various forms of mischief (e.g., sabotage) was discussed. It was noted that the energy cost of security measures to minimize this vulnerability would lower the expected net energy of nuclear power systems. It was also observed that truly decentralized energy systems, such as isolated wind systems, will be much less vulnerable to such disruption.

CHAPTER 7

ESTIMATED NET ENERGY FROM NUCLEAR POWER

Precis

As noted in chapter 4, there is a wide range of methodologies used in making net-energy analyses. Consequently, there is a corresponding variety of conclusions. Several of those studies will be noted. It will be observed that most of the cited studies arrive at conclusions much different from those reached in the current study.

The general arguments for the procedures used in this study were developed in chapters 4 through 6. The methodological controversy centers on a system-boundary definition. In this study the system boundary is defined as the economic boundary. All economic costs are assumed to be proxy indicators for the amount of energy that is needed to sustain nuclear power plants. Chapter 5 makes the case for this procedure.

Most studies have considered only the costs of the production plant (the electricity-generating system) in estimating energy-inputs and, even then, excluded the energy-input costs of labor, government and financial services. The current study includes all economic costs, including so-called Other Plant Costs, which include transmission and distribution costs, overhead costs, capital costs, interest, and taxes.

Another area of methodological controversy is the so-called Capacity Factor argument, which relates to the amount of output-energy to be expected from nuclear plants. In chapter 6, the combined Generating Capacity of large United States utilities is compared to actual electrical sales. A maximum efficiency of 57 per cent was reached in 1957 but fell steadily to about 40 per cent in 1983. The term Efficiency Factor is adopted to include a consideration of the amount of backup Generating Capacity that is needed to meet the varying conditions. The argument in chapter 6 provides the basis for choosing a smaller Efficiency Factor than some analysts have chosen. Since total-system efficency has fallen to 40 per cent, it is believed that the 50 per cent Efficiency Factor chosen for this study is a conservative practice.

The procedure followed in this study is to determine the life-cycle economic cost of nuclear plants and multiply that cost times selected Energy/GNP Ratios as described in chapter 5. Energy-input is then compared to energy-output.

The economic cost data developed by Komanoff will be used to develop the energy-input estimates.[1] Later data published by Komanoff[2] show that he originally underestimated the future cost of his so-called Base-Case and Northeast plants by about 25 per cent. Therefore, the net-energy results calculated for these generic-type plants overstate expected net energy from nuclear power stations accordingly. A summary

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[1]Komanoff, Power Plant Cost, Idem. pp. 294-296.

[2]Charles Komanoff, "Assessing the High Cost of New Nuclear Power Plants, Public Utilities Fortnightly, (October 11, 1984): 33-38.

of selected analyses, using recently published Komanoff cost projections (1984), is included. It is the author's view that the 1984 cost estimates are the most appropriate for estimating future net-energy potential for nuclear power systems.

Computer models were developed for static and dynamic net-energy calculations. The models are explained in detail, line-by-line, in appendix B, along with the underlying rationale for each entry.

Static net-energy analyses were calculated for all 46 of the nuclear plants in the 1981 Komanoff data base, using an Energy/GNP ratio of 35,791 Btu's/$1979. A summary of the results are shown in table 7.3. The results show that there has been a steady decrease of the net-energy ratios over time. Sensitivity analyses were done for the lowest Energy/GNP Ratio (i.e., 27134 Btu's/$1979) and for the highest value (i.e, 37,342 Btu's/$1979). The results are shown in appendix B.

The results of analyses based on 1984 Komanoff data are shown in table 7.5 for 34 plants that were not in the 1981 data base.[1] These costs are expressed in 1982 dollars. Analyses are done at low-value (21,436 Btu's/$1982), 37-year mean (28,266 Btu's/$1982), and high (34,324 Btu's/$1982) values of Energy/GNP coefficients. Based on mean-value calculations, it will be seen that 15 of the 34 plants show positive static Output/ Input Ratios, although 5 of those are essentially break-even ratios. The remaining 19 plants (at 28,266 Btu's/$1982) have Output/Input Ratios less than 1.0. Output/Input Ratios less than 1.0 have negative net energy, i.e., are net-energy consumers. It will be observed that, as installed costs of nuclear

[1]Ibid.

power plants approach $2000 per kilowatt (Energy/GNP Ratio of 28,266/$1982), the plants become net consumers of energy, even under Static Net Energy Analysis. It will be noted that the break-even cost for 50-year Dynamic Net Energy Anlysis is approximately $1500 per installed kilowatt of capacity (i.e., 28,266 Btu's/$1982). Of course, at the lower Energy/GNP Ratio (i.e., 21,436 Btu's/$1982) the 50-year Dynamic Net Energy Analysis break-even cost increases to approximately $2700 per kilowatt ($1982).

The major concern is whether these plants can replicate themselves using their own output-energy and leave net energy to meet other needs of society. Or, is it necessary to have an external energy subsidy for their being? The conlusions are that, if real costs remain as high as Komanoff predicts, then nuclear-generated electricity systems will not be independent sources of net energy but will instead require an external subsidy for their existence. As fossil fuels are depleted, it is not clear what this external energy source will be.

Findings Of Others

In 1971, Klystra and Han,[1] of the Odum net-energy school, argued that the Output/Input Ratio for nuclear-powered electricity-generating systems was about 2.7 to 1; i.e., that the plants provided about 2.7 times as much output-energy as input-energy.

Several energy analyses were done beginning in 1975. Most held that the net-energy Output/Input Ratios were considerably larger than

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[1]C. Klystra and Ki Han, "Energy Analysis of U. S. Nuclear Power Systems," ed. Howard T. Odum, Energy Models For Environment Power And Society, (New York: Wiley-Interscience, 1971).

those held by Klystra and Han.

For example, Perry, et al,[1] in 1975 argued that these nuclear-powered electricity-generating systems provided a significant amount of net energy. Studying thirteen different types of systems, they reported Output/Input Ratios varying from 4.3 to 1 to 19.9 to 1.

Chapman[2], studying six different types of reactor systems, found static Output/ Input Ratios that varied from 10.5 to 1 to 16.5 to 1.

Rombough[3] found Static Output/Input Ratios ranging from 10 to 1 to 13 to 1.

Aussord,[4] of Electricity de France concluded the following:

> . . . Once the principles of energy analysis have been laid down with precision, it can be seen that in fact a nuclear power plant of the PWR [Pressurized Water Reactor] type produces eleven times more energy than it consumes and its energy yields become positive after three months of operation at full power.

Koenne noted the following:[5]

> . . . It shows that statements regarding a negative energy ratio in the case of nuclear power stations lack a concrete basis.

Amado, in an amazing claim, seems to have found a way to reverse the Second Law of Thermodynamics by holding that even

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[1]A. M. Perry, R. M. Rotty, and D. B. Reister, "Net Energy From Nuclear Power," Energy 1 (1975): 720.

[2]Peter F. Chapman, "Energy Analysis of Nuclear Power Stations," Energy Policy, (December 1975): 188.

[3]C. T. Rombough, Total Investment in Nuclear Power Plants, (Ann Arbor: University Microfilms, 1975).

[4]P. Aussord, Energy Research Abstract, EDB-77-79: 130884 U. S. Department of Energy (DOE).

[5]W. Koenne, "Net Energy Output of Growing Power Systems," Energy Research Abstract EDB-78-79: 130884, Department of Energy.

electricity-generating systems fueled by crude oil yield positive net energy.[1] She commented as follows on both crude-oil systems and nuclear systems:

> . . . In general, it is concluded that even after redefining the system boundary by including capital investment, regulation, and R&D as an energy cost and after computer "upper bound" inputs using fairly conservative estimates, both the LWR [light water reactor] system and crude oil system of electricity generation are net-energy producers. Nuclear energy is seen to be more efficient of the two.[2]

Penner, et al.,[3] studied the net-energy effects of an "all-nuclear economy." Their study focused on the effects of declining quality of uranium ores. They assumed that all nuclear power plants would be constructed and their related fuel-cycle facilities would be constructed and operated using nuclear electricity. The study was not a dynamic analysis like the one in this study. Following is a comment on their reported results:

> Initially it takes .34 Btu of additional electricity to deliver one Btu to the purchaser (the situation of today's technology). . . When conventional ores are depleted and the transition to shales is complete, about .72 Btu are required to deliver one Btu to the user.

Lovins and Price, although following Mainstream Energy Analysis procedures for static analysis, noted that, even with larger

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[1]Note: It is widely recognized that electricity-generating systems powered by fossil fuels require more than three to four Btu's of input-energy for every Btu of output-energy.

[2]Donna Amado, "Effects of Redefining the system boundary on the Net Energy of Electricity Generating Systems," (Urbana: Center for Advanced Computation, University of Illinois at Urbana-Champaign, [1977].

[3]Peter S. Penner, Clark W. Bullard, and Donna L. Amado, "Net Energy Effects and Resource Depletion , An All-Nuclear Economy," CAC Document No. 238, (Urbana: Center For Advanced Computation, University of Illinois at Urbana-Champaign, [1977]), p. 9.

Output/Input Ratios, the dynamic implications of developing a large system were substantial. Lovins noted the following:

> The possibility that single reactors may have zero or negative yields of net energy in the long run may sound bizarre but cannot yet be ruled out: the main uncertainty is future energy requirements for waste management and safeguards. These requirements may be small each year, but may be cumulatively significant for 10,000,000 years or more, [i.e. considering the long-life of some radioactive materials].[1]

In 1977 Odum[2] continued to endorse the Klystra and Han study.[3] That study is more closley allied with the current study. Odum noted:

> Of all our sources of energy, nuclear reactions may require the most kinds of special feedbacks of energy. . . For thirty years, nuclear energy was directly subsidized by fossil fuels. Costly as these installations and processes were, they would have been much more expensive if all the goods and services had not been made with cheap fossil fuel. . . . The return for energy invested may not be as large as with other sources; estimates suggest that 2.7 Calories of energy are yielded back for 1 Calorie invested; fossil fuels yield more.

Net Energy Analysis of Nuclear Power

Two types of analyses were done. First, Static Net Energy Analysis is designed to estimate the expected net energy from a single entity over its lifecycle. Static analysis must be done before dynamic analysis can be done, because data from the former is needed to calculate the latter. The second is Dynamic Net Energy Analysis, which estimates the expected net energy from the sustained development and

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[1]Amory B. Lovins and John H. Price Non-Nuclear Futures: The Case For An Ethical Energy Strategy, (New York: Harper Colophon Books, 1975), p. 122.

[2]Howard T. Odum, Energy Basis for Man and Nature, Idem, p.180.

[3]C. Klystra and Ki Han, "Energy Analysis of U. S. Nuclear Power Systems," Idem.

operation of a system (a number of individual entities) over various time periods.

Appendix B shows the results of the numerous calculations. Power plants which were constructed earlier are smaller than those constructed more recently. The smallest in the 1981 Komanoff data base was the Fort Calhoun plant, listed at 457 megawatts of Generating Capacity. The largest plants were Sequoyah 1 and 2, listed at 1148 megawatts of capacity. A plant size of 1150 megawatts is a typical plant (single) size to be completed in the future.

Most other studies measured net energy at the bus bar. Other Plant Costs are all costs not included in Production Plant Costs (i.e., so-called bus-bar studies account only for Production Plants Costs.) Other Plant Costs include transmission and distribution costs and overhead plant costs such as office buildings needed in utility administration. So-called bus-bar costs are useful for relative comparisons. They are not adequate for a Net Energy Analysis to determine if systems can replicate themselves out of their own energy-output.

The data show that large United States utilities invest in so-called Other Plant capital, on average, about 170 per cent of what they invest in Production Plant capital, although there is a variety of ratios. Data are included in appendix A. For example, Other Plant Costs of Oklahoma Gas and Electric were only about 87 per cent of Production Plant Costs, whereas Pacific Gas and Electric's Other Plant Costs were 196 per cent of Production Plant Costs.[1] For the Base-Case it was assumed that at least an equal amount was invested in Other Plant, thereby causing the conclusions to be robust accordingly.

Static Analysis of Komanoff Base-Case Plant

Table 7.1 shows the framework of the computer model developed for static net-energy analyses of nuclear power stations. Calculations were made using so-called "electronic spread-sheet" software. The data in the table 7.1 model, using Komanoff 1981 cost data, are for a typical Komanoff Base-Case nuclear power plant expected to come into service in 1988.[1] A 1150-megawatt plant, costing $1460 per kilowatt of capacity,[2] would cost approximately $1.68 billion ($1979 = 100).

A 30-year expected life of each plant was assumed for the Base-Case of this study. The nuclear power industry presumes that nuclear power plants will last for 30 years. How long they can be kept in service affects the expected economic performance and, hence, the net-energy expectations. For example, Three-Mile-Island No. 2 was in service for one year before it was shut down.[3] Another example, according to the Union of Concerned Scientists, is the situation involving pressurized water reactors.[4] Apparently, these systems have been developing unexpected cracks in the steam pipes and pressure vessels. These may present serious safety hazards, contribute to high

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[1]Komanoff, Power Plant Cost, Idem: 281.

[2]A kilowatt of Generating Capacity operated for one hour will produce 1 kilowatt-hour. One megawatt of capacity operated for one hour will produce 1000 kilowatt-hours. A 1,150 megawatt plant will produce 1,150,000 kilowatt-hours in one hour of operation. One kilowatt-hour is equivalent to 3413 Btu's, thermal.

[3]Barbara Coffin, "Nuclear Power Plants in the United States: Current Status and Statistical History," Union of Concerned Scientists Unnumbered Pamphlet, December 31, 1983.

[4]Union of Concerned Scientists, "Reactor Vessel Rupture: 'Incredible' Safety Hazard with Growing Credibility," Nucleus, 3 (Fall 1981): 3.

Table 7.1

STATIC NET ENERGY ANALYSIS OF KOMANOFF BASE CASE TYPE PLANT
Location: Central United States

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Expected Life-Cycle:	30 Years		
2	Gen. Capacity, MWe:	1150 Megawatts		
3	Hours in 365-Day Year:	8760 Hours		
4	Prod Plant Cost ($):	$1460 ($1979)	C2*C4 =	1.6790e09
5	Other Plant Cost (=Prod):			1.6790e09
6	Elec. Gen. @60% (kWh):	0.6000	C1*C2*C3*C6=	1.8133e11
7	Elec Gen @50%, 30 Yrs.:	0.5000	C1*C2*C3*C7=	1.5111e11
8	Fix. Chg. Prod. Plant ($):	0.1029	C1*E4*C8 =	5.1830e09
9	Fix. Chg. Other Plant, ($)	0.1029	C1*E5*C9 =	5.1830e09
10	Prod. Plant O & M ($):	0.0062	E6*C10 =	1.1242e09
11	Other Plant O & M ($):	0.0011	E6*C11 =	2.1473e08
12	Fuel Charge ($):	0.0109	E6*E12 =	1.9765e09
13	Decomm. Cost (10% C4, $):	0.0021	E6*C13 =	3.8079e08
14	Total Distr. Cost ($):		SUM(E8>E13)-	
15			(E4+E5) =	1.0704e10
16	Lifecycle Plant Cost ($):		SUM(E8>E13)=	1.4062e10
17	Distr. Energy INPUT, (Btu's)	35,791	E15*C17 =	3.8312e14
18	Total Input Energy, Btu's:		E16*C17 =	5.0330e14
19	Total Output Energy, Btu's	3413/kWh	E7*C19 =	5.1573e14
20	Output/Input Ratio:		E19/E18 =	1.0246
21	Net Energy, Btu's:		E19-E18 =	1.2429e13
22	Front-End Energy, Btu's:		E4+E5(C17)=	1.2018e14
23	Decomm. Energy, Btu's:		E13*C17 =	1.3629e13

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 23.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E13) means that the quantities in column E from lines 8 through 13 are added together.

E19/E18 is notation to mean that cell E18 is divided by cell E17.

Line 20 shows the Output/Input Ratio to be 1.0246 to 1.

Line 21 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield 1.2429e13 British thermal units of net energy, where "e13" means that the decimal point is 13 places to the right. Also, 1.2429e13 = .012429 quads.

Note: Model fits computer software known as electronic spread sheet.

costs, and lead to a lowering of net energy even further.

Komanoff found that over the lifetime of new power stations:[1]

> . . .capital costs will account for approximately two-thirds of total "bus-bar" generating costs for nuclear and one-third for coal plants. . .
>
> Virtually all nuclear plants completed in the 1970's cost much more to construct than originally estimated by reactor manufacturers and electric utilities, even after adjusting for the effects of inflation. The failure to predict accurately nuclear capital costs reflects a fundamental limitation in the power industry's technique of engineering estimation which employs conceptual plant designs to calculate the labor, materials, equipment, and engineering effort needed to build a plant. The technique requires that the scope of work be known at the start of construction, yet nuclear plants, as the largest reactor builder has noted, are subject to 'new requirements . . . imposed after the design and construction are well advanced, requiring substantial rework that increases both schedule and cost. The 1979 nuclear accident at Three Mile Island (TMI), moreover, has provoked a thorough and still-continuing reappraisal of nuclear regulation that promises to produce many new, more stringent standards.

The Komanoff cost projections are based on a "sector-size" hypothesis which is explained as follows:[2]

> The sector-size approach implies that costs will rise as more reactors are licensed, due to the many strong connections between growth in sector size and increased regulatory stringency; it does not suggest that there is a simple, explicit causal link between the number of reactors and costs.
>
> It implies that licensing interventions are among the factors engendering increased regulatory stringency; not that construction delays caused by nuclear opponents have been a major factor in rising real capital costs.
>
> Use of the sector-size hypotheses to project costs also implies that, for the foreseeable future, increases in the number of operating plants will reveal new safety and operating problems, leading to new regulatory requirements and design changes which, in turn, will cause costs to rise. It does not deny that reactor construction has evidenced a "learning curve." Rather, it implies

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[1]Komanoff, Power Plant Cost, Idem, pp. 14-15.

[2]Ibid, p.31.

> that, as in the past, increasing architect-engineer familiarity with nuclear construction will be outweighed by advancing regulatory criteria requiring A-E's [Architectural Engineers] to employ more labor, equipment, and materials to build nuclear plants.[1]

Capacity Factor and Efficiency Factor

Capacity Factor is an industry term that is used in a special way that is understood by electrical engineers and utility economists. It is somewhat inadequate for Net Energy Analysis. Efficiency Factor is a term chosen to identify the ratio of the estimated hours a system actually generates electricity at 100 per cent of its design capacity to total-system life. See table 7.2.

Used in this way, the Efficiency Factor can be chosen to incorporate the concept of total-system efficiency, for example, to take account of the cost of secondary systems that are required to back up primary systems as described in chapter 6.

Table 7.2

EFFICIENCY FACTOR EQUATION

$$EF = \frac{\text{lifecycle hours system generates elec. at design power}}{\text{hours in lifecycle (e.g., 8760 x 30 Yrs.) of system}}$$

Capacity Factor, as used by utility economists and engineers is an expression of the individual performance of a single generating plant. Although a low Capacity Factor for an individual plant implies that backup systems must be available, the need for backup plant capacity is explicitly considered in choosing an Efficiency Factor.

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[1] Ibid.

Fixed Charge Costs

As noted above, Fixed-Charge Costs have not been included in prior net-energy analyses, to the best of the author's knowledge. They are included in this analysis, following the reasoning developed in chapter 5. As with any other private-enterprise endeavor, the company must earn enough money to compensate savers for financing the project, pay its share of taxes, and provide for interim equipment replacement.

Komanoff notes the following:[1]

> . . .The revenue requirements are proportional to the plant's capital cost, as are the corporate income taxes on net revenue, property taxes assessed by local municipalities, allowances for interim replacement of equipment, and insurance. These costs are together referred to as "fixed charges" and the ratio of annual fixed charges to total capital cost is the fixed charge rate.

Normally fixed-charge rates are related to current dollars and generally range from 13 to 20 per cent. Accurate net-energy calculations require that the fixed-charge relate to uninflated dollars; therefore, a real fixed-charge rate of 10.29 per cent ($1979) is used, the same as used by Komanoff to compare the relative economics of nuclear and coal plants. The fixed-charge rate is applied both to Production Plant and Other Costs (including transmission and distribution plant).

Running Costs and Decommissioning Costs

Fuel, operation and maintenance, and decommissioning costs are presumed to be proportional to electricity generated at 60 per cent Capacity Factor and are expressed as a mills per-kilowatt-hour charge. This procedure results in arriving at costs equivalent to those costs used by Komanoff for the cost of Production Plant, although energy-

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[1]Ibid, p. 270.

output is calculated on the assumption of a 50 per cent Efficiency Factor.[1]

Pasqualetti points out that there are three basic methods of getting rid of obsolete nuclear reactors:[2]

> (1) immediate dismantlement, (2) safe storage, and (3) entombment, . . . financial, social, and environmental implications differ with each option . . . Most worrisome is that the majority of the utilities have no way to ensure that, when the time comes, money will be available for decommissioning.

Energy Output/Input Ratio

You will note that the Output/Input Ratio on line 20, table 7.2, shows that the Komanoff Base-Case plant barely breaks even with an Output/Input Ratio of 1.0246 to 1. That is, over its lifecycle, such a plant would yield only 2.46 per cent more energy than was required to construct and operate it.

A system of plants, with this small Static Output/Input Ratio, does not show positive net energy, even in 100 years. Dynamic analyses of plants with even higher Static Output/Input Ratios will be discussed in a following section.

Discussion of a Komanoff Northeast Plant

Table 7.3 shows the results of Static Net Energy Analysis of a typical Komanoff Northeast plant,[3] where costs will be considerably more than one constructed in the Midwest (the Base-Case area). It increases

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[1]Ibid, p.267-270.

[2]Martin Pasqualetti, "The Decommissioning Dilemma," Sierra, (September/October 1984): 263.

[3]Komanoff, Power Plant Cost Escalation, Idem, p.281.

Table 7.3

STATIC NET ENERGY ANALYSIS, KOMANOFF NORTHEAST-TYPE PLANT
Location: Northeastern United States

(A)	(B)	(C)	(D)	(E)
1	Expected Life-Cycle:	30 years		
2	Gen. Capacity, MWe:	1150 megawatts		
3	Hours in 365-Day Year:	8760 hours		
4	Prod Plant Cost ($):	$1820/Kilowatt	C2*C4 =	2.0930e09
5	Other Plant Cost (=Prod):			2.0930e09
6	Elec. Gen. @60% (kWh):	0.6000	C1*C2*C3*C6=	1.8133e11
7	Elec Gen @50%, 30 Yrs.:	0.5000	C1*C2*C3*C7=	1.5111e11
8	Fix. Chg. Prod. Plant ($):	0.1029	C1*E4*C8 =	6.4610e09
9	Fix. Chg. Other Plant, ($)	0.1029	C1*E5*C9 =	6.4610e09
10	Prod. Plant O & M ($):	0.0071	E6*C10 =	1,2874e09
11	Other Plant O & M ($):	0.0012	E6*C11 =	2.1759e08
12	Fuel Charge ($):	0.0109	E6*E12 =	1.9765e09
13	Decomm. Cost (10% C4, $):	0.0033	E6*C13 =	6.0927e08
14	Total Distr. Cost ($):	($)	SUM(E8>E13)-	
15			(E4+E5) =	1.2827e10
16	Lifecycle Plant Cost ($):		SUM(E8>E13)=	1.7013e10
17	Distr. Energy INPUT, Btu:	35791Btu/$	E15*C17 =	4.5909e14
18	Total Input Energy, Btu's:		E16*C17 =	6.0891e14
19	Total Output Energy, Btu's	3413 Btu/kWh	E7*C19 =	5.1573e14
20	Output/Input Ratio:		E19/E18 =	0.8469
21	Net Energy, Btu's:		E19-E18 =	-9.3174e13
22	Front-End Energy, Btu's:		E4+E5(C17)=	1.4982e14
23	Decomm. Energy, Btu's:		E13*C17 =	2.1806e13

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 23.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E13) means that the quantities in column E from lines 8 through 13 are added together.

E18/E17 is notation to mean that cell E18 is divided by cell E17.

Line 20 shows the Output/Input Ratio to be 0.8666 to 1.

Line 21 shows that over its 30-year lifecycle a Komanoff Northeast plant would yield -9.3174e13 British thermal units of net energy, where "e13" means that the decimal point is 13 places to the right. Also, -9.3147e13 = -.093147 quads.

This model includes no "retrofit" costs.

Model fits "electronic spread sheet" computer software.

from $1460 per kilowatt to $1820 per kilowatt. It is assumed that the cost of Other Plant (including transmission and distribution) increases accordingly. According to Komanoff, the fixed-charge rate would increase 28 per cent over the Base-Case. A conservative 10.3 mills per-kilowatt-hour real fixed-charge rate was used (less than the 28 per-cent increase projected by Komanoff) in order to be on the conservative side.

The Decommissioning Cost increased to $172 per kilowatt and Operation and Maintenance (O & M) Costs from 62 mills to 71 mills per kilowatt-hour in accordance with the Komanoff estimates.[1] The net-energy results of the model show that a Komanoff Northeast plant would generate only about 85 per cent (Output/Input Ratio in cell E19 = 0.8469) as much energy as was input into the system. Plants with Output/Input Ratios of less than one, of course, do not produce net energy. They clearly require an external subsidy for their existence.

If nuclear plants being constructed in the northeastern part of the United States continue to cost as much as Komanoff predicts, then we must realize that they are clearly being subsidized by other sources of net energy, such as the fossil fuels.

46-Plant Data Base

Appendix B shows summary results of static net-energy calculations made for the 46 plants in the 1981 Komanoff data base. Table 7.4 summarizes the size, cost, Static Output/Input Ratios, and 50-year Dynamic Output/Input Ratios. Discussion of the dynamic net-energy results will be reserved for a subsequent section of this chapter. It

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[1]Ibid, p.281.

Table 7.4

SUMMARY, 46-PLANT KOMANOFF 1981 DATA BASE
Static Net Energy Analyses

(A) Line	(B) Plant Name	(C) Gen Cap. MW	(D) Cost Per KW	(E) Static O/I Ratio	(F) 50-Year Dynamic O/I Ratio	(G) 50-Year Dynamic Avg. Ann. Net Energy (Quads)
1	Palisades	821	367	2.2859	1.1469	1.27
2	Turkey Point 3	745	281	2.5313	1.1980	1.52
3	Turkey Point 4	745	308	2.4487	1.1759	1.38
4	Brown's Ferry 1	1098	430	2.1344	1.0855	1.07
5	Brown's Ferry 2	1098	412	2.1756	1.0980	1.21
6	Brown's Ferry 3	1098	421	2.1548	1.0917	1.14
7	Oconee 1	886	324	2.4023	1.1632	1.54
8	Oconee 2	886	307	2.4519	1.1767	1.65
9	Oconee 3	886	299	2.4756	1.1832	1.70
10	Vermont Yankee	514	693	1.6717	0.9312	0.42
11	Peach Bottom 2	1065	607	1.7992	0.9867	-3.14
12	Peach Bottom 3	1065	589	1.8284	0.9361	-1.77
13	T.M.I. No. 1†	819	828	1.5043	0.8679	-1.54
14	Surry 1	823	341	2.3549	1.1560	1.33
15	Surry 2	823	578	1.8467	0.9929	-0.007
16	Fort Calhoun	457	699	1.6635	0.9282	-0.44
17	Prairie Island 1	530	784	1.5551	0.8876	-0.83
18	Prairie Island 2	530	551	1.8953	1.0086	0.006
19	Cooper	778	590	1.8268	0.9861	-0.14
20	Pilgrim 1	670	690	1.6758	0.9327	-0.60
21	Kewaunee	560	624	1.7725	0.9637	-0.27
22	Salem 1	1090	1066	1.2786	0.7750	-3.91
23	Crystal River 3	825	706	1.6540	0.9247	-0.83
24	Maine Yankee	790	530	1.9311	1.0212	0.20
25	Rancho Seco	913	605	1.8024	0.9777	-0.26
26	Zion 1	1050	468	2.0523	1.0602	0.74
27	Zion 2	1050	467	2.0544	1.0608	0.75
28	Arkansas 1	850	464	2.0606	1.0628	0.62
29	Cook 1	1090	784	1.5510	0.8876	-1.71
30	Cook 2	1090	506	1.9763	1.0359	0.47
31	Calvert Cliffs 1	845	816	1.5178	0.8732	-1.52
32	Calvert Cliffs 2	845	546	1.9022	1.0226	0.12

Notes: Column C shows Generating Capacity in Megawatts.
Column D shows Cost per Installed Kilowatt ($1979).
Column E shows Static Net Energy Analysis Output/Input Ratio.
Column F shows 50-Yr. Dynamic Output/Input Ratio.
Column G shows Average annual net energy over 50-yr period.
All Calculations at 35,791 Btu's/$1979 for E/GNP coefficient.

Table 7.4 Continued

SUMMARY NET ENERGY CALCULATIONS, 46-PLANTS

(A)		(B)	(C)	(D)	(E)	
					50-Year Dynamic	
Line	Plant Name	Gen Cap. MW	Cost Per KW	Static O/I Ratio	O/I Ratio	Avg. Ann. Net Energy (Quads)
33	Indian Point 3	965	859	1.4705	0.8546	-2.03
34	Hatch 1	786	757	1.5879	0.9001	-1.08
35	T. M. I. #2†	906	942	0.0924	n/a	n/a
36	Brunswick 2	821	726	1.6274	0.9149	-0.94
37	Brunswick 1	821	534	1.9238	1.0188	0.19
38	Fitzpatrick	821	796	1.5409	0.8821	-1.36
39	Duane Arnold	538	843	1.4878	0.8614	-1.07
40	Beaver Valley	852	1004	1.3306	0.7972	-2.68
41	St. Lucie 1	810	879	1.4496	0.8462	-1.82
42	Millstone 2	828	784	1.5551	0.8876	-1.30
43	Trojan	1130	605	1.2786	0.9777	-0.32
44	North Anna 1	907	1066		0.7750	-3.25
45	David Besse 1	906	957			
46	Farley 1	829	1113	1.2418	0.7589	-3.25
47	Base-Case††	1150	1460	1.0242	0.6583	-7.38
48	Northeast†††	1150	1820	0.8666	0.5781	-10.35
49	50-Yr Break-Even	1150	565.35	1.8769	1.0001	-0-

Notes: Column C shows Generating Capacity in Megawatts.
Column D shows Cost per Installed Kilowatt ($1979).
Column E shows Static Net Energy Analysis Output/Input Ratio.
Column F shows 50-Yr. Dynamic Output/Input Ratio.
Column G shows Average annual net energy over 50-yr period.
All Calculations at 35,791 Btu's/$1979 for E/GNP coefficient

Source of columns C & D: Cost information from: C. Komanoff, Power Plant Cost Escalation, pages 291-301.

Dynamic analyses assume construction rate @ 52 new plants/Year.

† T.M.I. = Three-Mile-Island. Three-mile-island No. 2 was licensed for 13 months, before the accident. Fixed charges continue. See "Nuclear Power Plants in the United States: Current Status and Statistical History," Union of Concerned Scientists, December 31, 1983.

† Refers to costs associated with Komanoff's Base Case and Northeast-type plants.

will be noted in column E that Turkey Point No. 3 plant (line 2) had the highest static Output/Input Ratio of 2.5313 to 1. This plant cost only $281 per kilowatt of capacity to construct.

The Output/Input Ratios have been steadily falling, with Farley 1 (line 46) having an Output/Input Ratio of only 1.2418 to 1. It will be noted that the installed cost of Farley 1 was estimated at $1113 per kilowatt of capacity ($1979=100), according to Komanoff.[1]

Selected results of the 50-year dynamic net-energy analyses were included. It can be seen in column F that even though plants may show a positive Static Output/Input Ratio, if the ratio is too small, even a large construction program of such plants will not show positive net energy in the 50-year dynamic net energy analyses. It will be noted that the Static Output/Input Ratio must be at least 1.8679 to 1 in order for the plants to achieve a "break-even" situation under 50-year Dynamic Net Energy Analysis. On line 49, table 7.5, it is shown that the 50-year break-even installed cost is $565.55 in 1979 dollars; i.e., under static analysis each plant consumes as much energy as it provides.

Static Analysis, 1984 Komanoff Data

Komanoff released a new set of cost projections for 34 nuclear power plant systems in the October 11, 1984, issue of Public Utilities Fortnightly. He notes the following:[2]

> The current generation of new nuclear power plants looms as a financial disaster for the U. S. electric power sector. Of the three dozen nuclear projects completed or scheduled for completion in 1982 or later, a handful at most -- and perhaps none at all -- will produce power at a cost competitive with coal-fired electricity over the lifetime of the plants. The rest will contribute to an $80 to $115 billion "nuclear power damage bill," comprised of three

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[1]Ibid, p.294-297.

[3]Charles E. Komanoff, "Assessing the High Cost of New Nuclear Power Plants," Public Utilities Fortnightly, (October 11, 1984): 33-38.

parts: $25 billion in reactor cancellations to date, $10 to $30 billion in potential future cancellations, and $45 to $60 billion in excess power costs from projects being completed....[1]

Table 7.5 is representative of the model used for the static net-energy analyses of the 34-plant (1984 cost estimates of Komanoff) data base. You will note that it is slightly different from the model used for evaluating the 46-plant data base. The capital costs of retrofitting plants with newly designed equipment to meet changing safety requirements have been added to the model. This cost has been approximately $40.50 per kilowatt of installed capacity and is escalating at a real (deflated) annual rate of approximately 1 per cent per year, according to Wallach.[2] It is assumed that each utility amortizes these costs over a 30-year period.

Since the cost estimates included in this data set are believed to be more representative of the future costs of nuclear power systems than the 46-plant data set, more extensive calculations are included. In addition to the calculations made at the 37-year mean value for the Energy/GNP Ratio, calculations are shown for the extreme high and low values. Table 7.6 is a summary of Net Energy Analysis results that were calculated using the latest (1984) Komanoff capital cost numbers. It will be noted that results are shown for the lowest value (21,436 Btu's/$1982), mean value (28,266 Btu's/$1982), and highest value (34,324 Btu's/$1982) Energy/GNP Ratios (see table 5.2).

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[1] Ibid.

[2] John Wallach, Personal Conversation, and draft of pending testimony before the Arkansas Public Utility Commission pertaining to Grand Gulf Nuclear Power System. Energy Systems Research Group, Boston, MA.

Table 7.5

STATIC NET ENERGY ANALYSIS, BELLEFONTE (TWIN REACTOR)

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Expected Life-Cycle, Yrs	30 years		
2	Gen. Capacity, MWe:	2426 megawatts		
3	Hours in 365-Day Year:	8760 hours		
4	Prod Plant Cost ($):	$1484/KW	C2*C4 =	3.6001e09
5	Other Plant Cost (=Prod)		E4 =	3.6001e09
6	Retrofitting Cost:	$22/KW	C2*C6 =	5.3372e07
7	Elec. Gen. @60% (kWh):	0.6000	C1*C2*C3*C7=	3.8253e11
8	Elec Gen @50%, 30 Yrs.:	0.5000	C1*C2*C3*C8=	3.1877e11
9	Fix. Chg. Prod. Plant $	0.1030	C1*E4*C9 =	1.1124e10
10	Fix. Chg. Other Plant,	0.1030	C1*E4*C10 =	1.1124e10
11	Fix. Chg. Retrofit.	0.1030	C1*E6*C11 =	1.6491e08
12	Prod. Plant O & M ($):	0.0077	E6*C12 =	2.9454e09
13	Other Plant O & M ($):	0.0012	E6*C13 =	4.5903e08
14	Fuel Charge ($):	0.0112	E6*E14 =	4.2843e09
15	Decomm. Cost (10% C4, $	0.0034	E7*C15 =	1.3006e09
16	Total Distr. Cost ($):	($)	SUM(E9>E15)-	
17			(E4>E6) =	2.4149e10
18	Lifecycle Plant Cost ($)		SUM(E9>E15)=	3.1403e10
19	Distr. Energy INPUT, Btu	28266 Btu/$	E17*C19 =	6.8261e14
20	Total Input Energy, Btu		E18*C19 =	8.8765e14
21	Total Output Energy, Btu	3413 Btu/kWh	E8*C21 =	1.0879e15
22	Output/Input Ratio:		E21/E20 =	1.2256
23	Net Energy, Btu's:		E21-E20 =	2.0033e14
24	Front-End Energy, Btu's:		E4+E5*(C19) =	2.0352e14
25	Decomm. Energy, Btu's:		E15*C19 =	3.6762e13

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 22.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E13) means that the quantities in column E from lines 8 through 13 are added together.

E18/E17 is notation to mean that cell E18 is divided by cell E17.

Line 19 shows the Output/Input Ratio to be 1.2418

Line 20 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield 1.9564e14 British thermal units of net energy, where "e14" means that the decimal point is 14 places to the right. Also, 1.9564e14 = .19564 quads

Based on the reasoning developed in chapter 5, it is the author's position that the mean value ($28,666 Btu's/$1982) is a conservative value to choose. However, sensitivity analyses were also done at the lowest and highest Energy/GNP values. The reader can choose his own scenario since none of them are very bright. In any event, if future real costs exceed $2500 per kilowatt ($1982), even the static net-energy results are negative (using the lowest Energy/GNP Ratio, i.e., 21436 Btu's/$1982). A discussion of the dynamic net-energy results is included in the succeeding section. If the lower values are used, higher net-energy Output/Input Ratios result, and conversely.

Table 7.6

34-PLANT SUMMARY
Net Energy Analyses
Using Low, Average, and High Energy/GNP Ratios

(A)		(B)	(C)	(D)	(E)	(F)
					50-Year Dynamic	
Group	Plant Name	Gen Cap. MW	Cost Per KW	Static O/I Ratio	O/I Ratio	Avg. Ann. Net Energy (Quads)
1	Braidiwood (Twin):					
	21436 Btu's/$82	2240	1113	1.9641	1.6582	11.15
	28266 Btu's/$82			1.4895	1.2702	5.89
	34324 Btu's$/82			1.2266	1.0460	1.22
	(Similarly for Catawba, LaSalle, McGuire, and Watts Bar.)					
2	Bellefonte (Twin):					
	21436 Btu's/$82	2426	1484	1.6162	1.3648	8.02
	28266 Btu's/$82			1.2256	1.0350	1.02
	34324 Btu's$/82			1.0093	0.8523	-5.19
	(Similarly for Byron, Comanche Peak, St. Lucie,and Sumner).					

Notes: Column C shows Generating Capacity in Megawatts.
Column D shows Cost per Installed Kilowatt ($1979).
Column E shows Static Net Energy Analysis Output/Input Ratio.
Column F shows 50-Yr. Dynamic Output/Input Ratio.
Column G shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table 7.6 Continued

SUMMARY OF NET ENERGY CALCULATIONS, 34 PLANTS
Using Low, Average, and High Energy/GNP Values

(A)		(B)	(C)	(D)	(E)	(F)
					50-Year Dynamic	
		Gen	Cost	Static		Avg. Ann.
		Capac.	Per	O/I	O/I	Net Energy
Line	Plant Name	MW	KW	Ratio	Ratio	(Quads)
3	Palo Verde (Twin)					
	21436 Btu's/$82	2200	1724	1.4500	1.2187	4.89
	28266 Btu's/$82			1.0096	0.9242	-2.23
	34324 Btu's$/82			0.9055	0.7611	-8.53
	(Similarly for San Onofre, Susquehanna, Vogtle, and Wolf Creek)					
4	Callaway (Twin)					
	21436 Btu's/$82	2240	2018	1.2878	1.0775	1.99
	28266 Btu's/$82			0.9766	0.8171	-6.19
	34324 Btu's$/82			0.8043	0.6729	-13.45
	(Similarly for Grand Gulf, Millstone 3, Perry, and South Texas.)					
5	Clinton (Twin)					
	21436 Btu's/$82	1866	2444	1.1082	0.9226	-1.93
	28266 Btu's/$82			0.8404	0.6997	-9.90
	34324 Btu's$/82			0.6921	0.5762	-16.92
	(Similarly for Fermi, Harris, Limerick 1, and Waterford.)					
6	Hope Creek (Twin)					
	21436 Btu's/$82	2144	2797	0.9934	0.8294	-5.64
	28266 Btu's/$82			0.7534	0.6252	-15.88
	34324 Btu's$/82			0.6204	0.5148	-24.97
	(Similarly for River Bend, Seabrook 1, WPPS 2, and Zimmer.)					
7	Beaver Valley 2					
	21436 Btu's/$82	833	3411	0.8147	0.6956	-4.50
	28266 Btu's/$82			0.6383	0.5275	-9.22
	34324 Btu's$/82			0.5257	0.4344	-13.40
	(Similarly for Midland 2, Nine Mile Pt. 2, and Shoreham)					

Notes: Column C shows Generating Capacity in Megawatts.
Column D shows Cost per Installed Kilowatt ($1979).
Column E shows Static Net Energy Analysis Output/Input Ratio.
Column F shows 50-Yr. Dynamic Output/Input Ratio.
Column G shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Based on calculations at 28,266 Btu's/$1982, it will be seen in Column E of table 7.6 that 15 plants (Braidiwood, Catawba, LaSalle, McGuire, Watts Bar, Bellefonte, Byron, Comanche Peak, St. Lucie, Summer, Palo Verde, San Onofre, Susquehanna, Vogtle, and Wolf Creek) show positive static net-energy Output/Input Ratios. However, the last five in the aforementioned set are essentially "break-even" output/input ratios of 1.0096 to 1. It will be shown in the subsequent discussion of Dynamic Net Energy Analysis that the Static Output/Input Ratios must be substantial before real, positive, net energy is realized.

Dynamic Net Energy Results

The question asked in this section is: Would a system of Bellefonte plants, for example, having a static net-energy Output/Input Ratio of 1.2256 to 1, yield positive results for society in the long run? The results of the dynamic net-energy analyses, which follow, show that, although the Static Net-Energy Output/Input Ratio of a single unit may be positive, under dynamic analysis the system may not yield net energy for some years in the future, if at all. This results from continuing energy investments in front-end capital concentrated in relative short time periods (9 years) and then having the energy returns spread out over long periods of time (30 years).

Figure 7.1 graphically illustrates the relative amounts of output-energy and input-energy that are involved in a continuous construction program. In this example it is assumed that an additional plant is started each year and that it takes 9 years to construct a single plant. It will be noted that capital energy-inputs are shown below

Figure 7.1

DYNAMIC NET ENERGY MODEL

																				1
																			1	1
																		1	1	1
Alpha Units ----->																	1	1	1	1
																1	1	1	1	1
															1	1	1	1	1	1
														1	1	1	1	1	1	1
													1	1	1	1	1	1	1	1
												1	1	1	1	1	1	1	1	1
											1	1	1	1	1	1	1	1	1	1
										1	1	1	1	1	1	1	1	1	1	1
+																				
Sum Cols.:										1	2	3	4	5	6	7	8	9	10	11
Sum Integers:										1	3	6	10	15	21	28	36	45	55	66
0																				
Year:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-	1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d	d	d
		1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d	d
			1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d
				1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d
					1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d
						1	1	1	1	1	1	1	1	1	d	d	d	d	d	d
							1	1	1	1	1	1	1	1	1	d	d	d	d	d
								1	1	1	1	1	1	1	1	1	d	d	d	d
									1	1	1	1	1	1	1	1	1	d	d	d
Beta Units ------>										1	1	1	1	1	1	1	1	1	d	d
											1	1	1	1	1	1	1	1	1	d
												1	1	1	1	1	1	1	1	1
													1	1	1	1	1	1	1	1
														1	1	1	1	1	1	1
Sum column integers:															.	.	.	.	.	.
	1	2	3	4	5	6	7	8	9	9	9	9	9	9	9	9	9	9	9	9

Sum Integers horizontally:

1 3 6 10 15 21 28 36 45 54 63 72 81 90 99 144

Notes: At the end of the plant life of the first plant constructed (30 yrs), zeros would begin to appear in that row and correspondingly, for the second plant, etc..
Alpha units refer to costs or outputs "above" the zero line.
Beta units (1's) refer to costs "below" the zero line.
"d's" refer to the costs that are annual costs that are distributed over the life of the plants and would be added to each column total

the zero line (beta units) and that, at the end of the ninth year, each plant respectively begins to generate electricity. That output is shown, correspondingly, by the "1's" **above** the zero line (noted as alpha units), beginning in the tenth year of the cycle.

Total Output-Energy is shown by horizontally summing the column totals above the zero line, beginning in the tenth year of the cycle. Total Front-End Energy is obtained by summing the column totals (beta units) below the zero line. It will be noted from figure 7.1 that, at the end of 19 years of construction, the output is 66 units. This compares to an energy-input of 144 units. This explanation will be continued in the discussion of tables 7.4 and 7.5. The beta units do not include the related energy that is distributed over the generating life (i.e., the "d's" below the line). The "d's" below the line are to show that each year each plant incurs an annual distributive cost, which includes the Fixed-Charge Costs, Fuel Charges, Operation and Maintenance Costs, and so forth.

Table 7.7 is an example of the computer model developed for the Dynamic Net Energy Analysis of nuclear power stations used in this study. The table shows the method and results of a 50-year analysis of Bellefonte twin-reactor-type systems which showed a positive static Output/Input Ratio of 1.2256 to 1. It will be noted that the dynamic Output/Input Ratio is 1.0349 to 1 (line 19). This results from the concentration of costs in the 9 years of construction prior to the beginning of the electricity-generation cycle.

At the end of 50 years, the total system yields 3.49 per cent more energy than was required to construct and operate it.

Table 7.7

50-YEAR DYNAMIC NET ENERGY ANALYSIS MODEL
Based on Static Net-Energy Results of Belefonte (Twin)

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Const. Time :	9 Years		
2	Cycle in Years:	50 Years		
3	Years of Generation:	41 Years		
4	No. Const. Per Year:	52 Per year		
5	System Life:	30 Years		
6	No. Decomm. Life-cycle:	572 Twin Systems		
7	Annual Output 1 Reactor			
8	(C8 from E21, static):	1.0879e15	C8/C5 =	3.6263e13
9	Alpha Units:	795.0000	=SUM(1>41)-SUM(1>41)	
10	Total Energy Output			
11	from total system:		C4*E8*C9 =	1.4991e18
12	Annual Front-End Energy,	1 set,		
13	(C14 from E24, Static):	2.0352e14	(C13/C1)*C4 =	1.1758e15
14	Beta Units:	414.0000	= SUM(1>9)+	(9*41)
15	Total System Front End			
16	Input Energy:		E13*C14=	4.8681e17
17	Annual Distrib. Energy,	1 set,		
18	(C19 from E19, Static):	6.8261e14	(C18/C5)*C4 =	1.1831e15
19	Total Distr. Energy:		C9*E18 =	9.4063e17
20	Decommissioning Energy			
21	(C22 from E25, static):	3.6762e13	C6*C21 =	2.1027e16
22	Total Energy Input:		E16*E19*E21 =	1.4484e18
23	Output/Input Ratio:		E11/E22 =	1.0349
24	Net Energy, 50 YRS.:	(Btu's)	E11-E22 =	5.0641e16
25	Plants in Service:		C4*C5 =	1560.0000
26	Annual Net Energy:	(Btu's)	E24/C2 =	1.0128e15

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.
Equations are shown in column D for results in column E.
Calculations start at line 8 and proceed, in sequence, through line 26.
The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.
C4*C5, for example, means that the quantity in column C, line 4 is multiplied times the quantity at column C, line 5.
SUM(1>41) means that integers 1,2,3...41 are summed.
E18/E17 is notation to mean that cell E18 is divided by cell E17.
Line 22 shows the dynamic Output/Input Ratio to be 1.0349 to 1.
Line 25 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield an average annual 1.0128e15 British thermal units of net energy, where "e15" means that the decimal point is 15 places to the right. Also, 1.0128 = 1.0128 quads of net energy.

Over the 50-year period, the system has generated a total of 50.64 quads of net energy (see cell E24), averaging 1.0128 quads of net energy per year. Meanwhile, 2600 twin-reactor plants will have been started, 1560 twin units will have operated continuously, and 572 twin units will have been decommissioned. A detailed explanation of the dynamic model is contained in appendix B.

Results of 100-Year Dynamic Analysis

Does the situation improve with time? Not much, as table 7.8 shows. Table 7.8 is a 100-year Dynamic Net Eenergy Analysis of a system of Bellefonte-type plants. Line 4 shows that 52 plants are started each year. Line 5 shows that it is assumed that each plant will last 30 years. This results in 3172 plants being decommissioned over the 100-year cycle as shown in cell C6.

Cell E24, table 7.8, shows the Dynamic Output/Input Ratio has increased to 1.1246 to 1. Over the 100-year period, 479.66 quads of net energy would be produced, averaging 4.7966 quads per year. Meanwhile, 5200 twin-reactor Braidiwood-type-plants would have been built, and 3172 would have been decommissioned.[1] This analysis assumes that no serious accidents would have occurred. The probability of an accident would be relatively high during 238,680 reactor years of operation, considering the Three-Mile-Island experience.[2]

[1]Actually, 10,400, 1120-megawatt, individual reactors would have been constructed and 6,344 would have been decommissioned.

[2]This latter number is reached by multiplying 2295 (cell C8 of table 7.6) times 52 (the number constructed each year shown in cell C4) times 2, since the system is a twin-reactor system.

Table 7.8

100-YEAR DYNAMIC ANALYSIS
Bellefonte Twin-Reactor-Type Systems

(A) LINE	(B) ITEM	(C) VARIABLE	(D) EQUATIONS	(E) RESULTS
1	Const. Time:	9 Years		
2	Cycle in Years:	100-year cycle of analysis		
3	Years of Generation:	91 Years		
4	No. Const. Per Year:	52.0000		
5	System Life:	30 Years		
6	No. Decomm. Life-cycle:	3172		
7	Annual Output 1 Reactor			
8	(C8 from E21, static):	1.0879e15	C8/C5 =	3.6263e13
9	Alpha Units:	2.2950e03	=SUM(1>41)	-SUM(1>41)
10	Total Energy Output			
11	from total system:		C4*E8*C9 =	4.3276e18
12	Annual Front-End Energy,	1 set,		
13	(C13 from E24, Static):	2.0352e14	(C13/C1)*C4 =	1.1758e15
14	Beta Units:	864.0000	= SUM(1>9)+	(9*41)
15	Total System Front End			
16	Input Energy:		E13*C14=	1.0159e18
17	Annual Distrib. Energy,	1 set,		
18	(C18 from E19, Static):	6.8261e14	(C18/C5)*C4 =	1.1831e15
19	Total Distr. Energy:		C9*E18 =	2.7154e18
20	Decommissioning Energy			
21	(C21 from E25, static):	3.6762e13	C6*C21 =	1.1660e17
22	Total Energy Input:		E16*E19*E21 =	3.8480e18
23	Output/Input Ratio:		E11/E22 =	1.1246
24	Net Energy, 100 YRS.:	(Btu's)	E11-E22 =	4.7966e17
25	Plants in Service:		C4*C5 =	1560.0000
26	Annual Net Energy:	(Btu's)	E24/C2 =	4.7966e15

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.
Equations are shown in column D for results in column E.
Calculations start at line 4 and proceed, in sequence, through line 26.
The notation C8 (cell C8), for example, refers to entry located at the intersection of column C and line 8.
C4*C5, for example, means that the quantity in column C, line 4 is multiplied times the quantity at column C, line 5.
SUM(1>41) means that integers 1,2,3...41 are summed.
E18/C2 means that cell E18 is divided by cell C2.
Data in cells C8, C13, C18, and C21 transferred from table 7.6.
Line 23 shows the dynamic Output/Input Ratio to be 1.1246 to 1
Line 26: average annual net energy produced is 4.7966 quads.
Notation "e15" means decimal point is 15 places to the right.
Detailed procedures provided in Appendix B.

Some interesting results are included in table 7.9 which is a summary of a simulation of events over a 100-year time span. It is assumed that 52 Bellefonte twin-reactor systems would be started each year (one new system each week). This construction rate was chosen to show that it would take approximately 50 years to show an annual net-energy production of more than one quad (i.e., Energy/GNP Ratio 28,266 Btu's/$1982.)

The summary shows the net-energy situation at 10-year intervals. Column B shows the Dynamic Net Energy Output/Input Ratios at the end of each 10-year period. Column C shows the accumulated net energy at the end of each period. Column D shows the average annual net energy over the period. Column E shows the number of plants that would be constructed at the end of each period. Column F shows the number that would be decommissioned at the end of each period. Column G shows the number of plants that would be continuously operated during each period. It will be seen that 1560 twin-reactor plants would be continuously operated after 30 years have passed. It will be seen that a huge energy deficit is incurred in the early years. The system would require an **external subsidy** of 46.8 quads of energy to develop this system in the first 10 years of operation, increasing to 106 quads in the first 20 years of operation.

The models are scalar with respect to the number constructed per year. Smaller construction rates will show proportionate changes in the magnitudes of table 7.9, although Output/Input Ratios and the mathematical signs (+/-) of columns C and D will remain the same.

Table 7.9

SUMMARY, 100-YEAR DYNAMIC NET ENERGY SIMULATION
Bellefonte Twin-Reactor Systems,
Construct 52 Twin-Reactor Units Per Year
All calculations use 28,266 Btu's/$1982

(A)	(B)	(C)	(D)	(E)	(F)	(G)
Year	Dynamic Output/ Input Ratio	Accum. Net Energy (quads)†	Annual Net Energy (quads)†	Number Const.	Number Decomm.	Number Operated
10	0.0291	-62.78	-4.68	520	0	52
20	0.5030	-122.96	-6.15	1040	0	1040
30	0.7941	-112.85	-3.05	1560	0	1560
40	0.9636	-35.16	-0.36	2080	52	1560
50	1.0349	+50.64	+1.47	2600	572	1560
60	1.0707	+136.44	+2.27	3120	1092	1560
70	1.0922	+222.25	+3.18	3640	1612	1560
80	1.1066	+308.10	+3.85	4160	2132	1560
90	1.1169	+393.85	+4.38	4680	2632	1560
100	1.1472	+479.66	+4.78	5200	3172	1560

Source: Results are calculations using models similar to table 7.8. The equations of lines 9 and 15 of table 7.8 are changed to account for differing time spans.
Note: †quad = one quadrillion (i.e. 1 x 10^{15}) Btu's.

Table 7.10 is a summary of the net-energy analyses calculated for representative plants in various cost categories of the 1984 Komanoff cost estimates. Calculations were made using low (21,436 Btu's/$1982), mean(28,266 Btu's/$1982), and high (34,324 Btu's/$1982) values. Static Output/Input Ratios are shown, along with Dynamic Output/Input Ratios and mean-value net-energy estimates, for both

Table 7.10

SUMMARY 50-YEAR AND 100-YEAR DYNAMIC CALCULATIONS
Varying Energy/GNP Ratios

(A)	(B)	(C)	(D)	(E)	(F)	(G)
			50-Years		100-Years	
NAME	Energy/GNP Ratios Btu's/$1982	Static I/O RATIO	Dynamic O/I Ratio	Mean Annual Net Energy	Dynamic O/I Ratio	Mean Annual Net Energy
Braidiwood	21436	1.9641	1.6582	+11.50	1.7997	+17.57
@ 2240MW	38266	1.4895	1.0951	+ 5.89	1.3648	+10.68
$1113/KW,$1982	23324	1.2266	1.0460	+ 1.22	1.1239	+ 4.41
(Similarly for Catawba, LaSalle, McGuire, and Watts Bar).						
Bellefonte	21436	1.6162	1.3648	+ 8.02	1.4830	+14.10
2426MW	28266	1.2256	1.0350	+ 1.02	1.1247	+ 4.78
$1484/KW,$1982	34324	1.0093	0.8523	- 5.19	0.9262	- 3.45
(Similarly for Byron, Comanche Peak, St Lucie, and Summer).						
Palo Verde	21436	1.4500	1.2187	+ 4.89	1.1833	+11.28
2540MW	28266	1.0096	0.9242	- 2.23	1.0097	+ 0.44
$1724/KW,$1982	34324	0.9005	0.7611	- 8.53	0.7390	-14.10
(Similarly to San Onofre, Susquehanna, Vogtle, and Wolf Creek)						
Callaway	21436	1.2878	1.0775	- 6.19	1.1833	+ 6.19
@ 2240MW	28266	0.9766	0.8171	- 6.19	0.8974	- 4.60
$2018/KW,$1982	34324	0.8043	0.6729	-13.45	0.7390	-14.10
(Similarly for Grand Gulf, Milstone 3, Perry, and South Texas).						
Clinton	21436	1.1082	0.9226	- 1.93	1.0191	+ 0.62
1866MW	28266	0.8404	0.6997	- 9.90	0.7728	- 9.78
$2444/KW,$1982	34324	0.6921	0.5762	-16.97	0.6364	-19.01
(Similary for Fermi, Harris, Limerick 1, and Waterford).						
Hope Creek	21436	0.9934	0.8244	- 5.64	0.9139	- 3.60
2144MW	28266	0.7534	0.6252	-15.88	0.6931	-16.93
$2797/KW,$1982	34324	0.6204	0.5148	-24.97	0.5707	-28.76
(Similarly for River Bend, Seabrook 1, WPPS2, and Zimmer).						
Beaver Valley 2	21436	0.8417	0.6956	- 4.50	0.7749	- 4.32
833MW	28266	0.6383	0.6956	- 9.22	0.5876	-10.43
$3411/KW, $1982	34324	0.5257	0.4344	-13.40	0.4839	-15.85
(Similarly for Midland 2, Nine Mile Pt. 2, and Shoreham).						
Komanoff Average	21436	1.2470	1.0422	+ 1.15	1.1461	+ 5.23
2300MW	28266	0.9457	0.7840	- 7.53	0.8691	- 6.18
$2104/KW,$1982	34324	0.778	0.6509	-15.25	0.7157	-16.29

Notes: All calculations made on basis of table 7.5 static model, and the 50 and 100-year dynamic models, previously shown.

50-year and 100-year analyses. The results from the first plant listed in each cost category are shown. The Output/Input Ratios for the other plants in each cost set would be the same, although the annual net-energy values would vary with plant size.

The mean value for the capital costs of the 1984 Komanoff data base is $2014 per installed kilowatt of capacity. The net-energy results are shown as the last set of calculations in table 7.10. It can be seen that, if the costs of nuclear power plants continue to be greater than $2014 per kilowatt, then the true value of the Energy/GNP coefficient must be considerably less than the mean value of 28,266 Btu's/$1982. However, even using the low-end Energy/GNP Ratio of 21,436 Btu's/$1982, it will be seen that, with a massive construction program of commencing one new 2300-megawatt system per week (52 per year), the net energy to be realized from such an undertaking would average only 1.15 quads of net energy at the end of 50 years and would average only 5.23 quads of net energy at the end of 100 years. Higher costs and higher Energy/GNP Ratios would yield less favorable results, and conversely.

All Things Considered

The energy cost of radiological waste disposal and other toxic wastes from the entire nuclear-fuel cycle are not included, except to the extent that the costs are included in the Fixed Charge Cost as a part of the utility's tax payments. The federal government has assumed much of the responsibility for long-term radioactive-waste disposal -- a burden that society must deal with for generations to come. The author feels that this cost is not covered in the Fixed-Charge Costs, and thereby adds a robust quality to the calculations. This point was briefly discussed earlier.[1]

Energy Systems Research Group (ESRG)[2] holds that Operations and Maintenance costs are escalating at faster rates than are considered in this study, saying that the costs would be "$65.56/kw in 1986, rising to $176.05/kw in 1999." Continuation of this trend will add a a robust quality (albeit conservative) to the conclusions of this study accordingly.

ESRG also argues that the costs of nuclear fuel is increasing at a real rate of 1 per cent per year (above the rate of inflation).[3] The presence of this future cost also adds a robust quality to this study since the increasing cost trend was not included.

ESRG also estimates that so-called Capital Additions (i.e., plant retrofitting additions due to changing safety requirements) will increase from "$37.23/kw in 1986 to $100.81/kw in 1999."[4] This trend was not included in the current study and the results are robust accordingly.

It has been assumed that all of the nuclear plants will last for 30 years without a major accident such as Three-Mile-Island No. 2 or worse. This is an unlikely scenario. If the average life turns out to

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[1]Amory B. Lovins and John H. Price, Non-Nuclear Futures, Idem.

[2]Stephen S. Bernow (Ph.D. Experimental Physics) of Energy Systems Research Group (ESRG) 120 Milk Street, Boston, MA 02109. Draft of pending testimony on Grand Gulf nuclear-powered electricity generating system (received August 15, 1985,) appendix A, unnumbered Exhibit, Schedule A, Sheets 1, 2, and 3.

[3]Ibid.

[4]Ibid.

be less than 30 years, then the results of this study will become become increasingly robust as the average lifespan declines.

Another major cost that is not accounted for in this study is the potential cost of insuring against a catastrophic accident. A substantial part of this insurance burden for United States nuclear utilities was assumed by the government of the United States with the passage of the Price-Anderson Act. The existence of this law substantially distorts the operating costs of utilities that operate nuclear power systems. Consequently, the conclusions of this study are robust accordingly, because this insurance cost is not accounted for in this study. It also strengthens the case for including the Fixed Charge Costs as an energy cost. Patterson has described the situation, as follows:

> Perhaps the most controversial financial aspect of civil nuclear power is insurance against third-party liability in the event of accident. In the mid 1950s . . . prospective operators of nuclear power stations in the USA shied away, worried at the monumental sums they might have to pay out in the aftermath of a major reactor accident. The numbers put forward by WASH-740 . . . were well outside actuarial experience. On the other hand, the probability of an accident was certainly declared to be very low. But on the other, the awesome consequences foreseen, should this improbably occurrence nonetheless occur, involved sums of money between ten and one hundred times the largest previously contemplated for third-party liability. Without even referring to the human dimensions of such a disaster it was clear that the largest utility in the country would be wiped out financially long before covering its liabilities, and so would most insurers.
>
> The deadlock was broken by the passage of the Price-Anderson Act of 1957, which established the principle of an upper limit to operator liability in claims for third-party damages, and provided a Federal umbrella of extra coverage . . . initially $60 million from private insurers, plus $500 million from the government.[1] . . .

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[1]Walter C. Patterson, <u>Nuclear Power</u> (New York: Penguin Books, 1976), pp.231-232.

> Beyond this total there shall be no further financial liability.' That is, in the event that the $7000 million property damage foreseen as worst possible by WASH-740 should someday occur, a maximum of . . . $500 million from government plus $60 million from private insurers would be available. Claims for the remaining $6440 million would not be entertained.[1]

Summary

In this chapter, the method of calculating both Static and Dynamic Net Energy Analyses was outlined. The detailed procedures for both methods are included in appendix B.

The chapter began with a review of net-energy analyses done by a number of authors. Except for the study by Klystra and Han, all of the studies showed subtantially higher static Output/Input Ratios than those found in this study. The Klystra and Han study was based on early engineering cost estimates and accounts for the relatively higher Output/Input Ratio. It was noted that most other net-energy studies did not include the Other Plant Costs (which include transmission and distribution plant) as an energy cost. Most other studies did not include the Fixed-Charge Cost as an energy cost. Prior energy analyses were based on older cost data or engineering cost estimates. Subsequently, it has been found that capital costs have substantially exceeded the engineering estimates of earlier years.

The analyses in this study are based on the argument of the proportionality of real economic cost and actual energy dissipation, which was discussed in chapter 5. Costs of the 46-plant data set were expressed in 1979 dollars. Costs of the 34-plant data set were expressed in 1982 dollars. The corresponding Energy/GNP Ratio

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[1]Ibid, p.172.

calculations are shown in appendix A, with selected years and mean values shown in table 5.3. Low-value, mean-value, and high-value Energy/GNP Ratios are used in net-energy calculations of the 34-plant data set.

Static Net Energy Analysis of the so-called Komanoff Base-Case plant, based on the 1981 cost estimates of Komanoff, shows that it barely yields net energy. The Komanoff Northeast-type plants, which are to have an even higher cost, do not yield positive net energy.

A summary of the results of Static Net Energy Analyses and 50-year dynamic analyses for the 1984 Komanoff cost estimates are shown in table 7.6. A more complete summary is included in table 7.10. In all cases of table 7.10, calculations were made by varying the Energy/GNP Ratios, using low, mean, and high values. The low-value Energy/GNP Ratios showed the most favorable net-energy results, i.e., have highest Output/Input Ratios. The mean-value for installed Capital Costs of the 1984 34-plant data set was $2014 per kilowatt of capacity ($1982). Calculations were done assuming a construction program of installing 52 new twin-reactor systems per year, costing $2014 per kilowatt of installed capacity. Even when the low-value Energy/GNP Ratio (i.e., 21,436 Btu's/$1982) is used, the results are not favorable. Such a program would yield only 5.23 quads of net energy per year over a 100-year period. Larger Energy/GNP Ratios and larger capital costs show negative net energy.

Finally, several examples of increasing cost trends (not considered in the current study) were briefly discussed. If these trends continue the conclusions of this study would turn out to be conservative accordingly.

It is the author's conclusion that, unless costs can be substantially lowered or efficiency materially improved, nuclear-powered electricity generating systems are not likely to be independent sources of net energy. They will require an external energy subsidy for their existence.

CHAPTER 8

ESTIMATED NET ENERGY FROM WIND SYSTEMS

Precis

The purpose of this chapter is to show that, given the present state of technology and economic-cost situation of Wind Energy Conversion Systems (WECS), this solar-driven technology, like nuclear-powered electricity-generating systems, is not an independent source of energy; rather, it is a roundabout way (a relatively benign way, however) of depleting the current stock of fossil fuels.

The results show that Wind Energy Conversion Systems, like nuclear power systems, are not likely to be independent sources of net energy at the present state-of-the-art and level of lifestyle enjoyed by the human participants. There would have to be a substantial lowering of unit costs (or increases in efficiency) in order for wind systems to become independent sources of net energy.

The methodologies used in this section are similar to those used in chapter 7 for nuclear power systems. Results of static and dynamic net-energy analyses of several wind systems are summarized. Detailed information is contained in appendix C.

The general approach followed in this chapter is the same as that followed in chapter 7 for nuclear power stations. The money-energy proportionality principal, as first introduced by Odum[1] and further developed by Costanza,[2] was elaborated in chapter 5 and is followed in this analysis. In order to be logically consistent, this means that all costs are included as energy-input costs. Fixed-Charge Costs and costs of transmission and distribution systems are included. Although some proponents of wind systems might argue that interconnection with the utility grid violates some of the decentralization benefits (national security, system resilience, and so forth), apparently the interconnection is the most cost-effective method of using the wind systems. Until it can be shown that there are ways of more efficiently using disconnected wind systems, the related energy cost of interconnection with the utility grid must be counted as an energy cost.

This writer often asks colleagues and students: "What do we use for energy when the fossil fuels are in short supply?" The answer, almost always, is: "We have nuclear fission, later nuclear fusion, and finally, an infinite source of energy from the sun." The Odum argument, which states that nuclear fission is not an independent source of energy but, rather, a roundabout way of consuming fossil fuels indirectly, is supported in chapter 7.[3]

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[1]Howard T. Odum, Environment Power And Society, (New York: Wiley Interscience, 1971).

[2]Robert E. Costanza, "Embodied Energy," Idem.

[3]Howard T. Odum, "Net Benefits to Society from Alternative Energy Investments," Business & Economic Dimensions, (Winter, 1977-78), p.15. Odum noted: "When all the energy used cumulatively by the Atomic Energy Commission and all other inputs to nuclear energy are calculated, one finds there has not yet been any net energy from nuclear energy. It was mainly running on fossil fuels in its early years. . ."
Note: It is the contention of this author that nuclear power is still running on fossil fuels.

Odum was also among the first to question the ability of the wind to be an independent source of net energy. He states:[1]

> . . .in most areas . . . wind speeds are low and erratic. Wind energy is dilute energy in these areas. If cheap materials are used. . . wind may be used to pump water. However, electric wind mills have so much energy cost concentrated in them that they do not yield net energy when the wind is 10 miles per hour.

It is recognized that the output provided by wind-powered electricity-generating systems (as well as nuclear systems) is a high-quality form of energy (electricity). However, it is assumed that a substantial amount of thermal energy will be needed for industrial processes to maintain the current type of civilization. For example, a considerable amount of thermal energy is needed in the production of the type of wind systems discussed in this chapter and the nuclear systems discussed in chapter 7. An all-electric energy system, such as one powered by nuclear or wind, would need to convert much of the electrical output to thermal energy for the process heat needs.

Wind systems were chosen as an analytical target over other solar-collection systems for three reasons: (1) data can easily be found, (2) the output of these electricity-generating systems is easily quantified at the bus-bar, and (3) the transmission and distribution systems are well developed and costs are generally available.

This author agrees with those who believe that the long-term environmental consequences and national security implications of nuclear power are substantial.[2] However, in this paper it is shown that neither

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[1]Howard T. Odum, Energy Basis for Man and Nature, Idem, p.16

[2]Amory B. Lovins, Brittle-Power, (Andover, MA: Brickhouse Publishing Co., 1982).

of the technologies (nuclear or wind) is an independent source of energy. We are still faced with the question: "What do we do when the fossil fuels are gone?"

Results of Net Energy Analysis

In 1983, questionnaires were sent to forty manufacturers of Wind Energy Conversion Systems (WECS). Apparently, some of the companies had gone out of business. Some were in other activities but not wind energy.

Twenty wind systems were analyzed. The manufacturer of the smallest system responding to the questionnaire markets a small direct-current generator which is only a fraction of a kilowatt of generating capacity. The largest machine studied is a 4000-kilowatt machine produced by Hamilton Standard, Inc. It will also be noted that there appears to be certain economies of scale up to around 200 kilowatts. A detailed, line-by-line explanation of the net-energy analysis models is included in appendix C.

Static Net Energy Analysis

The Energy Sciences 200-kilowatt wind system had the highest Output/Input Ratio. Table 8.1 is used as a model for illustrative purposes. The system (at full cost) yields a Static Net Energy Output/Input Ratio of only 0.7098 to 1 at twelve miles-per-hour (MPH) average wind speed. It will also be seen that, either the average wind speeds must be higher, or costs substantially lower, to realize net energy.

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[1]The Output/Input Ratio was very small and the results are not included.

Table 8.1

ENERGY SCIENCES 200-KILOWATT WECS
12 MPH Average Wind
Capital Cost @ $950 Per Kilowatt

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Expected Life, Yrs.:	25.0000		
2	Capacity Factor:	0.5000		
3	kWe Capacity:	200.0000		
4	kWh's Generated			
5	@ 12 MPH:	3.5000e05	C1*C2*C5 =	4375000.0000
6	Installed Cost:	950.0000	C3*C6 =	190000.0000
7	Trans. & Distr. Plant:		.5*E6 =	95000.0000
8	Total Front-End Cost:		E6+E7 =	285000.0000
9	Fixed Charge:	0.0950	C1*E8*C9 =	676875.0000
10	Decomm. Cost:			0.0000
11	O. & M. Cost:	2850.0000	C1*C11 =	71250.0000
12	Tot. Life-Cycle Cost:		SUM(E9>E11)=	748125.0000
13	Distributable Cost:		E12-E8 =	463125.0000
14	Output in Btu's:	3413.0000	E5*C14 =	1.4931e10
15	Front-End Input Energy:	2.8116e04	E8*C15 =	8.0130e09
16	Distrib. Input Energy:		E13*C15 =	1.3021e10
17	Total Input Energy:		E15+E16 =	2.1034e10
18	Net Energy:		E14-E17 =	-6.1024e09
19	Output/Input Ratio:		E14/E17 =	0.7098

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 17.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C3*C5, for example, means that the quantity in column C, line 3 is multiplied times the quantity at column C, line 5.

SUM(E8>E10) means that the quantities in column E from lines 8 through 10 are added together.

E13/E16 is notation to mean that cell E13 is divided by cell E16.

line 18 shows net energy is -1.6101e10, where "e10" is scientific notation meaning decimal is 10 places to right. -1.6101e10 = .000016101 quads.

line 19 shows the Output/Input Ratio to be 0.7098 to 1.

line 20 shows that over its 30-year lifecycle

Model fits "electronic spread sheet" computer software.

As will be noted in appendix C, of the 103 selected cities reviewed, only 44 show average wind speeds of more than twelve miles per hour. Only 17 of these sites show wind speeds in excess of fourteen miles per hour.[1] All other (except Energy Sciences) systems analyzed showed even smaller Output/Input Ratios than those estimated to be achieved by the Energy Sciences, Inc., 200-kilowatt machine.

Based on responses from questionnaires, wind systems are expected to last 25 years. An Efficiency Factor of 50 per cent for all systems was chosen. The argument for adopting this figure was developed in chapter 6. In chapter 6 it was shown that the Efficiency Factor for United States electric utilities has fallen from a high of 55 per cent in 1956 to about 40 per cent in 1982. It is assumed that an all wind-powered electricity-generating system would encounter the same varying demand situation as one powered by fossil fuels or nuclear power. In fact, if a region were to rely solely on wind power, the entire region might be without power unless a redundant system, or stored energy, was in place to supply electricity on demand.

Energy Sciences, Inc., reported that their 200-kilowatt machine would cost $950 per kilowatt of capacity (See appendix 3). Transmission and distribution costs were estimated at 50 per cent of Production Plant Cost. This is believed to be a conservative allowance because, as discussed in chapter 5, this cost has been greater than cost of

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[1]Donald Marier, Wind Power For The Homeowner, (Emmaus, PA: Rodale Press, 1981), pp. 286-301. Data from National Climatic Center, Ashville, NC, and are average wind speeds at 30, 50 and 100 feet above the surface. Appendix C shows selected data from 105 cities and only 44 of them showed an average wind speed in excess of twelve miles per hour at 100 feet above the surface.

Generating Plant for United States utilities. The rationale for charging wind-energy systems with a portion of the electric utility grid was discussed in chapter 6. Most wind systems are being marketed on the basis of interconnection with the central-power-station utility grid system and therefore must be charged with a share of that energy cost.

A real fixed-charge rate of 9.5 per cent was used to calculate total real economic cost of Production Plant and Other Plant including transmission and distribution costs.[1] This is slightly lower than the rate used by Komanoff for coal plants (9.78 per cent).[2] The rationale for including this cost as an energy-input cost has been argued in chapters 4, 5, and 6. The total Fixed-Charge Cost accounts for amortization of initial capital cost, interest charges, and taxes.

An Energy/GNP Ratio of 28,116 Btu's/$1983 was used for the Base Case. The underlying rationale for this procedure was developed in chapter 5 (see appendix A). It will be noted that this Energy/GNP Ratio is slightly smaller than that used for the nuclear calculations, which was 35,791 Btu's/$1979. The costs for wind machines are for 1983 dollars (1983 was the year of the survey). The mean value for the 35-year survey of Energy/GNP Ratios ($1983) is 29,116 Btu's per dollar. See appendix A for the calculations.

Table 8.2 shows the resulting Output/Input Ratios of the 20 wind systems studied under varying conditions. Output/ Input Ratios in column C are the Base-Case estimates.

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[1] Production Plant pertains to the actual electrical generating capital. Other Plant refers to all other capital costs except the electricity-generating system.

[2] Komanoff, <u>Power Plant Cost Escalation</u>, Idem, p. 281.

Table 8.2

SUMMARY OF STATIC NET ENERGY ANALYSES
Selected Wind-Energy Conversion Systems

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
1.	Energy Sciences Inc:			
	a. 200-KW MACH:			
	21333 Btu's/$1983	0.9355	1.2474	1.8711
	28116 Btu's/$1983	0.7098	0.9465	1.4197
	34172 Btu's/$1983	0.5845	0.7794	1.1691
	b. 68-KW MACH:			
	21333 Btu's/$1983	0.5915	0.7966	1.1950
	28116 Btu's/$1983	0.4533	0.6044	0.9067
	34172 Btu's/$1983	0.3733	0.4978	0.7467
2.	Boeing Co:			
	2500-KW Mach:			
	21333 Btu's/$1983	0.6708	0.8944	1.3416
	28116 Btu's/$1983	0.5089	0.6786	0.1017
	34172 Btu's/$1983	0.3852	0.5137	0.7705
3.	Carter Wind Systems			
	a. 200-KW Mach:			
	21333 Btu's/$1983	0.6029	0.7963	1.1945
	28116 Btu's/$1983	0.4531	0.6042	0.9063
	34172 Btu's/$1983	0.3732	0.4976	0.7464
	b. 25-KW Mach:			
	21333 Btu's/$1983	0.6021	0.8028	1.2042
	28116 Btu's/$1983	0.4568	0.6091	0.9136
	34172 Btu's/$1983	0.3458	0.4610	0.6916
4.	Bergey Windpower Co.			
	a. 10-KW Mach:			
	21333 Btu's/$1983	0.4668	0.6251	0.7032
	28116 Btu's/$1983	0.3557	0.4742	0.5335
	34172 Btu's/$1983	0.2143	0.2857	0.4286

Source: Basic cost and performance data taken from questionnaires or marketing brochures of respective manufacturers.
Column C data at 28,116 Btu's per $1983 is this author's "Base-Case" results. All other results are results of sensitivity analysis under varying conditions.
Column D shows results at 25% reduction in capital costs.
Column E shows results with no charge for Other costs, to include transmission and distribution costs (plus 25% cost reduction over column C. See Appendix C for details.

Continuation of Table 8.2

SUMMARY OF STATIC NET ENERGY ANALYSES
Selected Wind Energy Conversion Systems

(A) NO.	(B) Manufacturer	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
4.	Bergey Wind Power Co. Continued:			
	b. 1.4-KW Mach:			
	21333 Btu's/$1983	0.1451	0.1934	0.2902
	28116 Btu's/$1983	0.1101	0.1468	0.2202
	34172 Btu's/$1983	0.0833	0.1111	0.1666
5.	Windworks Inc.:			
	12-KW Mach:			
	21333 Btu's/$1983	0.4825	0.6433	0.9650
	28116 Btu's/$1983	0.3660	0.4881	0.7321
	34172 Btu's/$1983	0.2771	0.6433	0.5542
6.	Hamilton Standard:			
	4000-KW Mach:			
	21333 Btu's/$1983	0.4444	0.5925	0.8888
	28116 Btu's/$1983	0.3371	0.4495	0.6743
	34172 Btu's/$1983	0.2552	0.3403	0.5105
7.	Jacobs Wind Elec.			
	a. 17.5-KW Mach:			
	21333 Btu's/$1983	0.3272	0.4363	0.6544
	28116 Btu's/$1983	0.2482	0.3310	0.4965
	34172 Btu's/$1983	0.1877	0.2506	0.3759
	b. 10-KW Mach:			
	21333 Btu's/$1983	0.3721	0.4961	0.7442
	28116 Btu's/$1983	0.2823	0.3764	0.5647
	34172 Btu's/$1983	0.2137	0.2849	0.4274

Source: Basic cost and performance data taken from questionnaires or marketing brochures of respective manufacturers.

Column C data at 28,116 Btu's per $1983 is this author's "Base-Case" results. All other results are results of sensitivity analysis under varying conditions.

Column D shows results at 25% reduction in capital costs.

Column E shows results with no charge for Other costs, to include transmission and distribution costs.

See Appendix C for details.

Continuation of Table 8.2

SUMMARY OF STATIC NET ENERGY ANALYSES
Selected Wind Energy Conversion Systems

(A) NO.	(B) Manufacturer	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
8.	WTG, Inc.			
	a. 750-KW Machine:			
	21333 Btu's/$1983	0.3415	0.4533	0.6830
	28116 Btu's/$1983	0.2591	0.3455	0.5182
	34172 Btu's/$1983	0.1961	0.2615	0.3923
	b. 300-KW Mach:			
	21333 Btu's/$1983	0.4951	0.4401	0.6602
	28116 Btu's/$1983	0.2504	0.3339	0.5009
	34172 Btu's/$1983	0.1896	0.2528	0.3792
9.	Hummingbird Windpower:			
	6-KW Mach:			
	21333 Btu's/$1983	0.2878	0.3837	0.5756
	28116 Btu's/$1983	0.2183	0.2911	0.4367
	34172 Btu's/$1983	0.1653	0.2204	0.3306
10.	Bertoia Studios:			
	3-KW Mach:			
	21333 Btu's/$1983	0.2539	0.3385	0.5078
	28116 Btu's/$1983	0.1926	0.2569	0.3853
	34172 Btu's/$1983	0.1458	0.1944	0.2917
11.	Flowind Inc.:			
	170-KW Mach @ 14 MPH			
	21333 Btu's/$1983	0.7885	0.6648	0.9972
	28116 Btu's/$1983	0.3988	0.5044	0.7566
	34172 Btu's/$1983	0.3019	0.3818	0.5728
12.	DAF Indal Ltd.:			
	a. 500-KW Mach:			
	21333 Btu's/$1983	0.3993	0.5324	0.7986
	28116 Btu's/$1983	0.3029	0.4039	0.6059
	34172 Btu's/$1983	0.2293	0.3057	0.4586

Source: Basic cost and performance data taken from questionnaires or marketing brochures of respective manufacturers.

Column C data at 28,116 Btu's per $1983 is this author's "Base-Case" results. All other results are results of sensitivity analysis under varying conditions.

Column D shows results at 25% reduction in capital costs.

Column E shows results with no charge for Other costs, to include transmission and distribution costs. See Appendix C for details.

Continuation of Table 8.2

SUMMARY OF STATIC NET ENERGY ANALYSES
Selected Wind Energy Conversion Systems

(A) NO.	(B) Manufacturer	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
	DAF Indal Ltd., Continued			
	b. 300-KW Mach:			
	21333 Btu's/$1983	0.1714	0.2285	0.3428
	28116 Btu's/$1983	0.1300	0.1734	0.2601
	34172 Btu's/$1983	0.0984	0.1312	0.1969
13.	North Wind Power Co. (Does not include cost of install.)			
	a. 16-KW Mach:			
	21333 Btu's/$1983	0.5531	0.7375	1.1063
	28116 Btu's/$1983	0.4197	0.5596	0.8394
	34172 Btu's/$1983	0.3177	0.4236	0.6354
	b. 2-KW Mach:			
	21333 Btu's/$1983	0.3731	0.4975	0.7462
	28116 Btu's/$1983	0.2831	0.3775	0.5662
	34172 Btu's/$1983	0.2143	0.2857	0.4286

Source: Basic cost and performance data taken from questionnaires or marketing brochures of respective manufacturers.
Column C data at 28,116 Btu's per $1983 is this author's "Base-Case" results. All other results are results of sensitivity analysis under varying conditions.
Column D shows results at 25% reduction in capital costs.
Column E shows results with no charge for Other costs, to include transmission and distribution costs.
See Appendix C for details.

Systems were evaluated using the mean-value Energy/GNP Ratio of 28,116 Btu's/$1983, as well as the extreme values of table 5.2; i.e., 21,333 Btu's/$ for 1947, and 34,172 Btu's/$ for 1983.

It will noted in column C that none of the systems yield positive static net energy (under the full-cost considerations of column C, using the Base-Case of 28,116 Btu's/$1983) at twelve miles per hour average wind speed. If costs are lowered by 25 per cent (column D), the Energy Sciences 200-kilowatt machine almost breaks even at average wind speeds of twelve miles per hour. Costs would need to be lowered 25 per cent and zero charge for Other Plant Costs (which are made up mostly of transmission and distribution plant) in order for the Energy Sciences 200-kilowatt system to show substantial, positive, static net energy. Ignoring these expected costs, however, would be inconsistent with the reasoning developed in chapter 5, i.e., the money-energy proportionality argument for recognizing all economic costs as energy-input costs.

It will be noted that, even if the lower Energy/GNP Ratio of 21,333 Btu's/$1983 is used, only the Energy Sciences, Boeing, and Carter Wind Systems machines show positive net energy. Even then, only the Energy Sciences 200-kilowatt machine shows substantial, positive net energy. More importantly, unless the static ratio is large, the dynamic analysis shows that most systems are net-energy consumers.

The 50 per-cent Efficiency Factor and the inclusion of Other Plant Costs may be challenged by promoters of wind-energy systems. They may charge that this constraint is a harsh stipulation for dispersed wind-energy systems. However, wind systems are being marketed under the presumption that users will consume all the power that they need from their own system and sell the surplus power to the electrical grid at the host utility's avoided cost. As a consequence of this interconnection, the WECS then becomes an integral part of that larger system and therefore cannot claim a greater efficiency than the host electrical grid.

If wind-powered electricity generators are to occupy a substantial niche in the energy picture of the nation, then some type of distribution system will be needed. As an option, society might reorganize itself into to some sort of decentralized, community-sufficiency basis, perhaps reducing Other Plant Costs, i.e., mostly transmission and distribution costs.

It is recognized that dispersed end-users might make 100 per-cent use of the power generated by their systems. To the best of my knowledge, however, this is not being done except through energy-storage systems. Energy storage incurs economic costs, and the author is unfamiliar with any energy-storage systems that have high cost-benefit ratios.

It will also be noted in appendix C that output from wind-energy systems increases rapidly as average wind speeds increase. The average wind at a given geographical location also varies with the height of the tower. The amount of wind power available at that point in space varies exponentially with the wind speed. For example, the Jacobs 17.5-kilowatt machine at twelve miles per hour will deliver 25,772 kilowatt-hours annually, but at fourteen miles per hour (a 17 per-cent increase in wind speed), it will deliver 37,517 kilowatt-hours annually (a 46 per-cent increase in power).[1]

Columns D and E show the Output/Input Ratios for more favorable (less costly) conditions. Column D reflects a 25 per-cent reduction in cost of both the generating system and the transmission and distribu-

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[1]Judy Weiss, Letter from Jacobs Wind Electric Company, and accompanying brochure.

tion system. It is believed that some economies of scale in wind-system production might be achieved by large-scale, assembly-line type of production of the machines themselves. However, the installation costs and the costs of transmission and distribution would probably not change proportionally. Column E shows both a 25 per-cent capital-cost reduction and complete elimination of Other Plant (including transmission and distribution) charges. This is done under the possible assumption that dispersed WECS designers might be able to eliminate the costs of transmission and distribution by more efficient matching of generator size and the control of end-using systems. It should be clearly understood that this is not the state-of-the-art, however, and will not be achieved without additional input cost.

Table 8.3 is included to show the static net-energy results of lowering the unit costs of the Energy Sciences 200-kilowatt WECS to 75 per cent of the reported cost of the system ($1983) and elimination of the Other Plant Cost (includes transmission and distribution plant). It will be noted in cell C5 that the cost is lowered to $712.50 per kilowatt of installed capacity and results in a Static Net-Energy Output/Input Ratio of 1.4197 to 1. Data from this table are used in the Dynamic Net Energy Analyses that follow. The results of table 8.3 are to be compared to an Output/Input Ratio of .7098 to 1 when the 100 per cent capital cost figure of $950 per kilowatt is used and Other Plant Cost is included (at 28,116 Btu's/$1983).

Dynamic Net Energy Analysis

Table 8.3 shows the results of a Static Net Energy Analysis of the Energy Sciences 200-kilowatt wind machine in a hypothetical

Table 8.3

ENERGY SCIENCES 200-KILOWATT WECS
12 MPH Average Wind
Capital Cost Reduced 25%
Zero Transmission & Distribution Cost

(A) LINE	(B) ITEM	(C) VARIABLE	(D) EQUATION	(E) RESULTS
1	Expected Life, Yrs.:	25.0000		
2	Capacity Factor:	0.5000		
3	kWe Capacity:	200.0000		
4	kWh's Generated			
5	@ 12 MPH:	3.5000e05	C1*C2*C5 =	4375000.0000
6	Installed Cost:	712.5000	C3*C6 =	142500.0000
7	Trans. & Distr. Plant:		.5*E6 =	0.0000
8	Total Front-End Cost:		E6+E7 =	142500.0000
9	Fixed Charge:	0.0950	C1*E8*C9 =	338437.5000
10	Decomm. Cost:			0.0000
11	O. & M. Cost:	1425.0000	C1*C11 =	35625.0000
12	Tot. Life-Cycle Cost:		SUM(E9>E11)=	374062.5000
13	Distributable Cost:		E12-E8 =	231562.5000
14	Output in Btu's:	3413.0000	E5*C14 =	1.4931e10
15	Front-End Input Energy:	2.8116e04	E8*C15 =	4.0065e09
16	Distrib. Input Energy:		E13*C15 =	6.5106e09
17	Total Input Energy:		E15+E16 =	1.0517e10
18	Net Energy:		E14-E17 =	4.4147e09
19	Output/Input Ratio:		E14/E17 =	1.4197

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.
Equations are shown in column D for results in column E.
Calculations start at line 4 and proceed, in sequence, through line 19.
The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.
C3*C5, for example, means that the quantity in column C, line 3 is multiplied times the quantity at column C, line 5.
SUM(E8>E10) means that the quantities in column E from lines 8 through 10 are added together.
E13/E16 is notation to mean that cell E13 is divided by cell E16. The O/I Ratio is 1.4197 to 1.
line 18 shows net energy is 4.4147e09, where "e09" scientific notation meaning decimal is 9 places to right. 4.4147e09 is = .000004147 quads.
line 19 shows the static Output/Input Ratio to be 0.7098 to 1.
Model fits "electronic spread sheet" computer software.

situation where costs are lowered 25 per cent and the assumed average wind speed is twelve miles per hour. Cell E17 of table 8.3 shows a positive Output/Input Ratio of 1.4197 to 1. Certain data from table 8.3 will be used in the Dynamic Net Energy calculations that follow.

Table 8.4 is the model used for a 50-year Dynamic Net Energy Analysis, based on certain information produced in Table 8.3. It takes about 6 months (22 weeks) to construct and install a single plant, based on information submitted by Energy Sciences, Inc. For ease of analysis, it was assumed that it would take a year to install any set of machines selected. A 50-year construction and operation program of installing 500,000 units per year rate was chosen to show the magnitude of the problem of delivering an average of more than one quad net energy per year over the period.

The Output/Input Ratio is obtained by dividing estimated output-energy by estimated input-energy. In the 50-year case of table 8.4, it is shown to be 1.2910 to 1. The net energy from 50 years of construction and generation is obtained by merely subtracting total-system input from total-system output.

The model is scalar with respect to Output/Input Ratios; i.e., you can double or quadruple the rate of construction and the ratio does not change, ceteris paribus. The average annual net-energy yield from the system over the 50-year period is approximately 1.2454 quads per year, about one-fiftieth of net energy realized from the 1983 production of fossil fuels in the United States (see chapter 5 and appendix A).

It will be noted that the <u>total</u> net energy delivered by the system over a period of 50 years is about 62 quads which is about 90

Table 8.4

50-YEAR DYNAMIC NET ENERGY ANALYSIS
Energy Sciences 200-Kilowatt WECS
Capital Cost Reduced 25%, Zero Other Plant Cost

(A) Line No.	(B) Item	(C) Variable	(D) Calculation:	(E) Result
1	Const. Time Yrs.:	1.0000		
2	Cycle in Years:	50.0000		
3	Years of Generation:	49.0000		
4	No. Constr. Per Year:	5.0000e05		
5	Annual Output, 1 Set			
6	(From E13, Static):	1.4931e10	(C5/25)*C4 =	2.9862e14
7	Front-End Input Energy			
8	(From E14, Static):	4.0065e09	C2*C4*C8 =	1.0016e17
9	Ann. Distr. Input Energy			
10	(C10 From E15, Static):	6.1506e09	(C10/25)*C4 =	1.2301e14
11	Accumulated WEC Years:	925.0000	=SUM(1,2,3,...49)	
12			-SUM(1,2,3,...24)	
13	Lifecycle System Output:	(Btu's)	E6*C11 =	2.7622e17
14	Lifecycle System Input:	(Btu's)	(E10*E11)+C8 =	2.1394e17
15	Output/Input Ratio:		E13/E14 =	1.2910
16	Net Energy, End Period:	(Btu's)	E13-E14 =	6.2274e16
14	No. Windmachines On Line			
15	End 50 Years:		25*C4 =	1.2500e07
16	Annual Net Energy:		E16/C2 =	1.2454e15
17	Total No. Constructed:		C2*C4 =	2.5000e07
18	Total No. Decommissioned:		(C2-25)*C4 =	1.2500e07

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.
Equations are shown in column D for results in column E.
Calculations start at line 4 and proceed, in sequence, through line 16.
The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.
C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.
SUM(1,2,3...49) means integers 1,2,3...41) are summed.
Sum(1,2,3...24), similarly. (accounting for decommission yrs.)
E9/E10 means that cell E12 is divided by cell E12.
E16 shows annual net energy of 1.2454e15 Btu's.
where "e15" is scientific notation meaning decimal is 15 places to right. 1.2454e15 = 1.2454 quads.
Model fits "electronic spread sheet" computer software.
Line 16 shows that 13 million wind machines would be decommissioned.

per cent of our 1983 gross-energy consumption. At the end of 50 years, 25 million 200-kilowatt wind machines would have been constructed and 13 million would have been decommissioned.

Table 8.5, which follows, shows that the situation does not materially improve with time. At the end of 100 years the system would have delivered 186.82 quads of net energy (averaging 1.8682 quads annually). Meanwhile, 49.5 million such machines would have been constructed and 37.4 million would have been decommissioned. The system would have produced 38.81 per cent more energy than was required to sustain it over the 100-year period.

Of course, another important point is that one would have to find locations for 12.5 million such wind machines at sites enjoying annual wind speeds of more than twelve miles per hour. The reader must also bear in mind that the dynamic models are based on the assumption that the capital costs of the Energy Sciences 200-kilowatt machine can be lowered at $712.50 per kilowatt of capacity (75 per cent of the costs reported by the manufacturer) and that so-called Other Plant Costs, which include transmission and distribution costs, would be zero -- an unlikely event.

Explanation of Table 8.6

Table 8.6 summarizes the 50-year dynamic net-energy results of varying the annual construction rate from 1,000 per year to 1,000,000 per year. Explanatory notes appear at the bottom of the table. It will be seen that the model requires an annual construction rate of almost 500,000 WECS to yield an annual output of more than one quad (10^{15} Btu's) of net energy over the 50-year period.

Table 8.5

100-YEAR DYNAMIC NET ENERGY ANALYSIS
Energy Sciences 200-Kilowatt WECS
Capital Cost Reduced 25%, Zero Other Plant Cost

(A) Line No.	(B) Item	(C) Variable	(D) Calculation:	(E) Result
1	Const. Time Yrs.:	1 year		
2	Cycle in Years:	100 years		
3	Years of Generation:	99 years		
4	No. Constr. Per Year:	500,000		
5	Annual Output, 1 Set			
6	(C6 from E13, Static):	1.4931e10	(C5/25)*C4 =	2.9862e14
7	Front-End Input Energy			
8	(C8 from E14, Static):	4.0065e09	C2*C4*C8 =	2.0032e17
9	Ann. Distr. Input Energy			
10	(C10 from E15, Static):	6.1506e09	(C10/25)*C4 =	1.2301e14
11	Accumulated WEC Years:	2.1750e03	=SUM(1,2,3,...99)	
12			-SUM(1,2,3,...74)	
13	Lifecycle System Output:	(Btu's)	E6*C11 =	6.4949e17
14	Lifecycle System Input:	(Btu's)	(E10*E11)+C8 =	4.6787e17
15	Output/Input Ratio:		E13/E14 =	1.3881
16	Net Energy, End Period:	(Btu's)	E13-E14 =	1.8162e17
14	No. Windmachines On Line			
15	End 100 Years:		25*C4 =	1.2500e07
16	Annual Net Energy:		E16/C2 =	1.8162e15
17	Total No. Constructed:		C2*C4 =	5.0000e07
18	Total No. Decommissioned:		(C2-25)*C4 =	3.7500e07

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.
Equations are shown in column D for results in column E.
Calculations start at line 4 and proceed, in sequence, through line 18.
The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.
C3*C4, for example, means that the quantity in column C, line 3 is multiplied times the quantity at column C, line 4.
SUM(1,2,3...99) means integers 1,2,3...99) are summed.
Sum(1,2,3...74), similarly. (accounting for decommission yrs.)
E13/14 means that cell E13 is divided by cell E14.
E16 shows annual net energy of 1.8162e15 Btu's of energy/yr. where "e15" is scientific notation meaning decimal is 15 places to right. 1.8.62e15 = 1.8162 quads.
Model fits computer software known as electronic spread sheet.
Line 18 shows that 37.5 million wind machines would be decomm.
Information in cells C6, C8, & C10 taken from table 8.3.
Model fits "electronic spread sheet" computer software.

An annual production rate of 500,000 per year would require that $71.25 ($1983) billion be annually invested in new generating plants.

Table 8.6

SUMMARY, DYNAMIC 50-YEAR ANALYSES
Energy Sciences Inc., 200 KWe Type Wind Machines
Capital Cost $712.50/kilowatt,
Zero Other Pland Cost
14 MPH Average Wind Speeds,
Varying Annual Construction Rates

(A) Tot. Const. Year	(B) Accum. Net Energy (Quads)†	(C) Annual Net Energy (Quads)†	(D) Total No. Constr. Millions	(E) Total No. In Operation (million)	(F) Total No. Decomm. (million)
1000	0.25	0.00249	0.035	.0025	0.024
5000	0.623	0.0125	0.25	.0125	0.12
10000	1.25	0.0249	0.50	.0250	0.24
20000	2.49	0.0498	1.00	.0500	0.48
50000	6.23	0.1245	2.50	0.1250	1.20
100000	12.46	0.2490	5.00	0.2500	2.40
500000	62.27	1.2450	25.00	1.2500	12.00
1000000	124.55	2.4900	50.00	2.5000	24.00

Notes: A - selected variables
B- Cell E12,50-Year Dynamic Model, table 8.4
C - Cell E14, ..., e.g., table 8.4.
D - Cell E15, ...
E - Cell E13, ...
F - Cell E16, ...

†quad = quadrillion (10^{15} Btu's). Quantities are in Btu's to compare to annual energy consumption which is usually expressed in Btu's. Gross Annual United States Energy Consumption in 1983 was about 70 quads., thermal. (also see appendix A for net-energy estimates.)

This would result in a 50-year cost of about $8.46 trillion ($1983).[1] In 50 years, 25 million machines would have been construction and 13 million would have been worn out and require decommissioning. It will be noted (table 8.1) that decommissioning cost are assumed to be zero. This might not be the case. Consequently, the results are robust accordingly.

It is recognized that these machines are producing electricity, a high-quality energy form. Electricity generation requires about 4 Btu's of fossil-fuel energy to produce each Btu of thermal energy (if the electricity is converted to thermal energy). Even in an all-electric economy, considerable energy would need to be in thermal form for process heat for processing ores, shaping metal, ad infinitum.

Dynamic Simulation Through Fifty Years

A different sort of summary is provided in table 8.7 which summarizes the dynamic energy analyses in a different dimension. Table 8.7 shows the status of various results at 10-year intervals from 10 to 100 years.

In all cases of table 8.7, the annual construction rate is 500,000 200-kilowatt wind machines. It will be noted that the system does not yield positive net energy until about 25 years have passed. Even then, at the end of 100 years, such a construction program would yield only an annual net-energy output of 1.82 quads of net energy, about one-thirtieth of the net-energy realized from the production of fossil fuels realized in 1983. (see chapter 5.)

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[1]Note: [($712.50 per kilowatt x 200) x (500,000/yr x 50 yrs)] x .0950 capital charge x 25 years = $8.46 trillion.

Table 8.7

SUMMARY, DYNAMIC NET ENERGY ANALYSES
Energy Sciences Inc., 200-Kilowatt Type Machines
Capital Cost Reduced 25%, Zero Other Plant Cost
12 MPH Average Wind Speeds, Construct 500,000 Per Year
Status at 10-Year Intervals

Years	Output/ Input Ratio	Accum. Net Energy† (Quads)†	Ann. Avg. Net Energy† (Quads)†	Total Number Constr. (millions)	Total Number Decomm. (millions)
10	0.5255	-12.1	-1.21	5.0	0
20	0.8943	-7.0	-3.35	1.5	0
30	1.1293	14.5	0.48	15.7	1.0
40	1.2353	38.4	0.96	20.0	7.0
50	1.2910	62.3	1.25	25.0	12.0
60	1.3253	86.1	1.44	30.0	17.0
70	1.3486	110.1	1.57	35.0	22.0
80	1.3645	133.4	1.67	40.0	27.0
90	1.3782	157.3	1.75	45.0	32.0
100	1.3881	181.6	1.82	50.0	37.0

Notes:
†quad = quadrillion (10^{15} Btu's). Quantities are in Btu'sto compare to annual energy consumption which is usually expressed in Btu's. Annual U. S. Energy Consumption in 1983 was about 70 quads., thermal.

Summary and Conclusions

In this chapter, selected Net Energy Analysis models were introduced which show that, at the current state-of-the-art, none of the wind systems in the United States will deliver net energy to our society at expected average wind speeds of twelve miles per hour unless costs are substantially reduced. Installed costs would need to be reduced by at least 50 per cent in order for some positive net energy to be realized by even the best-performing system (Energy Sciences 200-kilowatt WECS).[1] Even if the true Energy/GNP Ratio were 21,333 Btu's/$1983, most of the wind machines do not show any positive net energy-output, even under the low-cost scenario.

Perhaps, it might be possible for unit costs to be lowered by such an amount through mass-production techniques such as are being practiced in the automobile industry. Even then, with a positive Static Net-Energy Ratio of 1.4179 to 1, the dynamic results are not favorable. At the end of 100 years, a 500,000 per-year rate of construction of Energy Sciences-type 200-kilowatt WECS would be yielding an annual net-energy output of only about 1.86 quads of net energy. The economic cost of such an undertaking would cost more than $8.6 trillion over 50 years, as shown in "Discussion of Table 8.6."

Therefore, it is concluded that the future, with respect to net-energy benefits from wind energy conversion machines as a source of net energy to replace fossil fuels, is indeed gloomy. The economic cost would need to be substantially reduced in order for the picture to improve, and even then, wind-powered systems must either have adequate, low-cost energy-storage systems or essentially have backup systems when speeds are inadequate to meet the demand schedule of an industrial society.

This study should not be construed as an attack on wind energy as a source of electricity. Fossil-fuel plants need 3 to 4 input-Btu's of coal, oil, or natural gas to produce one output-Btu of heat; i.e., the Output/Input Ratio is about 0.25 to 1. The point being made is that, at the present state-of-the-art and level of economic cost, wind-powered electricity-generating systems are not independent sources of net energy. They would not be able to replicate themselves out of their own energy. They require an external, energy subsidy for their being.

CHAPTER 9

INTERCONNECTED PROBLEMS AND IMPLICATIONS

Precis

In this chapter selected global issues will be discussed as they relate to the findings of this study. The current study shows that nuclear-powered and wind-powered electricity-generating systems are not independent sources of net energy. They are being externally subsidized. They could not replicate themselves out of their own energy and leave a sufficient quantity to meet societal needs. Rather, they are roundabout ways of consuming finite fossil fuels. It is generally believed that these types of technologies are being counted on to provide a source of net energy as fossil fuels are depleted. This study finds that they will not meet those expectations. Other sources of net energy must be found or society faces serious problems.

The current (1985) glut of fossil fuels has temporarily lulled society into a false notion that there is no longer an energy problem or that the problem is so far into the future that it is a non-problem. Growth economists and other technological optimists have been a major party to this self-deception. For example, see Landsberg [1] and Simon.[2]

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[1]Hans Landsberg, Arrow, et al, Energy The Next 20 Years, Idem.

[2]Julian Simon, The Ultimate Resource, (Princeton, NJ: Princeton University Press, 1981).

In 1949, Hubbert[1] warned us that the stocks of each of the fossil fuels would be exhausted on the following approximate chronology: 1960 to 2030 for 80 per cent of the petroleum, 1934 to 1999 for 80 per cent of the natural gas, and 2000 to 2300 for 80 per cent of the coal. Hubbert's estimates for coal assumed that the amount produced would only double three times.

Merklein and Hardy[2] pointed out that the coal supply could be reduced to 60 years at a 5 per cent growth rate. Fowler,[3] using later data, confirmed Hubbert's earlier estimates for petroleum production in the United States. Hall and Cleveland,[4] citing both Hubbert and Fowler, and using later data, found that drilling for domestic petroleum "could cease to be a net source of energy by about 2004 at low drilling rates and 2000 at high drilling rates."

All of the foregoing have found that an increasing increment of physical effort is needed for each additional increment of fossil-fuel output. The implications of this trend have not been identified by traditional economic analysis. Unfortunately, the economic estimates, such as those of Barnett and Morse,[5] dominate the view in the scientific community and the community at large.

Our society is highly dependent on petroleum as a portable

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[1]M. King Hubbert, "The Energy Resources of the Earth," Idem.

[2]Helmut A. Merklein and W. Carey Hardy, Energy Economics Idem.

[3]Richard G. Fowler, "Longevity of Searchworthiness," Idem.

[4]Charles A. S. Hall and Cutler J. Cleveland, "Yield Per Effort and Net Energy Analysis of the American Petroleum Industry," Idem.

[5]Harold J. Barnett, and Chandler Morse, Scarcity and Growth, (Baltimore: Johns Hopkins Press, 1963).

energy source. Most of the stocks of net-energy-yielding petroleum probably lie outside the United States, mostly within the Organization of Petroleum Exporting Countries (OPEC). Once the value of these major sources of net energy is fully realized, there is likely to be a frantic scramble for their control.

The implications are even more ominous when they are considered in the context of other global problems that will become more serious as each of them encounters the impending energy-materials crisis.

Selected, Interacting Global Problems

Energy Supply and Military Implications

Except for the rockets, military machines run on oil. It appears likely there may be a struggle to control the rich net-energy sources of petroleum as stocks are depleted. The use of force, however, may be self-defeating. First, efforts to control the oil supplies by force would require that much of the oil be fed back into the military machines to gain or maintain control of oil; i.e., the various military machines might need most of the oil energy (both directly, and indirectly) in the struggles for control, leaving little for other societal needs. Second, rising tensions may then tempt military powers to use the ultimate weapons when they perceive that "their" fuel supplies are threatened.

No doubt, the most ominous problem facing humanity is the growing possibility of nuclear holocaust and the consequent destruction of the planet. Aside from the direct blast and burn effects of a nuclear war,[1] the so-called nuclear winter effect will cause atmospheric conditions which prevent sufficient sunlight from reaching the Earth to sustain the biological systems.[2] In a way, we are living in a sort of "high tech" Jonestown. We are quite prepared to commit suicide on a global scale.

Growing World Population

The problem of a growing world population also presents serious problems. There is general agreement that the current world population of approximately 5 billion will double by about the year 2020 unless other population-limiting events occur.[3] Unfortunately, there is an inherent momentum to the growth process in those countries having a preponderance of young inhabitants. For example, if Mexico were to suddenly achieve a situation where each female replaces herself only once, it would take another 60 years for Mexico's population to stop growing. No doubt, Mexico will share their bountiful output with the United States.

This population growth is taking place in the midst of dwindling Earth resources, which include energy, non-fuel Earth materials, fresh water, agricultural land, and other environmental resources. Not only is the population growing, but wants are also growing. The quasi-educated have led others to believe that the they can achieve Western

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[1]R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack, and Carl Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," Science 222,(23 December 1983): 4630.

[2]Paul Ehrlich, et al., "The Long Term Biological Consequences of Nuclear War," Science, 222 (23 December 1983).

[3]Paul E. Ehrlich, The Population Bomb, (New York: Ballantine Books, 1971). Also see with Anne Ehrlich, Mother Earth News, for example, see issues, all of 1984 and 1985, for more recent views.

lifestyles simply by more education and technology transfer. It is quasi-education because biophysical limits are not at the forefront of the process. It will be difficult to explain to aspiring, developing, countries why many needs, let alone wants, may not be forthcoming.

Increasingly, society faces more difficult social and moral questions with respect to the size of human population and how to deal with limiting its size. It is the author's view that population size may have already gone well beyond any semblance of long-run carrying-capacity of the Earth and that society must make hard choices with respect to population reduction, or nature will make them for us in a cruel and vicious way, as is now being experienced in Ethiopia and several other countries in Africa and Asia. Some of the most influential moral leaders of the world are not facing up to this issue in an honest way.

Global Food Prospects

Brown,[1] of the Worldwatch Institute, has warned that, whereas we had always had two sources of food security (grain stocks and idle cropland), we entered the 1980's with only the reserve grain stocks. We no longer enjoy a large reserve in the form of idle cropland.

Unfortunately, this ominous food prospect occurs in the context of the problems of dwindling net energy, a growing population, and increasing water-supply, as will be discussed below.

Some nations plan to use agricultural crops for liquid fuels (alcohol). As Brown has pointed out, a typical third-world consumer

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[1]Lester Brown, "Food Prospects: Shadow of Malthus, Challenge, (January-February 1982).

requires about one-fourth hectare of agricultural land to meet his annual food needs. The affluent needs about one hectare, but a "typical American car fueled entirely by ethanol would require . . . over seven tons of grain per year -- the output from nine hectares of average land," according to Brown.[1] The problems of food supply are closely related to the problems of water supply, and population growth, and all interact with the problems of net-energy supply.

Water Quantity and Quality

The 1980 Global 2000 Report to the President noted the following:[2]

> Regional water shortages will become more severe. In the 1970-2000 period population growth alone will cause requirements for water to double in nearly half the world. Still greater increases, would be needed to improve standards of living. In many LDC's [Less Developed Countries] water supplies will become increasingly erratic by 2000 as a result of severe deforestation. Development of new water supplies will become more costly virtually everywhere. . .
>
> . . . Increases of at least 200-300 percent in world water withdrawals are expected over the 1975-2000 period. By far the largest part of the increase is for irrigation. . . .
>
> . . . Much of the increased demand for water will be in the LDC's of Africa, South Asia, the Middle East, and Latin America, where in many areas fresh water for human consumption and irrigation is already in short supply. . . Moreover, many LDCs will also suffer destabilization of water supplies following extensive loss of forests. In the Industrialized countries competition among different uses of water -- for increasing food production, new energy systems (such as synthetic fuels from coal and oil shale), increasing power generation, expanding food production, and increasing needs of other industry -- will aggravate water shortage in many areas.

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[1]Ibid.

[2]The Global 2000 Report to the President: Entering the 21st Century A report Prepared by the Council on Environmental Quality and the Department of State. (Washington, D. C.: Superintendent of Documents, U. S. Government Priting Office, [1980], p.2.

Even this grim picture of global water availability was based on a more optimistic net-energy situation than is suggested by the findings of this study; i.e., see the preceding comment on "new energy systems."

Finite Non-Fuel Resource Problems

There is increasing evidence that the rich, non-fuel resources are being depleted at rates that cannot long be sustained. The energy-materials problems were anticipated by economist Georgescu-Roegen.[1]

Chynoweth, Director of the Materials Research Laboratory, Bell Laboratories, notes the following:[2]

> ... many of the materials are in ores much too dilute or too geologically or geographically remote to be economically workable, either by current reckonings or realistically predictable ones.

He says that it takes a lot of energy, capital, and labor to mine, transport, smelt, and refine raw materials, but that as we move from the richer to the leaner ores, much more of all the inputs are needed to provide the same amount. Meanwhile, there is an increasing world demand for materials.

Brian J. Skinner, Eugene Higgins Professor of Geology and Geophysics at Yale University, holds:[3]

> The distribution of chemical elements in the Earth's crust sets natural limits to man's supply of metals that are much more important to the future of society than limits on energy. . .

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[1]Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process, Idem.

[2]A. G. Chynoweth, "Materials Conservation A Technologist's Viewpoint ," Challenge, (January-February 1983)

[3]Brian J. Skinner, "A Second Iron Age Ahead?" American Scientist, (May-June, 1976): 64.

> However one views the use of geo-chemically scarce metals in the future it is clear that there are very real limits to the amounts available in traditional ore deposits of the continental crust. Efficient recycling, which surely must come as existing deposits are worked out and new ones become harder to find, will guarantee that even the scarces metals will always be available in at least small amounts. But recycling can at best sustain a declining use rate. While growth or even level use rates pertain, newly mined material must continue to be added. When the traditional deposits have all been found and mined, however, our responses will inevitably be governed by geochemical abundances, and little, if any newly mined scarce metals will be available to be added to the pool in use.
>
> The critical time in man's future technological development cannot be pinpointed, but it cannot be too far in the future. The date depends on future use rates of metals, and since some metals will be effectively used up before others, we are likely to see an extended decline rather than a sudden cutoff. . . .
>
> Whichever way we turn, we are forced back to the realization that one day soon we will have to come to grips with the way in which earth offers us its riches. That day is less than a century away, perhaps less then half a century. When it dawns, we will have to learn to use iron and other abundant metals for all our needs. The dawn of the second iron age is much closer than most of us suspect.[1]

Skinner's position was based on the assumption that energy supply is not a large problem. This study finds that the energy-supply problem may be greater than Skinner might have realized. It appears to this writer that the growing problem of finding net energy will compound the problems of mining the deeper and leaner grades of ore, as pointed out by Skinner. In turn, the difficulty of mining the deeper ores will further affect the net-energy availability problem.

Economic Growth and Economic Justice

There is a characteristic of economic growth that is not widely understood. If something is increasing, a doubling process ensues. If

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[1]Ibid.

something is growing exponentially, say, 10 per cent per year, then the quantity doubles in about seven years -- such is the nature of compound interest. The quantity involved in the last doubling time is greater than the sum of the previous doublings in the series. The point being made is that economic growth is being carried out by some doubling rate of depletion of the stocks of Earth resources. It should seem obvious that such a pattern cannot be sustained.

The problem of distributive justice has heretofore been swept under the rug of economic growth. We have concentrated on making the "pie" larger, rather than worrying very much about the distribution of relative shares of Earth resources. If the availability of Earth resources is decreasing, then we must squarely face the issue of distributive justice, not only for the current populations, but for future populations of the Earth. Most of the rest of the intellectual community have been content to hear what they wanted to hear from well-meaning economists and other technological optimists.

Limits To Growth

In 1972, Meadows, et. al., concluded:[1]

> 1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
>
> 2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. [emphasis added] The state of

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[1]Donella H. Meadows, Dennis L. Meadows, Jorgen Randers, William W. Behrens III, The Limits to Growth, (New York: Universe Books, 1974). p. 24.

global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.

3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.[1]

Meadows has not altered her conclusions. She still has some optimism that the second outcome can occur if we don't delay too long.[2] Her "optimism" scenario however, is based on the assumption of availability of certain resources:

. . . The list of necessary ingredients is long. . .includes the physical necessities that support all physiological and industrial activity--food, raw materials, fossil and nuclear fuels, and the ecological sytems of the planet which absorb wastes and recycle important basic chemical substances.[3]

The conclusions of this study and the issues raised by others cited in this study show that, perhaps, many of the necessary ingredients for the "optimistic" outcome may not be forthcoming.

Steady-State Economics

Daly has uniquely disconnected himself from mainstream growth economics. With stinging clarity he has challenged the orthodoxy to become concerned with the business of living on a finite Earth.[4]

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[1]Ibid.

[2]Donella H. Meadows, "Limits to Growth Revisited," Cassandra Conference Papers, (College Station, TX: Texas A & M, 1985) Publication pending, and personal conversation with Donella Meadows..

[3]Meadows, et. al., Limits To Growth, Idem, p. 45.

[4]Herman E. Daly, Economics, Ecology, Ethics: Essays Toward a Steady-State, (San Francisco: W. H. Freeman and Company, 1980), pp. 324-325.

By a steady-state Daly means:[1]

1. A constant population of human bodies.

2. A constant population or stock of artifacts (exosomatic capital or extentions of human bodies).

3. The levels at which the two populations are held constant are sufficient for a good life and sustainable for a long future.

4. The rate of throughput of matter-energy by which the two stocks are maintained is reduced to the lowest feasible level. For the population this means that birth rates are equal to death rate at low levels so life expectancy is ;high. For artifacts it means that production equals depreciation at low levels so that artifacts are long lasting, and depletion and pollution are kept low.

Although the author fully endorse Daly's notion of a steady-state as a desireable intermediate goal, it must be recognized that Daly attaches much significance to the linking of the permanent steady-state to energy derived from solar income.

Odum cautioned against expecting too much from solar energy, warning us that:[2]

> Solar energy is very dilute and the inherent energy cost of concentrating solar energy into form for human use has already been maximized by forests and food producing plants. Without energy subsidy there is no yield from the sun beyond the familiar yields from forestry and agriculture.

The results of this study confirm that wind systems (a well-developed, solar-energy technology) are not independent sources of net energy. For solar energy to be a net-energy source (for example, biomass conversion to, say, alcohol) it would be necessary to use agricultural land for both food and energy crops. In such case, global population size must be considerably smaller than 5 billion, because we are

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[1]Ibid.

[2]Howard T. Odum, "Energy, Ecology and Economics, The Whole Earth Epilog, (Baltimore: Penguin Books, 1974), p. 471.

already having difficulty just feeding the current population from available agricultural land, as noted by Brown above.

It is recognized that much of the agricultural land is now used for relatively unnecessary grain production in order to have "high-quality proteins" in the form of beef production. This could be changed by changing reducing the consumption of livestock protein, according to Pimentel:[1]

> More than 3 billion livestock are maintained to supply the animal protein consumed annually in the United States. . . In addition to the large amounts of forage, this livestock population consumes about ten times as much grain as is consumed by the total U. S. human population. . . . Providing plant food for these animals uses land. In fact more than 420 million hectares of land are used to feed the U. S. livestock population forage and grain, and the remainder is in crop production.

Implications

If other energy-transformation technologies (other than nuclear power and wind power) are not independent sources of net energy, then the implications for society are indeed grave. The suspicious technologies would include the following: (1) fossil-fuel mining; secondary and tertiary petroleum-recovery mining; (2) oil-shale mining; (3) tar-sand mining; (4) nuclear-fusion systems ; (5) solar-voltaic systems; (6) geothermal systems; (6) various solar-energy systems; (7) fast-neutron-reactor systems; and (8) hydro-electric systems.

It would seem to be prudent to make this investigation at the earliest possible time. Much net energy that now comes from fossil-fuels is being used in research and development of these uncertain

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[1] David Pimental, et al, "The Potential for Grass-Fed Livestock: Resource Constraints," Science 207 (22 February 1980): 843.

technologies. At the same time, society is squandering much greater amounts for relatively trivial consumption purposes, generally unaware of the implications as it will affect their progeny. These implications include the following selected elements.

Economic Growth

For some time we have measured social progress on the basis of how fast the Gross National Product and Income accounts are growing. The effectiveness of political leadership has been measured by its ability to maintain the growth process. Changing realities would seem to require a new way of measuring the effectiveness of the socio-political-economic apparatus that has so long been tied to the goal of economic growth. Unstable conditions may tempt some to call for central control and stronger police powers to deal with instability, whereas, what would be needed most is decentralized, small-group, decision-making institutions to work out problems that can be dealt with locally. The unstable conditions may lead to increasing levels of crime, and the declining resource base may not leave a sufficient amount to maintain the traditional justice and punishment institutions. New integrating institutions may be necessary to deal with the larger problems.

The goal of economic growth would need to be abandoned as quickly as possible. Daly's "steady-state"[1] would seem to be a desireable intermediate goal. This course change, however, has many serious ramifications because growth economies are conditionally unstable. Many jobs are tied to growth, and substantial unemployment would ensue from zero economic growth. Rising unemployment will cause a decrease in aggregate demand, and a recession, followed by deep economic depression is likely unless some sort of minimum, guaranteed-incomes policy is adopted to assist in the transition. Profit and income expectations would also need to adjust to the new realities of not growing. The political apparatus may be unprepared to deal with the financial instability that is likely to result from declining incomes and tax bases.

Access to Food

The access to food has been intimately interconnected to an agribusiness system which has been heavily dependent on fossil fuels, not only to grow the food, but to package and distribute it in a complex, roundabout way. A declining energy base will, no doubt, alter the patterns of food production and distribution. Suburban, small-town, and rural dwellers should be able to provide a substantial part of their own home-grown food, provided that seed, hand-tool, and water-distribution systems are operational. However, those living in concentrated urban centers would be more vulnerable to any disruption or shortage. No doubt, "have nots" would want to share with those who have access to their own supplies, and the lack of integrating institutions might lead to further instability, tension, and crime. Traditional jobs in the industrial and commercial sectors might have to be shared on the most efficient basis, and the time not spent on the job would need to be devoted to maintenance of dwellings, clothing, and food-growing and preserving activity.

Science and Education

The scientific discoveries of the past several years are awesome. Most are highly-specialized pursuits and only those closely connected to the particular discoveries know very much about them. The many successes have lulled us into believing that we are learning more and more and therefore, opportunities for the good life are increasing accordingly. The conclusions being developed in this study are generally contradictory to that view.

Most of the educational process has been intimately connected to the support of a growing industrial society. If much of the industrial apparatus is not sustainable, then much of the so-called new knowledge may be less useful accordingly. Much of the formal educational process, for example, marketing and advertising, is associated with the encouragement of squandering of precious energy and materials for relatively trivial purposes. Much of the so-called new knowledge in engineering and physics is related to a growing industrial process.

A viable society (one that can continue to replace itself) must take on an educational process that is intimately connected to bio-physical realities. The new leaders in the educational process are likely to be those most intimately familiar with the inter-connected aspects of those bio-physical limitations along with the personal and organizational skills that will be needed to adapt to the changing institutions and lifestyles of the steady-state. This will be a difficult task because the scientific community has generally identified with the "good life" associated with perpetual economic growth.

Environmental Ethics

There has been an underlying presumption on the part of some environmentalists that there is no particular inconsistency between resource conservation and economic growth. There have even been studies to show that conservation technology enhances economic growth. But economic growth, in whatever package, conserves nothing. In fact, all economic activity always depletes energy and materials. Economic goods can only be had by the depletion of finite supplies of energy and materials of the Earth. Not only are Earth materials depleted but other Earth resources are despoiled by the accompanying pollution in lock-step fashion. A declining energy base means less will be available for cleaning up the despoiled part of the Earth. We may also find that cleaning up things has its own set of costs, because a fundamental law of ecology holds that "everything must be somewhere." There is even a limit to recycling because each recyling always results in the loss of energy and materials. As environmentalists, we must recognize that no set of rules or regulations will make the growth process viable, although they (rules and regulations) are vital to the process.

As noted in an earlier chapter, some have argued that the purchase of an energy conservation gadget results in conservation of resources. If the differential savings (resulting from having the conservation gadget) is spent on something else, however, then nothing is conserved. Maximum conservation means maximum abstinence. Few of us are likely to voluntarily follow such an extreme course, but we must recognize this simple fact before we can place ourselves on the course to true energy and materials conservation.

Wendell Berry's observation is noted:[1]

"Energy," said William Blake, "is Eternal Delight." And the

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[1] Wendell Berry, The Unsettling Of America, Agriculture and Culture (San Francisco: Sierra Club Books, 1978).

scientific prognosticators of our time have begun to speak of the eventual opening, for human use, of "infinite" sources of energy.

In speaking of the use of energy, then, we are speaking of an issue of religion, whether we like it or not.

Religion, in the root sense of the word, is what binds us back to the source of life. Blake also said that "Energy is the only life..." And it is superhuman in the sense that humans cannot create it. They can only refine or convert it. And they are bound to it by one of the paradoxes of religion; they cannot have it except by losing it; they cannot use it except by destroying it. The lives that feed us have to be killed before they enter our mouths; we can only use the fossil fuels by burning them up. We speak of electrical energy as "current": it exists only while it runs away; we use it only by delaying its escape. To receive energy is at once to live and to die.

. . .We have two means of bringing energy to use: by living things (plants, animals, our own bodies) and by tools (machines, energy-harnesses). For the use of these we have techniques. All three together comprise our technology. Technology joins us to energy, to life. It is not, as many technologists would have us believe, a simple connection. Our technology is the practical aspect of our culture. By it we enact our religion, or our lack of it. . . .

And yet, in the long term, this liberation of the machine is illusory. Mechanical technology is based on quantities of materials and fuels that are finite. If the prophets of science foresee "limitless abundance" and "infinite resources," one must assume that they are speaking figuratively, meaning simply that they cannot comprehend how much there may be. In that sense, they are right: there are sources of energy that, **given the necessary machinery** [emphasis added], are inexhaustible as far as we can see.

The great difficulty, which these cheerful prophets do not acknowledge at all, is that we are trustworthy only as far as we can see. The length of our vision is our moral boundary.[1]

It is this author's view that some of the "necessary machinery" can be made available only through the further expenditure of what is already generally believed to be finite.

Our moral boundary must be expanded to include not just our own family, country, and continent. It must be expanded to include not

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[1]Ibid.

only the humanity of our own generation and future generations, but to all of the living species of the Earth, now and in the future. The existence of all the species is inextricably entertwined.

Summary

In this chapter, several selected global issues were discussed and related to the issues of the problems of a depleting energy supply; i.e., war, population, food, finite non-fuel resources, water quality and quantity, economic justice, and economic growth. It is the author's position that most of the arguments cited above were made in the context that substituting energy-transformation technologies would fill the gap as the fossil fuels become in short supply.

It is the author's judgement that these problems are closely interactive. For example, as problems develop in nonfuel Earth resources (say, deterioration of ore quality) greater problems will develop in the net-energy picture; hence, cost of agricultural equipment and fertilizers would rise, which would affect water availability, food production, ad infinitum. As these problems develop, social tensions are likely to increase, which bring forth many problems of our industrial-based society with respect to the roles of science, government, and education. New socio-economic-political mechanisms for dealing with new realities may be needed.

Finally, selected philosophical, ethical, and educational issues were discussed in the context of a declining resource base.

CHAPTER 10

SUMMARY

Problem Statement

The introductory chapter outlined the dimensions of the study. The finitude of fossil fuels was discussed. The question of what we are to do as we exhaust these finite resources was addressed. It is the author's view that most economists (hence, most of the citizenry) have carelessly assumed that, as we exhaust fossil-fuel resources, rising prices will trigger the inifinite ingenuity of civilized man to provide himself with all the energy that he would like to have. Mainstream economic thought does not acknowledge any supply limits of Earth esources to include energy resources, non-fuel resources, or Earth carrying-capacity resources.

The specific problem addressed in this study is, Do certain energy-transformation systems provide enough energy to replicate themselves (or equivalent substitutes) and leave a residual amount of energy to provide for other necessary aspects of human civilization such as food, clothing, shelter, health, and enjoyment of life. The two technologies evaluated in this study are nuclear-powered and wind-powered electrical-generating systems. The evidence provided in this study shows that neither of these technologies are likely to be an independent source of net energy.

Discussion of the Study

The study rests on six fundamental assumptions:

First, it is assumed that some minimum amount of net energy is a necessary, but not a sufficient, condition for the continuance of human civilization on the Earth. However, the relative magnitudes of net-energy flow, human population size, and the carrying-capacity of the Earth are not known at this time.

Second, it is assumed that energy is not an ordinary economic commodity for which other classes of commodities may be substituted. Energy is a unique quality in nature which is essential for anything on Earth to occur. Therefore the implicit assumption of infinite substitution among commodities, held by many growth economists, does not hold for energy. The assumption does not hold in the same sense that it does not hold for air, water, food, soil, and so forth. Some substitution may occur within broad classes of air, water, food, soil, and energy, for example, but not between them. Consequently, energy must be treated as a special, essential aspect of nature for which there is no substitution.

Third, it is assumed that the Second Law of Thermodynamics (the entropy law) holds for all times. Stated crudely, the entropy law holds that the transformation of energy from a low-entropy state (order) to a high-entropy state (disorder) is a non-reversible process. Once energy is transformed and the heat is irreversibly dispersed in nature, its recovery is not possible.

Fourth, it is assumed that there is a proportionality between the real prices of goods and services and the amount of energy that was involved in the provision of those goods and services.

Fifth, it is assumed that there is a crude, but identifiable, relationship between per-capita consumption of goods and services and the amount of net energy that can be made available from energy-transformation entities. In other words, it should be possible to increase the net-energy yield from energy-transformation entities by lowering the level of consumption of the human participants. Slavery would be an extreme example of the possibilities.

Sixth, it is assumed that there is some upper boundary of energy-transformation efficiency that is achievable. Engineers usually measure the efficiency of furnaces and fuels without accounting for the energy embodied in providing the furnaces. It should be noted that engineers seem to unwittingly assume that the furnace (and the reactor) are "energy-free goods."

Criticism of Standard Economics

In chapter 2 it was argued that modern growth economists, relying on a macroeconomic theory which assumes infinite-substitution reasoning, do not have a reliable way of knowing whether contemplated energy-transformation entities are viable. A viable energy system is defined as one which is able to reproduce itself (or a viable substitute) and at the same time provide a net surplus of energy to sustain the other essential aspects of life; i. e., food, clothing, shelter, and so forth.

The modern growth economists argue that a market economy provides an environment which will provide adequate incentives, rewards, and information to encourage entrepreneurs to always come forth with new, substituting energy resources as old sources are depleted. It was argued that such reasoning is founded more on faith in technology than on hard, scientific evidence.

No doubt, rising real prices will alter consumer behavior and lead to more efficient use of resources and perhaps even reduce frivolous consumption. However, much more is at issue. Vested interests are continuously being externally subsidized (tax subsidies, research and development grants, and so forth) for the alleged purpose of providing us with an infinite supply of energy resources. Meanwhile, the finite stock of fossil fuels is being depleted at frightening rates and, when considered in an intergenerational sense, for relatively frivolous purposes.

It was argued that it is possible to make a short-run economic profit from energy-transformation activity but, at the same time, not provide net energy. This observation is based on the idea that entrepreneurs are currently using out of existing capital structure and the infrastructure that were provided when energy was cheaper (higher net energy). Current public policy encourages the underevaluation of the stock of Earth resources and existing capital stock. This is manifested through depletion allowances, investment tax credits, accelerated depreciation schedules, tax shelters, ad infinitum.

The economist's cost-benefit test is inadequate for public-policy decisions concerning energy transformation. The real test must be an adequate measurement of the capability of energy-transformation entities to continuously replicate themselves or viable substitutes. It was argued that the current macroeconomic model is inadequate for such strategic (long-term) considerations.

Criticism of Standard Energy Analysis

Faced with such questions, the author searched for a way of estimating the viability of various energy-transformation technologies. Howard T. Odum and others were pessimistic about the prospect of many energy-transformation entities that are being counted on as replacements for the fossil fuels. The author was curious as to whether Odum was correct, and if so, why had he and his followers been generally ignored?

In reviewing the literature it was found that there are a great variety of methodologies being used in Energy Analysis. Mainstream analysts had agreed on a set of conventions for making energy analyses. There has been some agreement on the output side of the balancing equations, but there was much disagreement on what was to be counted as inputs. Mainstream analysts count as inputs (1) the direct burning of fuels (or use of electricity) and (2) the energy embodied in the physical materials that go into the energy-transformation processes. They explicitly exclude the energy embodied in the goods and services consumed by those who receive wages, interest, and taxes.

A case was made in this study that Odum was correct in his argument that there is a proportionality between money and energy flows. Money is a symbol of the rights that society grants to the holders of money to claim a proportionate share of energy-embodied goods and services -- either now or in the future. In addition to payments for fuels and physical materials, payments are also made for labor, financial, and government services under the institutional guarantee that the recipients of that money are entitled to have a proportionate share of the energy-embodied goods and services. None of these goods and services are available except through a proportionate depletion of the Earth's energy and material stocks. Although the energy-embodied goods and services do not always physically flow across a particular energy-transformation company's physical boundary, they do flow across the abstract boundary. Essential to this line of reasoning is the recognition, for example, that, if labor is hired to perform services for the energy-transformation company, they must be paid a wage that will attract them to that activity. It is assumed they are hired only if needed and paid no more than the market demands. The entrepreneur can choose the most economical mix of men and machines based on marginal cost and marginal revenue considerations. However, all of the so-called factors of production (land, labor, capital, and other materials) require a proportionate share of energy to make them available in the transformation process.

The only reason that a company borrows money is for lack of alternatives to finance the project. It must compensate the money lendors for the use of their money. Again, institutionally, the recipients of the interest are entitled to have a proportionate share of energy-embodied goods and services -- either out of the current flow of annual GNP or some future flow of GNP. No GNP flow is available except through a proportionate depletion of Earth's stock of energy and other material resources.

Governments (world, federal, state, county, and local), provide services to the energy-transformation company for which they demand a payment of taxes. The tax revenues are used to purchase energy-embodied goods and services (or hire workers, who in turn purchase energy-embodied goods and services). It is assumed that the government services provided are proportional to the taxes paid.

The reasoning for expanding the system boundary to include labor, government, and financial services is illustrated by the two allegories in chapter 4. In both cases the essentiality of the participants is explicitly recognized. The sustenance of those participants, at whatever lifestyle that is institutionally customary in order to attract them to do the work, is acknowledged. Consequently, the material standard-of-living is a variable and can be altered, either voluntarily, politically, or by price-induced responses to changing economic realities. The current (1985) famine in Ethiopia and some twenty other countries of the world is an example of political and market responses to changing resource realities. As noted above, the lifestyles of the human participants can be lowered and the net-energy yield increased accordingly.

Net Energy Models

Following Odum's and Costanza's energy-money proportionality hypothesis, an estimate of this relationship was made by dividing annual GNP into annual energy consumption for data from 1947 to 1983. In chapter 5, it was shown that it took 35,791 Btu's of energy to produce each dollar's worth of real Gross National Product ($1979 = 100), 28,266 Btu's per 1982 dollar, or 28,116 Btu's per 1983 dollar. The years 1979 and 1982 were chosen because two sets of data for nuclear power plant costs were already available and were expressed in 1979 and 1982 dollars respectively. The wind-systems costs are in 1983 dollars and the Energy/GNP Ratio (28,116 Btu's/$1983) is used accordingly. Strong support was provided for this practice. It was pointed out that most prior energy analyses accounted for only a part of the energy-inputs to the provision of Generating Plant and did not account for Other Plant Costs, which include costs of transmission and distribution, among others. Sensitivity analyses were done at the largest and smallest values of the Energy/GNP Ratio data base (see chapter 5 and appendix A.)

Chapter 6 provided the basis for choosing a 50 per cent Efficiency Factor in the net-energy analyses. It was pointed out that most energy analyses had been for isolated systems without considering the environment in which they existed. A single transformation entity cannot be given credit for its performance in isolation when secondary systems are needed to provide energy when the primary is out of service for maintenance and refueling. It was pointed out that the overall efficiency of the combined large utility systems had fallen from 57 per cent in 1979 to 40 per cent in 1983. Therefore, the use of a 50 per cent Efficiency Factor was robust accordingly. Also in chapter 6, preliminary evidence was introduced to show that the introduction of large nuclear systems seems to have contributed to a declining efficiency of large United States utilities.

Two general types of Energy Analysis were done: (1) Static Net Energy Analysis, which refers to the total output-energy produced over the lifecycle of a single energy-transformation entity versus the amount of input-energy related to that single entity, i.e., subtracting total input-energy from total output-energy and (2) Dynamic Net Energy Analysis, which refers to the relationship of output-energy to input-energy involved with constructing, operating, and disposing of large systems of individual entities and measuring the net energy of the entire system at various points in time .

Unique Approach

This study is different from most previous studies in the following ways:

First, as discussed above, most standard energy analyses have counted as inputs only the direct energy depletion of fuels (and electricity) and the indirect energy involved in the use of physical materials. The energy costs of labor, government, and financial services have been omitted in previous studies. The procedure followed in this study is to add up the total economic cost of the complete system, multiply the total times a constant (Energy/GNP Ratio), and compare the estimated lifecycle-output to the estimated lifecycle energy-input. The cost of labor is included in the direct cost of constructing and operating the energy facilities. The costs government services and the payments of interest interest, as well as the cost of financial services, are captured through the Fixed-Charge Cost.

Second, most analyses have been for Generating Plant (Production Plant), only. It was argued that electrical energy is not useful until it is transmitted and distributed to the end-users. Further, all Other Plant and Equipment is presumed essential to the operation of the electrical generation, transmission, and distribution entity -- otherwise it is assumed that it would not have been purchased. Therefore, a substantial amount of the energy cost that has been left out of previous studies has been included in this study. Consequently, the findings of this study are substantially different from those of most other studies, except those associated with the Odum school of analysis.

Net Energy Analysis of Nuclear Power

Static Net Energy Analysis

Static Net Energy Analysis shows the amount of net energy from one transformation entity over its lifecycle without respect to any other system. The analytical model (table 7.1) was applied to all 46 nuclear plants in the Komanoff 1981 data base, and summary results are shown in table 7.4. Plants in the 1981 data base were listed in order of the relative date of the issuance of the respective construction permits. Plants completed at a later date had smaller Output/Input Ratios than those completed earlier. Table 7.1 showed the results of static analysis of the Komanoff Base-Case-type plant based on costs typical of plants he thought (1981 report) would be coming on line in the central United States in 1988. The static Output/Input Ratio of a Base-Case plant was found to be only 1.0242 to 1. In other words, the output-energy would be only about 2.4 per cent more than the input-energy.

In 1984, Komanoff published cost estimates for 34 more plants. These latter estimates are more indicative of what future costs are likely to be. Static net-energy analyses were calculated for the 34-plant set and are shown in table 7.9. The static model was slightly changed to include plant "retrofitting." Based on an Energy/GNP Ratio of 28,266 Btu's/$1982, using Static Net Energy Analysis, 10 plants show some positive net energy and 5 plants have "break even" ratios; i.e., they use as much energy as they produce. The remaining 19 plants are clearly net energy consumers, even under static analysis.

Lowering the Energy/GNP Ratio to 21,333 Btu's/$1982 results in 15 additional plants showing a small amount of positive net energy under static analysis. However, even then, the dynamic results are not favorable.

Dynamic Net Energy Analysis

Dynamic Net Energy Analysis estimates the potential net energy from the development, construction, operation, and continuing disposal of worn-out units of a large energy-transformation system. A system will not yield positive net energy unless the individual entities show substantial positive net energy; therefore, the Bellefonte twin-reactor system, showing a static Output/Input Ratio of 1.2256 to 1, was chosen for hypothetical analysis.

Table 7.7 showed the estimated net energy that might be forthcoming from a large system of Bellefonte-type plants (expected to come on line in 1988). An analysis of a system that involved the starting of 52 new plants each year for 50 years was done. Under such a program, after 50 years, construction would have started on 2,600 plants, 1,560 would have been continuously operated, and 572 would have been decommissioned. The average (mean) annual net-energy yield of the system, over the 50-year period, would be 1.02 quads.

A 100-year analysis shows that the average (mean), annual output increases to 5.1289 quads per year (about one tenth of our current net-energy consumption rate). In the hundred years, construction would have been undertaken of over 5,000 nuclear plants, and over 3,172 would require decommissioning.

Increasing the annual construction rate to 1,000 per year increases the net-energy yield to about 35 quads of net energy per year. The reader must bear in mind that the foregoing Dynamic Net Energy Analysis is based on the speculation that nuclear-power costs would be $1113 per-kilowatt ($1982), or less -- a very unlikely prospect. None of the studies include the cost of disposal of residual radioactive wastes. Further, decommissioning costs may larger than assumed.

Wind System Results

A summary of the results of the Wind Energy Conversion System (WECS) analyses is shown in table 8.2 and individual analyses of each type of system are shown in appendix C.

The analytical models used for wind systems are based on the same general models used for Nuclear Power System Analysis in chapter 7. The net-energy performance of wind-powered systems is highly dependent on the average wind speed available at a particular site and the economic cost of the units. Based on the models adapted for this study, the results show that wind systems now being marketed in the United States are not independent sources of net energy but are being subsidized by other sources of net energy.

Table 8.2 shows that none of the wind systems provide positive net energy with average, annual wind speeds of 12 miles per hour or less under the full-cost considerations (assumed Energy/GNP Ratio of 28,116 Btu's/$1983). Even if costs are reduced 25 per cent from their 1983 reported costs, only the Energy Sciences 200-kilowatt WECS shows a small amount of net energy. Three systems show a small amount of net energy if plant costs are reduced 25 per cent and Other Plant (transmission and distribution) costs are not included as an energy cost.

Sensitivity analyses were done. Three additional systems show some positive net energy under static analysis using an Energy/GNP Ratio of 21,333 Btu's/$1983. These results also assume that costs can be reduced 50 per cent (25 per cent reduction in capital cost and no charge for transmission and distribution). The Energy/GNP Ratio of 21,333/$1983 is the smallest ratio in the 37-year data base of appendix A. If the largest Energy/GNP Ratio (34,172 Btu's/$1983) is used, only the Energy Sciences shows positive, static, net energy.

Using the Energy Sciences 200-kilowatt system (cost $712.50 per kilowatt and no charge for transmission and distribution) as a typical system, a 50-year dynamic net-energy analysis shows that a construction program of 500,000 units per year would yield an average (mean), annual net-energy yield of 1.2910 quads. The annual average increases to 1.8162 quads per year over a 100-year period. The issue of available space, with appropriate wind conditions, was also raised. Construction sites where the wind exceeds 12 miles per hour are limited.

Implications and Interconnected Problems

In chapter 9, the issue was again raised, as to what society was going to do as we depleted the fossil fuels which provide our current supplies of net energy. The probable time scale for depletion of these fuels was reviewed. It was pointed out that the author believes that society has been lulled into a false sense of security by the current (1985) glut of fossil fuels.

This study showed that two of the energy-transformation technologies that society has been counting on as replacements for the fossil fuels will not be independent sources of energy unless costs can be substantially lowered or efficiences materially improved.

Although there is little doubt that the fossil fuels are in finite supply, there is much doubt (on the author's part) as to whether other technologies besides nuclear and wind power would yield net energy, and if so, how much. These other technologies would include solar-voltaic systems, geothermal-energy systems, various forms of solar technology, breeder-reactor systems, and fusion energy systems. Also, similiar net-energy analyses need to be done for so-called fossil-fuel recovery processes such as: deep-gas mining, oil-shale mining, tar-sands mining, and secondary and tertiary petroleum mining processes. The analysis of hydro-electricity generating systems will be a high priority research project for the author.

The author believes (based on preliminary crude calculations) that many of these other technologies will not fair much better than nuclear or wind, although this must be confirmed through careful investigation. It is the author's view, however, that as fossil-fuel supplies are depleted, the problem of energy supply in the form needed to support a growing industrial economy will be considerable.

The implications of a dwindling energy supply, resulting from the exhaustion of fossil fuels, were related to certain, selected global problems that have already been made known. It was argued that most of the problems cited would be greatly exacerbated by a dwindling energy supply situation. It was pointed out that problems of this sort are interconnected and that as one problem becomes greater, it affects the others and there are feedbacks which work their way through in first, second, and third-order effects among each other.

Several personal observations were also made with respect to the political, educational, and ethical implications.

Conclusions

At the current state-of-the-art (hence, economic cost), neither a nuclear-powered nor wind-powered electricity-generating system is an independent source of net energy. There is a strong likelihood that similar findings would hold for other energy-transformation technologies.

If none of the other energy-transformation technologies meet the viability test of being able to replicate themselves out of their own energy and leave a sufficient residual to meet societal needs, then the implications for human civilization are ominous. Schumacher notes:[1]

> You can go on and on blowing air into a balloon. The balloon then becomes bigger and bigger, and more and more impressive.
>
> Historians can record with pride and satisfaction the dates when the first efficient pump was invented, and then ever more efficient pumps, and marvelous new chemicals which increased the stretchability of the balloon, and when the balloon reached a certain size, and then twice that size, and how "doubling times" became shorter and shorter and so on.
>
> All these will be important and interesting dates. But none so important and interesting as the date when a hole appeared in the skin of the balloon -- perhaps, to start with, quite a small hole -- and the air started whistling out.
>
> That date was October 6, 1973.
>
> Things will never be the same again.

---

[1]E. F. Schumacher, Good Work,(New York, Hagerstown, San Francisco, London: 1979), p.5. Schumacher was referring to the announcement by OPEC on curtailment of oil production.

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APPENDIX A.1

This appendix shows the method of arriving at the Energy/GNP coefficients used in the net-energy analyses of this study. Table A-5 also shows the amount of investment that United States utilites make in Other Plant, i.e., other than Production Plant.

Table A-1, column E, shows the raw data for nominal gross national product (GNP). The 1972 implicit price deflators are shown in Column C. For example, the base year was changed to a 1979 base year by dividing the 1979 index number into each of the 1972 = 100 index numbers and the results are shown in Column D. Gross National Product ($1979 = 100) is then obtained by dividing nominal GNP (Column E) by the index numbers in Column D and the results are shown in Column F. To obtain the Energy/GNP Ratios of column G, Annual Energy Consumption (Column B) was divided by Gross National Product (Column F) for each year, respectively.

Table A-1 shows the ratios for the base year for Gross National Product for the year 1979. Table A-2 shows the same information for the year 1982 as the base year. Table A-3 shows ratios with 1983 as the base year. Table A-4 shows ratios with 1972 as the base year.

Table A-1
ENERGY/GNP RATIOS (1979=100)

(A) YEAR	(B) BTU'S CONSUMED	(C) 1972=100 DEFLATOR	(D) 1979=100 DEFLATOR	(E) CURRENT GNP	(F) 1979=100 GNP	(G) ENERGY/GNP RATIO
1947	3.305e16	49.70	30.41	2.313e11	7.604e11	43461.00
1948	3.388e16	53.13	32.51	2.576e11	7.922e11	42764.68
1949	3.108e16	52.59	32.18	2.565e11	7.969e11	38998.21
1950	3.362e16	53.64	32.82	2.848e11	8.675e11	38752.02
1951	3.611e16	57.27	35.04	3.284e11	9.369e11	38538.91
1952	3.583e16	58.00	35.49	3.455e11	9.733e11	36810.75
1953	3.676e16	58.88	36.03	3.646e11	1.011e12	36330.76
1954	3.573e16	59.69	36.52	3.648e11	9.986e11	35778.96
1955	3.917e16	60.98	37.31	3.980e11	1.066e12	36728.72
1956	4.075e16	62.90	38.49	4.192e11	1.088e12	37420.09
1957	4.080e16	65.02	39.79	4.411e11	1.108e12	36805.94
1958	4.065e16	66.06	40.42	4.473e11	1.106e12	36740.76
1959	4.241e16	67.52	41.32	4.837e11	1.170e12	36230.35
1960	4.375e16	68.67	42.02	5.070e11	1.206e12	36264.78
1961	4.441e16	68.28	41.78	5.201e11	1.244e12	35680.86
1962	4.648e16	70.55	43.17	5.603e11	1.297e12	35817.10
1963	4.827e16	71.59	43.81	5.905e11	1.347e12	35814.40
1964	5.044e16	72.71	44.49	6.324e11	1.421e12	35491.57
1965	5.262e16	74.32	45.48	6.910e11	1.519e12	34635.89
1966	5.559e16	76.76	46.97	7.499e11	1.596e12	34823.80
1967	5.750e16	79.02	48.35	7.939e11	1.641e12	35025.71
1968	6.094e16	82.57	50.53	8.642e11	1.710e12	35633.49
1969	6.412e16	86.72	53.07	9.303e11	1.752e12	36579.49
1970	6.636e16	91.36	55.91	9.930e11	1.776e12	37364.67
1971	6.782e16	96.02	58.76	1.063e12	1.809e12	37477.51
1972	7.119e16	100.00	61.19	1.171e12	1.913e12	37202.57
1973	7.421e16	105.80	64.74	1.326e12	2.047e12	36237.02
1974	7.248e16	116.02	71.00	1.434e12	2.019e12	35888.04
1975	7.048e16	125.80	76.98	1.549e12	2.011e12	35030.23
1976	7.430e16	132.30	80.96	1.718e12	2.121e12	35016.55
1977	7.621e16	140.10	85.74	1.918e12	2.236e12	34068.21
1978	7.804e16	150.40	92.04	2.164e12	2.351e12	33193.70
1979	7.884e16	163.40	100.00	2.418e12	2.418e12	32605.45
1980	7.590e16	178.40	109.17	2.632e12	2.410e12	31484.63
1981	7.394e16	195.10	119.40	2.954e12	2.474e12	29886.43
1982	7.082e16	206.90	126.62	3.073e12	2.426e12	29181.10
1983	7.045e16	208.00	127.29	3.305e12	2.596e12	27134.43

Notes: Source of Column A, Annual Energy Review, DOE/EIA 0384 (83), April 1984, Table 3, p.9.
Source of Column E, Survey of Current Business.
Column D = Column C divided by 163.40 (1979=100 index).
Column F = Column E divided by Column D.
Column G = Column B divided by Column F.
Notation "e16" means decimal pt. is 16 spaces to the right.

Table A-2

ENERGY/GNP RATIOS (1982=100)

YEAR	ANN. ENERGY CONSUMPTION	1972=100 DEFLATOR	1979=100 DEFLATOR	CURRENT GNP	1982=100 GNP	ENERGY/GNP RATIO
1947	3.305e16	49.70	24.02	2.313e11	9.628e11	34323.51
1948	3.388e16	53.13	25.67	2.576e11	1.003e12	33773.56
1949	3.108e16	52.59	25.41	2.565e11	1.009e12	30798.97
1950	3.362e16	53.64	25.92	2.848e11	1.098e12	30604.55
1951	3.611e16	57.27	27.68	3.284e11	1.186e12	30436.24
1952	3.583e16	58.00	28.03	3.455e11	1.232e12	29071.42
1953	3.676e16	58.88	28.45	3.646e11	1.281e12	28692.35
1954	3.573e16	59.69	28.84	3.648e11	1.264e12	28256.55
1955	3.917e16	60.98	29.47	3.980e11	1.350e12	29006.64
1956	4.075e16	62.90	30.40	4.192e11	1.378e12	29552.65
1957	4.080e16	65.02	31.42	4.411e11	1.403e12	29067.62
1958	4.065e16	66.06	31.92	4.473e11	1.400e12	29016.14
1959	4.241e16	67.52	32.63	4.837e11	1.482e12	28613.04
1960	4.375e16	68.67	33.18	5.037e11	1.517e12	28827.87
1961	4.441e16	68.28	33.00	5.201e11	1.575e12	28179.08
1962	4.648e16	70.55	34.09	5.603e11	1.643e12	28286.68
1963	4.827e16	71.59	34.60	5.905e11	1.706e12	28284.54
1964	5.044e16	72.71	35.14	6.324e11	1.799e12	28029.59
1965	5.262e16	74.32	35.92	6.849e11	1.906e12	27597.44
1966	5.559e16	76.76	37.10	7.499e11	2.021e12	27502.22
1967	5.750e16	79.02	38.19	7.939e11	2.078e12	27661.68
1968	6.094e16	82.57	39.90	8.642e11	2.165e12	28141.67
1969	6.412e16	86.72	41.91	9.303e11	2.219e12	28888.78
1970	6.636e16	91.36	44.15	9.640e11	2.183e12	30396.59
1971	6.782e16	96.02	46.40	1.077e12	2.320e12	29224.24
1972	7.119e16	100.00	48.33	1.171e12	2.423e12	29380.86
1973	7.421e16	105.80	51.13	1.326e12	2.593e12	28618.31
1974	7.248e16	116.02	56.07	1.434e12	2.557e12	28342.71
1975	7.048e16	125.80	60.80	1.549e12	2.547e12	27665.25
1976	7.430e16	132.30	63.94	1.718e12	2.686e12	27654.44
1977	7.621e16	140.10	67.71	1.918e12	2.832e12	26905.49
1978	7.804e16	150.40	72.69	2.154e12	2.963e12	26336.55
1979	7.884e16	163.40	78.97	2.418e12	3.061e12	25750.27
1980	7.590e16	178.40	86.22	2.632e12	3.052e12	24865.10
1981	7.394e16	195.10	94.29	2.954e12	3.132e12	23602.91
1982	7.082e16	206.90	100.00	3.073e12	3.073e12	23045.88
1983	7.045e16	208.00	100.53	3.304e12	3.286e12	21436.00
					MEAN VALUE:	28265.88

Notes: Source of Column A, Annual Energy Review, DOE/EIA 0384 (83), April 1984, Table 3, p.9.
Source of Column E, Survey of Current Business.
Column D = Column C divided by 206.90 (1982=100 deflator).
Column F = Column E divided by Column D.
Column G = Column B divided by Column F.
Notation "e12" means decimal pt. is 12 spaces to the right.

Table A-3
ENERGY/GNP RATIOS (1983=100)

(A) YEAR	(B) BTU'S CONSUMED	(C) 1972=100 DEFLATOR	(D) 1983=100 DEFLATOR	(E) CURRENT GNP	(F) 1983=100 GNP	(G) ENERGY/GNP RATIO
1947	3.305e16	49.70	23.89	2.313e11	9.680e11	34141.99
1948	3.388e16	53.13	25.54	2.576e11	1.008e12	33594.95
1949	3.108e16	52.59	25.28	2.565e11	1.014e12	30636.09
1950	3.362e16	53.64	25.78	2.848e11	1.104e12	30442.69
1951	3.611e16	57.27	27.53	3.284e11	1.192e12	30275.28
1952	3.583e16	58.00	27.88	3.455e11	1.239e12	28917.67
1953	3.676e16	58.88	28.30	3.646e11	1.287e12	28540.61
1954	3.573e16	59.69	28.69	3.648e11	1.271e12	28107.12
1955	3.917e16	60.98	29.31	3.980e11	1.357e12	28853.23
1956	4.075e16	62.90	30.24	4.192e11	1.386e12	29396.36
1957	4.080e16	65.02	31.25	4.411e11	1.411e12	28913.90
1958	4.065e16	66.06	31.75	4.473e11	1.408e12	28862.69
1959	4.241e16	67.52	32.46	4.837e11	1.490e12	28461.72
1960	4.375e16	68.67	33.01	5.037e11	1.525e12	28675.42
1961	4.441e16	68.28	32.82	5.201e11	1.584e12	28030.06
1962	4.648e16	70.55	33.91	5.603e11	1.651e12	28137.09
1963	4.827e16	71.59	34.41	5.905e11	1.715e12	28134.96
1964	5.044e16	72.71	34.95	6.324e11	1.809e12	27881.36
1965	5.262e16	74.32	35.73	6.849e11	1.916e12	27451.49
1966	5.559e16	76.76	36.90	7.499e11	2.032e12	27356.77
1967	5.750e16	79.02	37.99	7.939e11	2.089e12	27515.39
1968	6.094e16	82.57	39.69	8.642e11	2.176e12	27992.85
1969	6.412e16	86.72	41.69	9.303e11	2.231e12	28736.00
1970	6.636e16	91.36	43.92	9.640e11	2.194e12	30235.84
1971	6.782e16	96.02	46.16	1.077e12	2.333e12	29069.69
1972	7.119e16	100.00	48.07	1.171e12	2.435e12	29225.48
1973	7.421e16	105.80	50.86	1.326e12	2.606e12	28466.96
1974	7.248e16	116.02	55.77	1.434e12	2.570e12	28192.82
1975	7.048e16	125.80	60.48	1.549e12	2.561e12	27518.94
1976	7.430e16	132.30	63.60	1.718e12	2.701e12	27508.19
1977	7.621e16	140.10	67.35	1.918e12	2.847e12	26763.20
1978	7.804e16	150.40	72.30	2.154e12	2.978e12	26197.27
1979	7.884e16	163.40	78.55	2.418e12	3.077e12	25614.09
1980	7.590e16	178.40	85.76	2.632e12	3.068e12	24733.60
1981	7.394e16	195.10	93.79	2.954e12	3.149e12	23478.09
1982	7.082e16	206.90	99.47	3.073e12	3.089e12	22924.00
1983	7.045e16	208.00	100.00	3.304e12	3.304e12	21322.63
					MEAN VALUE:	28116.39

Notes:Source of Column A, Annual Energy Review, DOE/EIA 0384 (83),
Source of Column E, Survey of Current Business.
Column D = Column C divided by 208.00 (1983=100 index).
Column F = Column E divided by Column D.
Column G = Column B divided by Column F.
Notation "e16" means decimal pt. is 16 spaces to the right.

Table A-4

ENERGY/GNP RATIOS (1972=100)

(A) YEAR	(B) ANN. ENERGY CONSUMPTION	(C) CURRENT GNP	(D) 1972=100 DEFLATOR	(E) GNP 1972=100	(F) E/GNP RATIO
1947	3.305e16	2.31e11	49.70	4.65e11	71015.34
1948	3.388e16	2.57e11	53.13	4.84e11	69877.50
1949	3.108e16	2.56e11	52.59	4.87e11	63723.08
1950	3.362e16	2.84e11	53.64	5.30e11	63320.81
1951	3.611e16	3.28e11	57.27	5.73e11	62972.58
1952	3.583e16	3.45e11	58.00	5.95e11	60148.76
1953	3.676e16	3.64e11	58.88	6.19e11	59364.47
1954	3.573e16	3.64e11	59.69	6.11e11	58462.82
1955	3.917e16	3.98e11	60.98	6.52e11	60014.73
1956	4.075e16	4.19e11	62.90	6.66e11	61144.44
1957	4.080e16	4.41e11	65.02	6.78e11	60140.92
1958	4.065e16	4.47e11	66.06	6.77e11	60034.40
1959	4.241e16	4.83e11	67.52	7.16e11	59200.39
1960	4.375e16	5.03e11	68.67	7.33e11	59644.87
1961	4.441e16	5.20e11	68.28	7.61e11	58302.53
1962	4.648e16	5.60e11	70.55	7.94e11	58525.14
1963	4.827e16	5.90e11	71.59	8.24e11	58520.73
1964	5.044e16	6.32e11	72.71	8.69e11	57993.23
1965	5.262e16	6.84e11	74.32	9.21e11	57099.11
1966	5.559e16	7.49e11	76.76	9.76e11	56902.09
1967	5.750e16	7.93e11	79.02	1.00e12	57232.01
1968	6.094e16	8.64e11	82.57	1.04e12	58225.13
1969	6.412e16	9.30e11	86.72	1.07e12	59770.89
1970	6.636e16	9.64e11	91.36	1.05e12	62890.55
1971	6.782e16	1.07e12	96.02	1.12e12	60464.96
1972	7.119e16	1.17e12	100.00	1.17e12	60789.00
1973	7.421e16	1.32e12	105.80	1.25e12	59211.29
1974	7.248e16	1.43e12	116.02	1.23e12	58641.07
1975	7.048e16	1.54e12	125.80	1.23e12	57239.40
1976	7.430e16	1.71e12	132.30	1.29e12	57217.05
1977	7.621e16	1.91e12	140.10	1.36e12	55667.47
1978	7.804e16	2.15e12	150.40	1.43e12	54490.32
1979	7.884e16	2.41e12	163.40	1.47e12	53277.32
1980	7.590e16	2.63e12	178.40	1.47e12	51445.89
1981	7.394e16	2.95e12	195.10	1.51e12	48834.44
1982	7.082e16	3.07e12	206.90	1.48e12	47681.93
1983	7.045e16	3.30e12	208.00	1.58e12	44351.08
			MEAN VALUE:		58482.10

Notes: Source of Column A, Annual Energy Review, DOE/EIA 0384 (83),
Source of Column E, Survey of Current Business.
Column D = Column C divided by 163.40 (1979=100 index).
Column F = Column E divided by Column D.
Column G = Column B divided by Column F.
Notation "e16" means decimal pt. is 16 spaces to the right.

Other Plant Data

The following table shows that utilities actually spend more on other plant than on production (generating plant). The net-energy calculations for this paper assume that production plant costs will increase as a per cent of total costs because of the increasing per-kilowatt cost of nuclear power plants. A simple linear trend analysis shows (Col A = Independent variable and Column F as dependent variable) projects the per cent as approximately 172 for the year 2000. This means that the relationship does not appear to be changing.

Table A-5

OTHER PLANT DATA
COMPARE PRODUCTION PLANT TO OTHER PLANT

(A) YEAR	(B) TOTAL PLANT	(C) PRODUCTION PLANT	(D) OTHER PLANT	(E) OTHER PLANT %	(F) OTHER/PROD %
1983	348752263	129296739	219455524	62.92	169.73
1982	321981535	117504517	204477018	63.50	174.01
1981	292747275	108629438	184117837	62.89	169.49
1980	266921691	100264723	166656968	62.43	166.21
1979	242312389	89381817	152930572	63.11	171.09
1978	218001011	83449236	134551775	61.72	161.23
1977	196814920	74645789	122169131	62.07	163.66
1976	177711410	66054451	111656959	62.83	169.03
1975	160711410	60050694	100660716	62.63	167.62
1974	146581033	53581033	93000000	63.44	173.56
				MEAN =	168.56

Source: Statistics of Privately-Owned Electrical Utilities, 1983. Energy Information Administration. (Washington, D. C.: Superintendent of Documents, U. S. G. P. O., DOE/EIA/0044 (1983)

Notes: Columns B, C, and D are raw Data from source.
Column E shows Other plant as a per cent of total.
Column F shows Other plant as a per cent of Production Plant.

Appendix A.2

NET-ENERGY, UNITED STATES FOSSIL-FUEL PRODUCTION

Order-of-magnitude calculations have been made to estimate the amount of energy is being fed back into the acquisition of fossil fuels are on the following tables of this section.

Basic information is taken from the Department of Energy, 1983 Annual Energy Review.[1] Value of Fossil Fuel Production is taken from Table 17[2] and Production of Energy by Source is taken from Table 2.[3]

All values are in 1972 dollars. Energy/GNP coefficients were calculated using GNP ($1972=100) and energy consumption data for respective years. The calculations are shown in table A-5 of appendix A.1

The Energy/GNP coefficient of 60,789 Btu's per dollar is obtained by dividing 1972 annual energy consumption (7.119e16[4] Btu's) by the 1972 Gross National Product (1.171e12 dollars $1972). This coefficient was then multiplied times the value of the yearly energy produced to obtain the Energy-Input estimates for each fossil fuel. Finding net energy was a matter of subtracting the Energy-Input estimate from the total amount of fossil fuel produced.

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[1] Annual Energy Review, Department of Energy, Energy Information Agency, DOE/EIA-0384(83), [April 1984].

[2] Ibid, p. 37.

[3] Ibid, p. 7.

[4] The notation "e16," for example means that the decimal point is actually 16 places to the right of where it is shown.

Table A-6

NET ENERGY FROM UNITED STATES PETROLEUM PRODUCTION

(A) YEAR	(B) VAL. OF OIL PRODUCTION	(C) EST INPUT ENERGY	(D) BTU'S OIL PRODUCED	(E) NET ENERGY	(F) RATIO COL C/ COL D
1949	8.920e09	5.422e14	1.068e16	1.013e16	0.050
1950	9.240e09	5.616e14	1.145e16	1.088e16	0.049
1951	9.970e09	6.060e14	1.304e16	1.243e16	0.046
1952	1.000e10	6.078e14	1.328e16	1.267e16	0.045
1953	1.074e10	6.528e14	1.367e16	1.301e16	0.047
1954	1.081e10	6.571e14	1.343e16	1.277e16	0.048
1955	1.131e10	6.875e14	1.441e16	1.372e16	0.047
1956	1.163e10	7.069e14	1.518e16	1.447e16	0.046
1957	1.246e10	7.574e14	1.518e16	1.442e16	0.049
1958	1.116e10	6.784e14	1.420e16	1.352e16	0.047
1959	1.105e10	6.717e14	1.493e16	1.425e16	0.044
1960	1.080e10	6.565e14	1.493e16	1.427e16	0.043
1961	1.093e10	6.644e14	1.521e16	1.454e16	0.043
1962	1.099e10	6.680e14	1.552e16	1.485e16	0.043
1963	1.111e10	6.753e14	1.597e16	1.529e16	0.042
1964	1.103e10	6.705e14	1.616e16	1.548e16	0.041
1965	1.096e10	6.662e14	1.652e16	1.585e16	0.040
1966	1.136e10	6.905e14	1.756e16	1.686e16	0.039
1967	1.188e10	7.221e14	1.865e16	1.792e16	0.038
1968	1.186e10	7.209e14	1.931e16	1.858e16	0.037
1969	1.201e10	7.300e14	1.956e16	1.882e16	0.037
1970	1.224e10	7.440e14	2.040e16	1.965e16	0.036
1971	1.220e10	7.416e14	2.003e16	1.928e16	0.037
1972	1.171e10	7.118e14	2.004e16	1.932e16	0.035
1973	1.236e10	7.513e14	1.949e16	1.873e16	0.038
1974	1.912e10	1.162e15	1.857e16	1.740e16	0.062
1975	1.864e10	1.133e15	1.773e16	1.659e16	0.063
1976	1.841e10	1.119e15	1.726e16	1.614e16	0.064
1977	1.841e10	1.119e15	1.745e16	1.633e16	0.064
1978	1.901e10	1.155e15	1.843e16	1.727e16	0.062
1979	2.414e10	1.467e15	1.810e16	1.663e16	0.081
1980	3.807e10	2.314e15	1.825e16	1.593e16	0.126
1981	5.094e10	3.096e15	1.815e16	1.505e16	0.170
1982	4.352e10	2.645e15	1.831e16	1.566e16	0.144
1983	3.819e10	2.321e15	1.832e16	1.599e16	0.126

Note: The notation 1.599e16, for example, is engineering notation where 'e16' means decimal point is actually 16 places to the right.

Column B is taken from Table 17, DOE/EIA-0384(83)
Column C is Column By multiplied by 60,789 Btu/$
Column D is taken from Table 2, DOE/EIA-0834(83)
Column E is column D minus column C
Column F is column C divided by column D

Table A-7

NET ENERGY FROM UNITED STATES NATURAL GAS PRODUCTION

(A) YEAR	(B) $ VALUE OF CONSUMPTION	(C) EST. INPUT ENERGY	(D) BTU N.G. PRODUCED	(E) NET ENERGY	(F) RATIO COL C/ COL D
1949	6.300e08	3.829e13	5.380e15	5.341e15	0.007
1950	8.200e08	4.984e13	6.230e15	6.180e15	0.008
1951	9.100e08	5.531e13	7.420e15	7.364e15	0.007
1952	1.100e09	6.686e13	7.960e15	7.893e15	0.008
1953	1.290e09	7.841e13	8.340e15	8.261e15	0.009
1954	1.460e09	8.875e13	8.680e15	8.591e15	0.010
1955	1.550e09	9.422e13	9.630e15	9.535e15	0.009
1956	1.770e09	1.075e14	1.000e16	9.892e15	0.010
1957	1.800e09	1.094e14	1.061e16	1.050e16	0.010
1958	2.000e09	1.215e14	1.094e16	1.081e16	0.011
1959	2.320e09	1.410e14	1.195e16	1.180e16	0.011
1960	2.610e09	1.586e14	1.266e16	1.250e16	0.012
1961	2.870e09	1.744e14	1.310e16	1.292e16	0.013
1962	3.140e09	1.908e14	1.372e16	1.352e16	0.013
1963	3.290e09	1.999e14	1.451e16	1.431e16	0.013
1964	3.200e09	1.945e14	1.530e16	1.510e16	0.012
1965	3.460e09	2.103e14	1.578e16	1.556e16	0.013
1966	3.580e09	2.176e14	1.701e16	1.679e16	0.012
1967	3.680e09	2.237e14	1.794e16	1.771e16	0.012
1968	3.740e09	2.273e14	1.907e16	1.884e16	0.011
1969	4.060e09	2.468e14	2.045e16	2.020e16	0.012
1970	4.080e09	2.480e14	2.167e16	2.142e16	0.011
1971	4.220e09	2.565e14	2.228e16	2.202e16	0.011
1972	4.280e09	2.601e14	2.221e16	2.194e16	0.011
1973	4.710e09	2.863e14	2.219e16	2.190e16	0.012
1974	5.630e09	3.422e14	2.121e16	2.086e16	0.016
1975	7.190e09	4.370e14	1.964e16	1.920e16	0.022
1976	8.740e09	5.312e14	1.968e16	1.914e16	0.026
1977	1.130e10	6.869e14	1.957e16	1.888e16	0.035
1978	1.209e10	7.349e14	1.949e16	1.875e16	0.037
1979	1.478e10	8.984e14	2.008e16	1.918e16	0.044
1980	1.799e10	1.093e15	1.991e16	1.881e16	0.054
1981	2.025e10	1.230e15	1.970e16	1.846e16	0.062
1982	2.202e10	1.338e15	1.825e16	1.691e16	0.073
1983	1.999e10	1.215e15	1.634e16	1.512e16	0.074

Note: The notation 1.299e10, for example, is engineering notation where 'e10' means decimal point is actually 10 places to the right.

Column B is taken from Table 17, DOE/EIA-0384(83)
Column C is Column By multiplied by 60,789 Btu/$
Column D is taken from Table 2, DOE/EIA-0834(83)
Column E is column D minus column C
Column F is column C divided by column D

Table A-8

NET ENERGY FROM UNITED STATES COAL PRODUCTION

(A) YEAR	(B) VAL. COAL PRODUCED	(C) EST INPUT ENERGY	(D) BTU/COAL PRODUCED	(E) NET ENERGY	(F) RATIO COL C/ COL D
1949	4.080e09	2.480e14	1.253e16	1.228e16	0.019
1950	4.670e09	2.838e14	1.462e16	1.433e16	0.019
1951	4.610e09	2.802e14	1.504e16	1.475e16	0.018
1952	3.950e09	2.401e14	1.323e16	1.298e16	0.018
1953	3.830e09	2.328e14	1.274e16	1.250e16	0.018
1954	2.970e09	1.805e14	1.098e16	1.079e16	0.016
1955	3.440e09	2.091e14	1.272e16	1.251e16	0.016
1956	3.840e09	2.334e14	1.372e16	1.348e16	0.017
1957	3.850e09	2.340e14	1.342e16	1.318e16	0.017
1958	3.010e09	1.829e14	1.118e16	1.099e16	0.016
1959	2.910e09	1.768e14	1.108e16	1.090e16	0.015
1960	2.840e09	1.726e14	1.077e16	1.059e16	0.016
1961	2.670e09	1.623e14	1.040e16	1.023e16	0.015
1962	2.680e09	1.629e14	1.085e16	1.068e16	0.015
1963	2.800e09	1.702e14	1.180e16	1.162e16	0.014
1964	2.980e09	1.811e14	1.246e16	1.227e16	0.014
1965	3.050e09	1.854e14	1.299e16	1.280e16	0.014
1966	3.150e09	1.914e14	1.340e16	1.320e16	0.014
1967	3.230e09	1.963e14	1.376e16	1.356e16	0.014
1968	3.090e09	1.878e14	1.355e16	1.336e16	0.013
1969	3.230e09	1.963e14	1.380e16	1.360e16	0.014
1970	4.120e09	2.504e14	1.453e16	1.427e16	0.017
1971	4.060e09	2.468e14	1.313e16	1.288e16	0.018
1972	4.560e09	2.771e14	1.403e16	1.375e16	0.019
1973	4.780e09	2.905e14	1.393e16	1.363e16	0.020
1974	8.260e09	5.021e14	1.401e16	1.350e16	0.035
1975	9.910e09	6.024e14	1.493e16	1.432e16	0.040
1976	9.970e09	6.060e14	1.565e16	1.504e16	0.038
1977	9.780e09	5.945e14	1.568e16	1.508e16	0.037
1978	9.630e09	5.853e14	1.486e16	1.427e16	0.039
1979	1.123e10	6.826e14	1.768e16	1.699e16	0.038
1980	1.132e10	6.881e14	1.854e16	1.785e16	0.037
1981	1.102e10	6.698e14	1.833e16	1.766e16	0.036
1982	1.093e10	6.644e14	1.860e16	1.793e16	0.035
1983	1.014e10	6.164e14	1.729e16	1.667e16	0.035

Note: The notation 1.014e10, for example, is engineering notation where 'e10' means decimal point is actually 10 places to the right.

Column B is taken from Table 17, DOE/EIA-0384(83)
Column C is Column By multiplied by 60,789 Btu/$
Column D is taken from Table 2, DOE/EIA-0834(83)
Column E is column D minus column C
Column F is column C divided by column D

Table A-9

VALUE OF FOSSIL FUELS PRODUCED IN UNITED STATES

(A) YEAR	(B) VAL OIL PRODUCED	(C) VAL N.G. PRODUCED	(D) VAL COAL PRODUCED	(E) VALUE FOSSIL	(F) FEEDBACK ENERGY
1949	8.920e09	6.300e08	4.080e09	1.363e10	8.285e14
1950	9.240e09	8.200e08	4.670e09	1.473e10	8.954e14
1951	9.970e09	9.100e08	4.610e09	1.549e10	9.416e14
1952	1.000e10	1.100e09	3.950e09	1.505e10	9.148e14
1953	1.074e10	1.290e09	3.830e09	1.586e10	9.641e14
1954	1.081e10	1.460e09	2.970e09	1.524e10	9.264e14
1955	1.131e10	1.550e09	3.440e09	1.630e10	9.908e14
1956	1.163e10	1.770e09	3.840e09	1.724e10	1.048e15
1957	1.246e10	1.800e09	3.850e09	1.811e10	1.100e15
1958	1.116e10	2.000e09	3.010e09	1.617e10	9.829e14
1959	1.105e10	2.320e09	2.910e09	1.628e10	9.896e14
1960	1.080e10	2.610e09	2.840e09	1.625e10	9.878e14
1961	1.093e10	2.870e09	2.670e09	1.647e10	1.001e15
1962	1.099e10	3.140e09	2.680e09	1.681e10	1.021e15
1963	1.111e10	3.290e09	2.800e09	1.720e10	1.045e15
1964	1.103e10	3.200e09	2.980e09	1.721e10	1.046e15
1965	1.096e10	3.460e09	3.050e09	1.747e10	1.061e15
1966	1.136e10	3.580e09	3.150e09	1.809e10	1.099e15
1967	1.188e10	3.680e09	3.230e09	1.879e10	1.142e15
1968	1.186e10	3.740e09	3.090e09	1.869e10	1.136e15
1969	1.201e10	4.060e09	3.230e09	1.930e10	1.173e15
1970	1.224e10	4.080e09	4.120e09	2.044e10	1.242e15
1971	1.220e10	4.220e09	4.060e09	2.048e10	1.244e15
1972	1.171e10	4.280e09	4.560e09	2.055e10	1.249e15
1973	1.236e10	4.710e09	4.780e09	2.185e10	1.328e15
1974	1.912e10	5.630e09	8.260e09	3.301e10	2.006e15
1975	1.864e10	7.190e09	9.910e09	3.574e10	2.172e15
1976	1.841e10	8.740e09	9.970e09	3.712e10	2.256e15
1977	1.841e10	1.130e10	9.780e09	3.949e10	2.400e15
1978	1.901e10	1.209e10	9.630e09	4.073e10	2.475e15
1979	2.414e10	1.478e10	1.123e10	5.015e10	3.048e15
1980	3.807e10	1.799e10	1.132e10	6.738e10	4.095e15
1981	5.094e10	2.025e10	1.102e10	8.221e10	4.997e15
1982	4.352e10	2.202e10	1.093e10	7.647e10	4.648e15
1983	3.819e10	1.999e10	1.014e10	6.832e10	4.153e15

Note: The notation 3.819e10, for example, is engineering notation where 'e10' means decimal point is actually 10 places to the right.
Columns B, C AND D ARE taken from Table 17, DOE/EIA-0384(83)
Column E is sum of columns B, C & D.
Column F is column E multiplied by 60,789 Btu/$

Table A-10

BTU'S OF FOSSIL FUELS PRODUCED IN U.S.

(A) YEAR	(B) BTU'S OIL PRODUCED	(C) BTU N.G. PRODUCED	(D) BTU/COAL PRODUCED	(E) BTU FOSSIL PRODUCED
1949	1.068e16	5.380e15	1.253e16	2.859e16
1950	1.145e16	6.230e15	1.462e16	3.230e16
1951	1.304e16	7.420e15	1.504e16	3.550e16
1952	1.328e16	7.960e15	1.323e16	3.447e16
1953	1.367e16	8.340e15	1.274e16	3.475e16
1954	1.343e16	8.680e15	1.098e16	3.309e16
1955	1.441e16	9.630e15	1.272e16	3.676e16
1956	1.518e16	1.000e16	1.372e16	3.890e16
1957	1.518e16	1.061e16	1.342e16	3.921e16
1958	1.420e16	1.094e16	1.118e16	3.632e16
1959	1.493e16	1.195e16	1.108e16	3.796e16
1960	1.493e16	1.266e16	1.077e16	3.836e16
1961	1.521e16	1.310e16	1.040e16	3.871e16
1962	1.552e16	1.372e16	1.085e16	4.009e16
1963	1.597e16	1.451e16	1.180e16	4.228e16
1964	1.616e16	1.530e16	1.246e16	4.392e16
1965	1.652e16	1.578e16	1.299e16	4.529e16
1966	1.756e16	1.701e16	1.340e16	4.797e16
1967	1.865e16	1.794e16	1.376e16	5.035e16
1968	1.931e16	1.907e16	1.355e16	5.193e16
1969	1.956e16	2.045e16	1.380e16	5.381e16
1970	2.040e16	2.167e16	1.453e16	5.660e16
1971	2.003e16	2.228e16	1.313e16	5.544e16
1972	2.004e16	2.221e16	1.403e16	5.628e16
1973	1.949e16	2.219e16	1.393e16	5.561e16
1974	1.857e16	2.121e16	1.401e16	5.379e16
1975	1.773e16	1.964e16	1.493e16	5.230e16
1976	1.726e16	1.968e16	1.565e16	5.259e16
1977	1.745e16	1.957e16	1.568e16	5.270e16
1978	1.843e16	1.949e16	1.486e16	5.278e16
1979	1.810e16	2.008e16	1.768e16	5.586e16
1980	1.825e16	1.991e16	1.854e16	5.670e16
1981	1.815e16	1.970e16	1.833e16	5.618e16
1982	1.831e16	1.825e16	1.860e16	5.516e16
1983	1.832e16	1.634e16	1.729e16	5.195e16

Note: The notation 1.832e16, for example, is engineering notation where 'e16' means decimal point is actually 16 places to the right.
Columns B, C, and D taken from Table 2, DOE/EIA-0384(83)
Column E is sum of columns B, C, and D

Table A-11

NET ENERGY FROM FOSSIL FUELS PRODUCED IN UNITED STATES

(A) YEAR	(B) $VALUE FOSSIL	(C) FEEDBACK ENERGY	(D) BTU FOSSIL PRODUCED	(E) NET ENERGY FOSSILS	(F) RATIO COL C/ COL D
1949	1.363e10	8.285e14	2.859e16	2.776e16	0.028
1950	1.473e10	8.954e14	3.230e16	3.140e16	0.027
1951	1.549e10	9.416e14	3.550e16	3.455e16	0.026
1952	1.505e10	9.148e14	3.447e16	3.355e16	0.026
1953	1.586e10	9.641e14	3.475e16	3.378e16	0.027
1954	1.524e10	9.264e14	3.309e16	3.216e16	0.027
1955	1.630e10	9.908e14	3.676e16	3.576e16	0.026
1956	1.724e10	1.048e15	3.890e16	3.785e16	0.026
1957	1.811e10	1.100e15	3.921e16	3.810e16	0.028
1958	1.617e10	9.829e14	3.632e16	3.533e16	0.027
1959	1.628e10	9.896e14	3.796e16	3.697e16	0.026
1960	1.625e10	9.878e14	3.836e16	3.737e16	0.025
1961	1.647e10	1.001e15	3.871e16	3.770e16	0.025
1962	1.681e10	1.021e15	4.009e16	3.906e16	0.025
1963	1.720e10	1.045e15	4.228e16	4.123e16	0.024
1964	1.721e10	1.046e15	4.392e16	4.287e16	0.023
1965	1.747e10	1.061e15	4.529e16	4.422e16	0.023
1966	1.809e10	1.099e15	4.797e16	4.687e16	0.022
1967	1.879e10	1.142e15	5.035e16	4.920e16	0.022
1968	1.869e10	1.136e15	5.193e16	5.079e16	0.021
1969	1.930e10	1.173e15	5.381e16	5.263e16	0.021
1970	2.064e10	1.254e15	5.660e16	5.534e16	0.022
1971	2.048e10	1.244e15	5.440e16	5.315e16	0.022
1972	2.055e10	1.249e15	5.628e16	5.503e16	0.022
1973	2.185e10	1.328e15	5.561e16	5.428e16	0.023
1974	3.301e10	2.006e15	5.379e16	5.178e16	0.037
1975	3.574e10	2.172e15	5.230e16	5.012e16	0.041
1976	3.712e10	2.256e15	5.259e16	5.033e16	0.042
1977	3.949e10	2.400e15	5.270e16	5.029e16	0.045
1978	4.073e10	2.475e15	5.278e16	5.030e16	0.046
1979	5.015e10	3.048e15	5.586e16	5.281e16	0.054
1980	6.738e10	4.095e15	5.670e16	5.260e16	0.072
1981	8.221e10	4.997e15	5.618e16	5.118e16	0.088
1982	7.647e10	4.648e15	5.516e16	5.051e16	0.084
1983	6.832e10	4.153e15	5.195e16	4.779e16	0.079

Note: The notation 5.153e15, for example, is engineering notation where 'e15' means decimal point is actually 15 places to the right.

Column B ($1972 = 100)) from Table A-5.
Column C (Btu) from Table A-6.
Column D (Btu) from Table A-7.
Column E (Btu) is column C subtracted from column D
Column F is column C divided by column D

Appendix B

NUCLEAR POWER

The Models

Explanation of Static Model

Following is a line-by-line explanation of the static net-energy model. The explanation follows the Komanoff Base-Case model of Chapter 1 which is reproduced in this section for easy reference.

Line 1 - Expected Lifecycle

A 30-year Expected lifecycle of each plant is assumed for the Base-Case of this study. The nuclear power industry presumes that nuclear power plants will last for 30 years. How long they can be kept in service affects the expected economic performance and hence, the net-energy expectations. All costs at all stages, including drawing-board designs, partially constructed plants, and prematurely abandoned plants, should be counted as input-energy costs when making energy analyses of the nuclear industry.

For example, a problem that might limit the operational life of nuclear power plants involves pressurized water reactors (PWR's) that have been developing unexpected cracks in the steam pipes and pressure vessels.[1] These may present serious safety hazards, high economic costs to repair, and even premature abandonment of the plants -- any of which will increase cost and lower the net-energy balance.

Line 2 - Generating Capacity

One kilowatt (KW) of Generating Capacity operating for one hour generates one kilowatt-hour (kWh) of electric power. 1150 megawatts (MW) of capacity (1,150,000 kilowatts of capacity) operated for one hour generates 1,150,000 kilowatt-hours of electric power. The number 1.1150E6 means 1,115,000 (i.e. 6 zeros after decimal point).

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[1]Union of Concerned Scientists, "Reactor Vessel Rupture: 'Incredible' Safety Hazard with Growing Credibility," Nucleus, 3 (Fall 1981): 3.

Table B-1

KOMANOFF BASE CASE TYPE PLANT, Location: Central United States

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Expected Lifecycle, Yrs.:	30.0000		
2	Gen. Capacity, KWe:	1.1500e06		
3	Hours in 365-Day Year:	8760.0000		
4	Prod Plant Cost ($):	1460.0000	C2*C4 =	1.6790e09
5	Other Plant Cost:	1460.0000	C2*C5 =	1.6790e09
6	Elec. Gen. @60% (kWh):	0.6000	C1*C2*C3*C6=	1.8133e11
7	Elec Gen @50%, 30 Yrs.:	0.5000	C1*C2*C3*C7=	1.5111e11
8	Fix. Chg. Prod. Plant ($):	0.1029	C1*C4*C8 =	5.1860e09
9	Fix. Chg. Other Plant, ($)	0.1029	C1*E5*C9 =	5.1860e09
10	Prod. Plant O & M ($):	0.0062	E6*C10 =	1.1242e09
11	Other Plant O & M ($):	0.0011	E6*C11 =	2.1473e08
12	Fuel Charge ($):	0.0109	E6*E12 =	1.9765e09
13	Decomm. Cost (10% C4, $):	0.0021	E6*C13 =	3.8079e08
14	Total Distr. Cost ($):	SUM(E8>E13)	-(E4+E5) =	1.0710e10
15	Lifecycle Plant Cost ($):		SUM(E8>E13)=	1.4068e10
16	Distributive Input Energy:	3.5791e04	E14*C16 =	3.8333e14
17	Total Input Energy:	3.5791e04	E15*C17 =	5.0352e14
18	Total Output Energy:	3413.0000	E7*C18 =	5.1573e14
19	Output/Input Ratio:		E18/E17 =	1.0242
20	Net Energy, Btu's		E18-E17 =	1.2212e13
21	Front-End Energy, Btu's:	3.5791e04	E4+E5(C21)=	1.2018e14
22	Decomm. Energy, Btu's:	3.5791e04	E13*C22 =	1.3629e13

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 22.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E13) means that the quantities in column E from lines 8 through 13 are added together.

E18/E17 is notation to mean that cell E18 is divided by cell E17.

Line 19 shows the Output/Input Ratio to be 1.0242 to 1.

Line 20 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield 1.2212e13 British thermal units of net energy, where "e13" means that the decimal point is 13 places to the right. Also, 1.2212e13 = .012212 quads.

Note: Model fits computer software known as electronic spread sheet.

Note: The notatiion 1.3629e13, for example, is engineering notation where 'e13' means decimal point is actually 13 places to the right.

Line 3 - Hours in Year

There are 8760 hours in a 365-day year.

Line 4 - Production Plant Cost

Production Plant Cost of electric power systems is usually expressed in dollars per kilowatt (KW) of capacity. This is obtained by summing the total-dollar cost and then dividing the result by Generating Capacity of the plant. In the current situation, the cost per kilowatt (KW) is known and the cost is obtained by multiplying Per-Kilowatt Cost times Generating Capacity (plant size).

The Komanoff cost projections are used as a basis for estimating the expected energy costs of building and operating the production plant portion of nuclear power stations.

Line 5 - Other Plant Costs

Other Plant Costs include the capital costs of constructing transmission and distribution plant, administrative facilties, and so on. The rationale for including this cost was developed in Chapters 4 through 6. The data of appendix A show that individual utilities invest about 169% more in so-called Other Plant Costs than in Production Plant. This is not uniform, however; for example, Other Plant Costs of Oklahoma Gas and Electric were only about 87% of Production Plant, whereas Pacific Gas and Electric's Other Plant Costs were 196% of Production Plant investment.[1] Throughout the analyses it was assumed that an equal amount (to production plant cost) would be invested in Other Plant Cost.

Line 6 - Electricity Generated at 60%

The amount of Electricity Generated at 60% (cell E6) is needed for the purpose of calculating the amount of Input-Energy Costs that are distributed over the 30-year life of the system. Komanoff cost factors (per-kilowatt-hour) are based on a a 60% capacity factor. Therefore, in order to arrive at the total cost of a plant using Komanoff numbers, it is necessary to assume that the plant would generate electricity at a 60% Efficiency Factor.[2]

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[1] Statistics of Privately-Owned Utilities, Idem.

[2] Capacity factor is a term that describes a "convention used in electrical engineering in a special, restricted way. My use of the term efficiency Factor refers to the ratio of the estimated number of hours the system operates at 100% of it's name-plate capacity to the estimated number of hours the plant is designed to be in existence before it is to be decommissioned.

It will be noted in line 7 explanation, however, that it is assumed that a nuclear power plant operates at only a 50% Efficiency Factor in calculating Total output-energy.

As used in this paper, Efficiency Factor (EF) means the following ratio:

$$EF = \frac{\text{Hours Plant Will Generate at 100\% Design Gen. Capacity}}{\text{Hours in Lifecycle (e. g. 8760 x 30 Yrs.)}}$$

Five major reasons why a nuclear power plant cannot be continuously operated at 100% of its designed capacity are listed:

Planned Shutdowns

Nuclear power plants are routinely shut down for refueling and maintenance. Approximately one-fourth to one-third of the fuel is replaced each year[1]. Maintenance is often scheduled or delayed until scheduled refueling times. It is suspected that premature refueling may occur to coincide with unexpected maintenance shutdowns.

Unplanned Shutdowns

Unanticipated problems develop, and the plant must either be completely shut down or operated at a lower temperature and pressure until a scheduled shutdown time is reached, resulting in a corresponding reduction in electrical generation.

Unsafe Conditions

This is related to line 2. Plants usually have sets of so-called minor safety conditions which require that the plant be operated at a reduced output (with respect to designed output) for extended periods.

Demand Deficiency

The demand for electricity varies depending on the time of day and the season of the year. Further, utility companies must do

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[1]Sam Schurr, Joel Darmstadter, William Ramsey, Harry Perry, and Milton Russel, Energy in America's Future: The Choices Before Us, A study Prepared for the RFF National Energy Strategies Project, (Baltimore: Johns Hopkins University Press, 1980), p. 281

advanced planning with respect to changing demand and a deficiency can result when when demand does not turn out to coincide with the utility's estimate.

Efficiency Factor

It was mentioned in the line 2 explanation that the demand for electricity also varies by time of day and the season of the year. It was expected that nuclear power stations, since they had high fixed costs and relatively low variable costs (the latter a result of relatively low fuel costs as compared with oil), natural gas, and coal -- would operate as much of the time as possible. Such plants, which we will call primary plants, are usually referred to as supporting the base-load of the utility. Primary plants would be scheduled to operate in precedence to secondary plants, i.e., oil, natural gas, and coal-fueled plants. Hence, secondary plants (so-called peaking plants) would be needed to meet the varying demand conditions and for the time that the primary plant is out of service, for whatever reason. In Chapter 6 it is argued that a primary power plant cannot take credit for the amount of time it operates if a secondary plant is needed when the primary plant is out of service. The total economic cost of operating the generating system includes both the cost of the primary and the secondary system.

It should also be noted that, if nuclear power is to occupy a higher per cent of the generating portfolio of a utility, then electric utilities will still have to face the varying demand conditions (hence lower efficiency) with a larger proportion of nuclear reactors. Even if technical improvements are made to radically lower the cost of these plants, an all-nuclear generating system will still face the varying demand problems, planned and unplanned "down time" and require primary and secondary plants.

Komanoff notes the following:

> Most utilities now estimate that new reactors will achieve 70% capacity factors, although some projections are as low as 65%. In practice, however, U. S. reactors averaged only 60% capacity factor through mid-1980 and have demonstrated compelling reasons to expect that future plants will fail to attain even this average.[1]

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[1]Komanoff, Power Plant Cost Escalation, Idem, p. 37.
Note: Komanoff is using Capacity Factor in the traditional engineering sense. If Komanoff were using my definition of Efficiency Factor his numbers would be considerably smaller.

Line 7 - Electricity Generated at 50%:

This calculation of is needed in order to determine Total Energy Output. Multiplying Generating Capacity times the Number of Hours in a 365-Day Year times a 50% Efficiency Factor yields the Electricity Generated at 50%. As mentioned earlier, it is assumed that future plants will operate at an average of 50% Efficiency Factor over their lifecycles. It will be recalled from chapter 6 that the U.S. utility grid is operating about 36% of its total capacity. Therefore, using a 50% Efficiency Factor adds a robust quality to the calculations.

Line 8 - Fixed Charge, Production Plant

As with any other private-enterprise endeavor, the company must earn enough money to compensate savers for financing the project and pay its share of taxes.[1]

Normally Fixed-charge rates are expressed in current dollars and generally range from 15% to 20% and are unadjusted for inflation. Accurate net-energy calculations require that this fixed-charge rate be in uninflated (real) dollars; therefore, a real fixed-charge rate is used. Komanoff used a real fixed-charge rate of 10.3 per cent (.10296) for nuclear power plants for the purpose of comparing nuclear and coal plants. Throughout the nuclear section a 10.29 per cent fixed-charge rate is used. Komanoff translates the 20.29 rate this to 2.68 cents per kilowatt hour (which assumes a plant operated at a 60% capacity factor for 30 years) at the bus bar. Bus-bar costs would not include transmission and distribution (Other Plant Costs) and are therefore included and noted below.

A 10.29 per cent fixed charge rate is considered to be a conservative number was taken from Komanoff.[2] It includes amortization of the principal and a utility's cost of capital on a real basis (i. e. discounted for inflation). The amount of the Fixed Charge is obtained by multiplying Expected Lifecycle times Production Plant Cost times the fixed-charge rate.

Line 9 - Fixed Charge Other Plant

Construction of Other Plant (including transmission and distribution plant) also incurs fixed charges. The explanation of line 8, above, shows the rationale for its inclusion. As mentioned above, Komanoff's bus bar costs do not include the cost of Other Plant. Electricity at the bus bar cannot be used until it is distributed to the

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[1]Ibid, p. 270.

[2]Ibid.

point of use. It is an economic cost, therefore, an energy cost of the energy-transformation entity.

Line 10 - Production Plant Operation And Maintenance

Production Plant Operation and Maintenance (O & M) includes all running costs except fuel, according to Komanoff.[1] For the purpose of this study, O. & M. Cost (cell E10) is calculated by multiplying kilowatt-Hours Generated at 60% times 6.2 mills per kilowatt-hour.

Line 11 - Other Plant Operation And Maintenance

According to the Energy Information Agency, this cost amounts to about 19% of Production Plant O.&M cost. This is approximated by multiplying .0011 per kilowatt hour times kilowatt-hours generated at 60% Efficiency Factor.[2]

Line 12 - Fuel Charge

Komanoff uses a figure of 10.09 mills per kilowatt-hour for ($1979 = 100) Fuel Charges related to electricity generated and includes escalation factors for uranium and enrichment costs, levelized over the period 1988 to 2017.[3] Lifecycle Fuel Charge is obtained by multiplying Total Electricity Generated at 60% times the per kilowatt-hour Fuel Charge of 10.9 mills.

Line 13 - Decommissioning Cost

This is a very uncertain cost area. No large commercial reactor has ever been dismantled, and only two small reactors have been decommissioned, (the 20-megawatt Elk River Boiling Water Reactor in Minnesota and the 10-megawatt Sodium Reactor Experimental facility near Los Angeles). Komanoff notes:

> Although both may have incurred unusual costs as decommissioning pioneers, they accumulated less radioactivity than will today's plants (Elk River operated for only four years) and thus should have been easier to dismantle. Both plants cost approximately one-fourth as much to decommission as to build, adjusted for inflation. Although it would be speculative to apply this ratio to current plants, the figure does suggest that dismantlement may be costly

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[1]Ibid, p. 269

[2]Department of Energy, Statistics Of Private Utilities, Idem.

[3]Komanoff, Power Plant Cost Escalation, Idem, p. 37.

The Department of Energy's (DOE) cost estimate of $125 per kilowatt of capacity seems to be "representative of the most current dismantlement assessments," according to Komanoff.[1]

The 10.9 mills per kilowatt-hour (@ 60% Efficiency Factor) is used for the expected net-energy calculations in this paper. Decommissioning Cost obtained by multiplying Electricity Generated at 60% times the Decommissioning Cost coefficient in cell C13.

For a Komanoff Northeast plant, Komanoff estimated that the Decommissioning Costs would increase to 172 dollars per kilowatt of installed capacity, or 26 mills per kilowatt-hour.[2]

Pasqualetti points out that there are three basic methods of getting rid of nuclear reactors:

> (1) immediate dismantlement, (2) safe storage, and (3) entombment, -- and that: financial, social, and environmental implications differ with each option . . . Most worrisome is that the majority of the utilities have no way to ensure that, when the time comes, money will be available for decommissioning.[3]

<u>Line 14 - Total Distributive Costs</u>

In order to have appropriate numbers for the Dynamic Net Energy Model, costs incurred before electrical generation begins (referred to as Front-End Costs) must be separated from those that are distributed over the generating life of the plant (identified as Distributive Costs). The total is obtained by merely summing Fixed Charge Costs, Operation and Maintenance Costs, and Decommissioning Cost (cells E8 through E13). Production Plant and Other Plant (cells E4 and E5) costs are subtracted because they are considered Front-End Costs.

<u>Line 15 - Lifecycle Plant Cost</u>

This cost is the sum of all Fixed-Charge Costs (Including Front-End Costs), Operation and Maintenance Costs and Decommissioning Cost.

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[1]Ibid, p. 273.

[2]Ibid.

[3]Martin Pasqualetti, "The Decommissioning Dilemma," <u>Sierra</u>, (September/October, 1984), p. 280.

Line 16 - Distributive Input-Energy

This item is needed for the Dyanamic Net Energy model and is obtained by multiplying Total Distributive Costs times the Energy/GNP coefficient (in the example case, 35791 Btu's per dollar).

Line 17 - Total Input-Energy

This is obtained by multiplying Lifecycle Plant Cost (cell E16) times the Energy/GNP coefficient.

Line 18 - Total Output-Energy

This item is shown in Btu's and is obtained by multiplying the constant 3413 (Btu's in one kilowatt-hour) times the total number of kilowatt-hours (kWh's) that are generated at 50% Efficiency Factor. The reason for expressing the output in Btu's (e.g., rather than joules or calories) is for the purpose of comparing the results to the standard method of expressing annual energy consumption which is expressed in quads of energy where a quad is an abbreviation for a quadrillion btu's of energy, i.e., (1×10^{15} Btu's.)

Line 19 - Output/Input Ratio

This ratio is obtained by merely dividing Total Lifecycle Output (cell E18) by Total Lifecycle Input-Energy (cell E17) and reflects the net-energy ratio for a single plant, using Static Net Energy Analysis of a single plant. For table B-1, the Komanoff Base-Case plant, the ratio is 1.0242 to 1.

Line 20 - Net Energy, Btu's

This result in Btu's is obtained by subtracting Total Output-Energy from Total Input-Energy (cell E17 from cell E18).

Line 21 - Front-End Energy, Btu's

The result in Btu's in cell E21 is calculated for use in the Dynamic Net Energy Model(table B-2) and is obtained by summing Production Plant Cost and Other Plant Cost (cells E4 and E5), multiplying the sum by the Energy/GNP coefficient.

Line 22 - Decommissioning Energy

This is obtained by multiplying estimated Decommissioning Cost (cell E13) by the Energy/GNP coefficient (35,791 Btu's per $1979 in the example case).

Final Notes on Static Analysis

In the foregoing example the Komanoff Base-Case type plant was used to explain the general procedure. Costs of the Base-Case plant, as well as the 46-plant data base were expressed in $1979. Costs of the 1984 data base were expressed in 1982 dollars and the corresponding Energy/GNP Ratios were used.

Further, the model for the 34-plant data base was amended to include costs of plant retrofitting, i.e., those changes to production plant that are made after a plant begins to generate electricity. Generally, these are modifications to meet safety considerations that were not recognized in the engineering design.

Also, the variables are changed to reflect the estimated costs in 1982 dollars (whereas the table A-1 model was expressed in $1979). Table A-2 reflects those changes. Energy/GNP Ratios are also changed to reflect costs expressed in 1982 dollars. In the example case of table B-2 the ratio is 28,266 Btu's/$1982.

Dynamic Net-Energy Analysis Model

Line 1 - Construction Time

Construction time in years refers to the length of time that is required to construct a single system. Komanoff showed this to be approximately 9 years for a single plant, on average.[1] It was assumed that it would be possible to expand construction capacity to 52 plants per year.

Line 2 - Cycle in Years

A 100-year cycle was chosen to show that, even in a very long time frame the net-energy situation is unfavorable.

Line 3 - Years of Generation

In the beginning of a 100-year cycle, 9 years pass before the first set of plants (set of 52) is completed. Therefore, only 91 years are left in a 100-year cycle to generate electricity, beginning with the first plant coming on line in the tenth year. It is assumed that a single plant will remain in service for 30 years; therefore, the first plant constructed will be retired at the end of 39 years of the program, and similiarly, for set 2, 3 and so on.

Table B-2

STATIC NET ENERGY ANALYSIS, BELLEFONTE (TWIN REACTOR)

(A) LINE	(B) ITEM	(C) VARIABLES	(D) EQUATIONS	(E) RESULTS
1	Expected Life-Cycle, Yrs	30 years		
2	Gen. Capacity, MWe:	2426 megawatts		
3	Hours in 365-Day Year:	8760 hours		
4	Prod Plant Cost ($):	$1484/KW	C2*C4 =	3.6001e09
5	Other Plant Cost (=Prod)		E4 =	3.6001e09
6	Retrofitting Cost:	$22/KW	C2*C6 =	5.3372e07
7	Elec. Gen. @60% (kWh):	0.6000	C1*C2*C3*C7=	3.8253e11
8	Elec Gen @50%, 30 Yrs.:	0.5000	C1*C2*C3*C8=	3.1877e11
9	Fix. Chg. Prod. Plant ($	0.1030	C1*E4*C9 =	1.1124e10
10	Fix. Chg. Other Plant, (	0.1030	C1*E4*C10 =	1.1124e10
11	Fix. Chg. Retrofit.	0.1030	C1*E6*C11 =	1.6491e08
12	Prod. Plant O & M ($):	0.0077	E6*C12 =	2.9454e09
13	Other Plant O & M ($):	0.0012	E6*C13 =	4.5903e08
14	Fuel Charge ($):	0.0112	E6*E14 =	4.2843e09
15	Decomm. Cost (10% C4, $)	0.0034	E7*C15 =	1.3006e09
16	Total Distr. Cost ($):	($)	SUM(E9>E15)-	
17			(E4>E6) =	2.4149e10
18	Lifecycle Plant Cost ($)		SUM(E9>E15)=	3.1403e10
19	Distr. Energy INPUT, Btu	28266 Btu/$	E17*C19 =	6.8261e14
20	Total Input Energy, Btu		E18*C19 =	8.8765e14
21	Total Output Energy, Btu	3413 Btu/kWh	E8*C21 =	1.0879e15
22	Output/Input Ratio:		E21/E20 =	1.2256
23	Net Energy, Btu's:		E21-E20 =	2.0033e14
24	Front-End Energy, Btu's:		E4+E5*(C19) =	2.0352e14
25	Decomm. Energy, Btu's:		E15*C19 =	3.6762e13

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 22.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E13) means that the quantities in column E from lines 8 through 13 are added together.

E18/E17 is notation to mean that cell E18 is divided by cell E17.

Line 19 shows the Output/Input Ratio to be 1.2246 to 1.

Line 20 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield 2.0033e14 British thermal units of net energy, where "e14" means that the decimal point is 14 places to the right. Also, 2.0033e14 = .20033 quads

Line 4 - Number of Plants Constructed

The number of plants constructed per year is shown in cell C4.

Line 5 - System Life

A System Life of 30 years is assumed. It is doubted that nuclear power systems will average even 25 years; therefore, the results of the analysis are robust accordingly.

Line 6 - Number Decommissioned Lifecycle

This figure is obtained by subtracting System Life (cell C5) from Years of Generation (cell C3) and multiplying the result by the Number of Plants Constructed each year [(91-30)*52 = 3172].

Lines 7 & 8 - Annual Output-Energy, One System

This number in cell C8 is taken from cell E18 of table B-3 (Static Net Energy Analysis) and is the Total Output Energy in btu's from a single plant. Since we are dealing with dynamic (time related) net-energy analysis, it is necessary to know the annual output of the system. Therefore, cell C7 is divided by 30 years, giving the annual output of each set in cell E7.

Line 9 - Alpha Units

This term is adapted to stand for the plant years (each year corresponds that each plant operates. after the plants begin to generate electricity.) The number in cell C8 is obtained by summing integers (1,2, . . . 91) and subtracting integers (1,2, . . . 61). An intuitive grasp of this procedure is illustrated in Figure 7.1. Subtracting out the sum of the integers 1 to 61 accounts for the alpha units that are involved in the retirement of plants at the end of their thirty-year expected life. The result is shown in cell C8 as 2295 AlphaUnits of output-energy at the end of one hundred years. This number will be used in equations D9 and D14.

Lines10 & 11 - Total Energy-Output, 100 Years

This number is obtained by multiplying the Number Constructed each year (cell C4) times the Annual Output-Energy of one set (cell E7) times the total number of Alpha Units in (cell C8). The result is shown in cell E9.

Table B-3

100-YEAR DYNAMIC ANALYSIS
Bellefonte Twin-Reactor-Type Systems

(A) LINE	(B) ITEM	(C) VARIABLE	(D) EQUATIONS	(E) RESULTS
1	Const. Time:	9 Years		
2	Cycle in Years:	100-year cycle of analysis		
3	Years of Generation:	91 Years		
4	No. Const. Per Year:	52.0000		
5	System Life:	30 Years		
6	No. Decomm. Life-cycle:	3172		
7	Annual Output 1 Reactor			
8	(C8 from E21, static):	1.0879e15	C8/C5 =	3.6263e13
9	Alpha Units:	2.2950e03	=SUM(1>41)	-SUM(1>41)
10	Total Energy Output			
11	from total system:		C4*E8*C9 =	4.3276e18
12	Annual Front-End Energy, 1 set,			
13	(C13 from E24, Static):	2.0352e14	(C13/C1)*C4 =	1.1758e15
14	Beta Units:	864.0000	= SUM(1>9)+(9*41)	
15	Total System Front End			
16	Input Energy:		E13*C14=	1.0159e18
17	Annual Distrib. Energy,	1 set,		
18	(C18 from E19, Static):	6.8261e14	(C18/C5)*C4 =	1.1831e15
19	Total Distr. Energy:		C9*E18 =	2.7154e18
20	Decommissioning Energy			
21	(C21 from E25, static):	3.6762e13	C6*C21 =	1.1660e17
22	Total Energy Input:		E16*E19*E21 =	3.8480e18
23	Output/Input Ratio:		E11/E22 =	1.1246
24	Net Energy, 100 YRS.:	(Btu's)	E11-E22 =	4.7966e17
25	Plants in Service:		C4*C5 =	1560.0000
26	Annual Net Energy:	(Btu's)	E24/C2 =	4.7966e15

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 26.

The notation C8 (cell C8), for example, refers to entry located at the intersection of column C and line 8.

C4*C5, for example, means that the quantity in column C, line 4 is multiplied times the quantity at column C, line 5.

SUM(1>41) means that integers 1,2,3...41 are summed.

E18/C2 means that cell E18 is divided by cell C2.

Data in cells C8, C13, C18, and C21 transferred from table 7.6.

Line 23 shows the dynamic Output/Input Ratio to be 1.1246 to 1

Line 26: average annual net energy produced is 4.7966 quads.

Notation "e15" means decimal point is 15 places to the right.

Line 12 - Annual Front-End Energy

The variable in cell C10 is taken from cell E22 of the static analyses (in this case from Table B-2). Annual Front-End Energy E10) is obtained by dividing the total energy input by 30 years and multiplying that dividend by the number of reactors to be constructed per year (cell C4).

Line 14 - Beta Units

This number will be used in calculating the costs that are involved before any plant begins to generate electricity. Total Beta Units are shown in cell C11. Since it takes 9 years to construct a single plant, and 52 new ones are assumed to begin each year (in Table B-3)., it is necessary to know the number of Beta Units involved in the construction program. The method of calculation is shown in cell D11 of table B-3. The number is obtained by summing integers 1, 2, 3, . . 9, plus 9 x 91, and corresponds to the intuitive illustration in Figure 7.1 and figure B-1.

Lines 15 & 16 - Total System Front-End Input-Energy

This total is shown in cell E12. All of the capital costs are incurred before a single kilowatt-hour of electricity is generated and are, correspondingly, front-end energy costs. The result in cell E12 is obtained by multiplying the Annual Front-end Energy outlay in cell E10 times input Beta Units.

Lines 17 & 18 - Annual Distributive Input

This number is shown in cell E13. Annual interest charges, taxes, and so forth, which make up the basis for the Fixed-charge cost, plus fuel, and operations and maintenance, are distributed over the 30-year life of each system. The total input-energy for a single reactor is obtained from cell E15 of table B-2 The Annual input (cell E13) is obtained by dividing cell C13 by 30 years, and that amount is then multiplied times the number of plants started each year (cell C4).

Line 19 - Total Distributive Energy

This amount (input-energy) is shown in cell E14. Similar to 13, the number in cell E14 is obtained by multiplying Annual Distributive Energy (cell E13) times the Alpha Units (cell C8).

Lines 20 & 21 - Decommissioning Energy

This amount is shown in cell E15. The total energy needed for a single system is taken from cell E22 of the static net-energy analyses. The energy inputs to decommission one reactor (cell E21, Table B-2) is multiplied times the number of reactors that would be decommissioned during the period of study.

Line 22 - Total Energy Input

This amount is shown in cell E16. cells E12, E14, and E15 are summed to obtain the total energy invested through year one 100 of the construction/operation cycle.

Line 23 - Output/Input Ratio

The ratio is obtained by dividing cell E9 by cell E16.

Line 24 - Net-Energy, 100 Years

The Number is obtained by subtracting cell E9 from cell E16.

Line 25 - Plants In Service

The number is included to show that in a construction cycle of starting 52 new plants each year (one per week), that the most individual plants that can be operating at one time is 1560.

Line 26 - Annual Net Energy Output

The quantity is a shown in (cell E20) and is determined by dividing total net energy by 100 years.

End Notes for Dynamic Analysis

Figure B-1 graphically illustrates the relative amounts of output-energy and input-energy that are involved in a continuous construction program. In this example it is assumed that an additional plant is started each year and that it takes 9 years to construct a single plant. It will be noted that capital energy-inputs are shown **below** the zero line (beta units) and that, at the end of the ninth year, each plant respectively begins to generate electricity. That output is shown, correspondingly, by the "1's" **above** the zero line (noted as alpha units), beginning in the tenth year of the cycle.

Total Output-Energy is shown by horizontally summing the column totals above the zero line, beginning in the tenth year of the cycle. Total Front-End Energy is obtained by summing the column totals (beta units) below the zero line. It will be noted from figure B-1 that, at

Figure B-1

DYNAMIC NET ENERGY MODEL

																				1
																			1	1
																		1	1	1
Alpha Units ----->																	1	1	1	1
																1	1	1	1	1
															1	1	1	1	1	1
														1	1	1	1	1	1	1
													1	1	1	1	1	1	1	1
												1	1	1	1	1	1	1	1	1
											1	1	1	1	1	1	1	1	1	1
										1	1	1	1	1	1	1	1	1	1	1
+																				
Sum Cols.:										1	2	3	4	5	6	7	8	9	10	11
Sum Integers:										1	3	6	10	15	21	28	36	45	55	66
0----------																				
Year:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-	1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d	d	d
		1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d	d
			1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d	d
				1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d	d
					1	1	1	1	1	1	1	1	1	d	d	d	d	d	d	d
						1	1	1	1	1	1	1	1	1	d	d	d	d	d	d
							1	1	1	1	1	1	1	1	1	d	d	d	d	d
								1	1	1	1	1	1	1	1	1	d	d	d	d
									1	1	1	1	1	1	1	1	1	d	d	d
Beta Units ------>										1	1	1	1	1	1	1	1	1	d	d
											1	1	1	1	1	1	1	1	1	d
												1	1	1	1	1	1	1	1	1
													1	1	1	1	1	1	1	1
														1	1	1	1	1	1	1
Sum column integers:															.	.	.	.	.	.
	1	2	3	4	5	6	7	8	9	9	9	9	9	9	9	9	9	9	9	9
Sum Integers horizontally:																				
	1	3	6	10	15	21	28	36	45	54	63	72	81	90	99	......				144

Notes: At the end of the plant life of the first plant constructed (30 yrs), zeros would begin to appear in that row and correspondingly, for the second plant, etc..
Alpha units refer to costs or outputs "above" the zero line.
Beta units (1's) refer to costs "below" the zero line.
"d's" refer to the costs that are annual costs that are distributed over the life of the plants and would be added to each column total

Table B-4

50-YEAR DYNAMIC ANALYSIS MODEL
Generic Model

(A) LINE	(B) ITEM	(C) VARIABLE	(D) EQUATIONS	(E) RESULTS
1	Const. Time, Yrs.:	9.0000		
2	Cycle in Years:	50.0000		
3	Years of Generation:	41.0000		
4	No. Const. Per Year:	52.0000		
5	System Life:	30.0000		
6	No. Decomm. Life-cycle:	572.0000		
7	Annual Output 1 Reactor			
8	(C8 from E21, static):	5.1573e14	C8/C5 =	1.7191e13
9	Alpha Units:	795.0000	=SUM(1>41)	-SUM(1>41)
10	Total Energy Output			
11	from total system:		C4*E8*C9 =	7.1067e17
12	Annual Front-End Energy, 1 set,			
13	(C14 from E24, Static):	1.2018e14	(C13/C1)*C4 =	6.9437e14
14	Beta Units:	414.0000	= SUM(1>9)+	(9*41)
15	Total System Front End			
16	Input Energy:		E13*C14=	2.8747e17
17	Annual Distrib. Energy,	1 set,		
18	(C18 from E19, Static):	3.8333e14	(C18/C5)*C4 =	6.6443e14
19	Total Distr. Energy:		C9*E18 =	5.2822e17
20	Decommissioning Energy			
21	(C21 from E25, static):	1.3629e13	C6*C21 =	7.7957e15
22	Total Energy Input:		E16*E19*E21 =	8.2349e17
23	Output/Input Ratio:		E11/E22 =	0.8629
24	Net Energy, 100 YRS.:	(Btu's)	E11-E22 =	-1.1281e17
25	Plants in Service:		C4*C5 =	1560.0000
26	Annual Net Energy:	(Btu's)	E24/C2 =	-2.2563e15

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 26

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C4*C4, for example, means that the quantity in column C, line 4 is multiplied times the quantity at column C, line 5.

SUM(1>9) means that the integers 1,2,3...9 are added together.

E11/E22 is notation to mean that cell E11 is divided by cell E22.

Line 23 shows the Output/Input Ratio to be 0.8629 to 1.

Line 26 shows that Annual Net Energy is =2.25 quads.

The data from C8, C12, C18, and C21 are always taken from the corresponding static net-energy model, as indicated.

the related energy that is distributed over the generating life (i.e., the "d's" below the line). The "d's" below the line are to show that the end of 19 years of construction, the output is 66 units. This compares to an energy-input of 144 units. These figures do not include the related energy that is distributed over the generating life (i.e., the "d's below the line). The "d's" below the line are to show that each year each plant incurs an annual distributive cost, which includes the Fixed-Charge Costs, Fuel Charges, Operation and Maintenance Costs, and so forth.

Table B-4 is included to show the model that was used to calculate the 50-year dynamic-net energy analyses of the 46-plant (Komanoff 1981) data base.

Following is a summary of the 46 nuclear plants included in the Komanoff 1981 cost-estimate data base:

Table B-5

SUMMARY NET ENERGY ANALYSIS RESULTS
Based on Capital Cost Estimates in 1981 Komanoff Data Base

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	(E) LIFECYCLE NET ENERGY (QUADS)
Palisades	821	367.00	2.2859	0.207
South Haven, MI				
Consumer'sPower Co.	50-Yrdynamicresults:		1.1469	1.27
Turkey Point No. 3	745	281.00	2.5313	0.202
Florida City, FL				
FL Power & Light Co.	50-yr dynamic results:		1.1980	1.52
Turkey Point No. 4	745	308.00	2.4487	0.198
FL City, FL City, FL				
FL Power & Light Co.	50-yr dynamic results:		1.1759	1.38
Brown'sFerryNo. 1	1098	430.00	2.1344	0.262
Athens, AL				
Tennessee Valley Auth.	50-yr dynamic results:		1.0855	1.07
Brown's Ferry No. 2	1098	412.00	2.1756	0.266
Athens, AL				
TVA	50-yr dynamic results:		1.0980	1.21
Brown's Ferry No. 3	1098	421.00	2.1548	0.264
Athens, AL				
TVA	50-yr dynamic results:		1.0917	1.14
Oconee No. 1	886	324.00	2.4023	0.232
Seneca, SC				
Duke Power Co.	50-yr dynamic results:		1.1632	1.54
Oconee No. 2	886	307.00	2.4519	0.235
Seneca, SC				
Duke Power Co.	50-yr dynamic results:		1.1767	1.65

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), pp.294-297. Use table 7.1 for static calculations.
Use table B-4 for 50-yr dynamic results.

Table B-5 Continued

SUMMARY OF NET ENERGY ANALYSES
Based on 1981 Komanoff Cost Estimates

NAME LOCATION PRINCIPLE OWNER	PLANT SIZE MEGAWATT	$COST PER KILOWATT	OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Oconee No. 3	886	299.00	2.4756	0.237
Seneca, SC				
Duke Power Co.	50-yr dynamic results:		1.1832	1.70
Vermont Yankee	514	693.00	1.6723	0.0927
Vernon, VT				
VT Yankee Nuclear	50-yr dynamic results:		0.9312	-0.42
Peach Bottom 2	1065	607	1.7992	0.212
York County PA				
Phila. Elec. Co.	50-yr dynamic results:		0.9867	-3.14
Peach Bottom 3	1065	589	1.8284	0.217
York County PA				
Phila. Elec. Co.	50-yr dynamic results:		0.9361	-1.77
Three-Mile Island No. 1	819	828.00	1.5043	0.123
Middletown, PA				
Metropolitan Edison Co.	50-yr dynamic results:		0.8679	-1.54
Surry No. 1	823	341.00	2.2349	0.212
Gravel Neck, VA				
VA Elec & Power Co.	50-yr dynamic results:		0.9929	-1.33
Surry No. 2	823	578.00	1.4867	0.169
Gravel Neck, VA				
VA Elec. & Power Co.	50-yr dynamic results:		1.1560	1.33
Fort Calhoun	457	699.00	1.6635	0.082
Fort Calhcund, NE				
Omaha Public Power	50-yr dynamic results:		0.9282	-0.44
Prairie Island No. 1	530	784.00	1.5551	0.085
Red Wing, MN				
Northern States Power	50-yr dynamic results:		0.8876	-0.83

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), pp.294-297. Use table 7.1 for static results.
Use table B-4 for 50-yr dynamic results.

Table B-5, Continued

SUMMARY, NET ENERGY ANALYSIS RESULTS
Based on 1981 Komanoff Capital Cost Estimates

NAME LOCATION PRINCIPLE OWNER	PLANT SIZE MEGAWATTS	$COST PER KILOWATT	OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Prairie Island No. 2	530	551.00	1.8933	0.021
Red Wing, MN				
Northern States Power	50-yr dynamic	results:	1.0086	0.006
Cooper	778	590.00	1.8268	0.158
Brownsville, NE				
Nebraska Public Power	50-yr dynamic	results:	0.9861	-0.14
Pilgrim No. 1	670	690.00	1.6758	0.121
Plymouth, MA				
Boston Edison Co.	50-yr dynamic	results:	0.9327	-0.60
Kewaunee	560	624.00	1.7725	
Salem, NJ				
Public Serv. Elec/Gas	50-yr dynamic	results:	0.9247	-0.23
Salem No. 1	1090	1066.00	1.2786	0.107
Lower Alloways Cr. NJ				
Pub Svc. Ele & Gas Co	50-yr dynamic	results:	0.7750	-3.91
Crystal River No. 3	825	706.00	1.6540	0.146
Red Level, FL				
FL Power Corp.	50-yr dynamic	results:	0.9247	-0.83
Maine Yankee	790	530.00	1.9311	0.171
Wiscasset, ME				
Maine Yanke Atomic Pwr	50-yr dynamic	results:	1.0212	0.20
Rancho Seco	913	605.00	1.8024	0.183
Clay Station, CA				
Sacramento Munic Util	50-yr dynamic	results:	0.9777	-0.26
Zion No. 1	1050	468.00	2.0523	0.242
Zion, IL				
Commonwealth Edison Co.	50-yr dynamic	results:	1.0602	0.74
Zion No. 2	1050	467.00	0.2054	0.242
Zion, IL				
Commonwealth Edison Co.	50-yr dynamic	results:	1.0608	0.75

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), pp.294-297. Use table 7.1 for static analysis. Use table B-4 for dynamic analysis.

Table B-5, Continued

SUMMARY, NET ENERGY ANALYSES
Based On 1981 Komanoff Cost Estimates

NAME LOCATION PRINCIPLE OWNER	PLANT SIZE MEGAWATT	$COST PER KILOWATT	OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Arkansas No. 1	850	464.00	2.0606	0.196
Russelville, AR				
AR Power & Light Co.	50-yr dynamic results:		1.0628	0.62
Cook No. 1	1090	784.00	1.5551	0.175
Bridgman, MI				
Indiana/Michigan Elec.	50-yr dynamic results:		0.8876	-1.71
Cook No. 2	1090	506.00	1.5178	0.242
Bridgman, MI				
Indiana/Michigan Elec.	50-yr dynamic results:		1.0359	0.47
Calvert Cliffs No. 1	845	816.00	1.5178	0.130
Lusby, MD				
Baltimore Gas & Elec. Co	50-yr dynamic results:		0.8732	-1.52
Calvert Cliffs No. 2	845	546.00	1.9022	0.180
Lusby, MD				
Baltimore Gas & Elec.	50-yr dynamic results:		1.0226	0.12
Indian Point No. 3	965	859.00	1.4705	0.165
Buchanan, NY				
Power Auth. of NY	50-yr dynamic results:		0.8546	-2.03
Hatch No. 1	786	757.00	1.5779	0.131
Baxley, GA				
Georgia Power Co.	50-yr dynamic results:		0.9001	-1.08
Three-Mile Island No. 2	906	942.00	0.0924	- - -
Middletown, PA				
Metropolitan Edison Co	(shut down for decommissioning)			
Brunswick No. 2	821	726.00	1.6274	0.043
Southport, NC				
Carolina Power & Light	50-yr dynamic results:		0.9149	-0.94

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), pp.294-297.
Use table 7.1 for static net-energy calculations.
Use table B-4 for 50-yr dynamic calculations.

Table B-5 Continued

SUMMARY OF NET ENERGY ANALYSES
Based on 1981 Komanoff Cost Estimates

NAME LOCATION PRINCIPLE OWNER	PLANT SIZE MEGAWATT	$COST PER KILOWATT	OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Brunswick No. 1	821	534.00	1.9238	0.177
Southport, NC				
Carolina Power & Light.	50-yr dynamic results:		1.0188	0.19
Fitzpatrick	821	796.00	1.5049	0.129
Scriba, NY				
Power Auth. of NY	50-yr dynamic results:		0.8821	-1.36
Duane Arnold	538	843.00	1.4878	0.079
Palo, IA				
Iowa Power & Light Co	50-yr dynamic results:		0.8614	-1.07
Beaver Valley No. 1	852	1004.00	1.3306	0.095
Shippingport, PA				
Duquesne Light Co.	50-yr dynamic results:		0.7972	-2.68
St. Lucie No. 1	810	879.00	1.4495	-1.07
Ft Pierce, FL				
FL Power & Light Co.	50-yr dynamic results:		0.8462	-1.82
Millstone	828	784.00	1.5551	
Waterford, CT				
Northeast Utilities	50-yr dynamic results:		0.8876	-1.30
Trojan	1130	605.00	1.8024	0.226
Prescott, OR				
Portland Gen. Elec.	50-yr dynamic results:		0.9777	-0.32
North Anna No. 1	907	1066.00	1.2786	0.086
Mineral, VA				
VA Elec. & Power Co.	50-yr dynamic results:		0.7750	-3.25
David Besse No. 1	906	957.00	1.3729	0.110
Oak Harbor, OH				
Toledo Edison Co.	50-yr dynamic results:			

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), pp.294-297.
Use table 7.1 for static net-energy calculations.
Use table B-4 for 50-yr dynamic calculations.

Table B-5 Continued

SUMMARY OF NET ENERGY ANALYSES
Based on 1981 Komanoff Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	(E) LIFECYCLE NET ENERGY (QUADS)
Farley No. 1	829	1113.00	1.2418	0.073
Dothan, AL				
Alabama Power Co.	50-yr dynamic results:		0.7589	-3.25
Komanoff Base Case	1150	1460.00	1.0242	0.012
Central United States				
Miscellaneous Utilities	50-yr dynamic results:		0.6583	-7.38
Komanoff Northeast	1150	1820.00	0.8666	-0.079
Northeast United States				
Miscellaneous Utilities	50-yr dynamic results:		0.5781	-10.35
50-Yr. Break-Even	1150	565.35	1.0242	
United States	50-yr dynamic results:		1.0001	0.00

Source: Columns B & C from Charles E. Komanoff, Power Plant Cost Escalation, (New York: Komanoff Energy Associates, 1981), p.281.
Use table 7.1 for static net-energy calculations.
Use table B-4 for 50-yr dynamic calculations.
NOTE: ALL COSTS EXPRESSED IN 1979 DOLLARS

Following are summary results of the net-energy analyses based on the 1984 Komanoff cost-estimate set.[1] The capital costs of these 34 plants were expressed in 1982 dollars. The individual calculations that appear for each plant were made using an Energy/GNP Ratio of 28,266 Btu's/$1982.

It will be noted that sensitivity analyses were also done for low-value and high-value Energy/GNP coefficients and the results are shown for both static and dynamic net-energy calculations.

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[1]Charles Komanoff, "Assessing the High Costs of New Nuclear Power Plants," Idem.

Table B-6

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Braidiwood (twin) Braidiwood, IL Commonwealth Edison Co.	2240	1113.00	1.4895	0.330
Catawba (twin) Lake Wyle, SC Duke Power Co.	2290	1113.00	1.4895	0.315
La Salle No. 2 Seneca, IL Commonwealth Edison Co.	1078	1113.00	1.4895	0.159
McGuire (twin) Cowan's Ford Dam, NC Duke Power Co.	2360	1113.00	1.4895	0.348
Watts Bar (Twin) Spring City, TN Tennessee Valley Auth.	2354	1113.00	1.4895	0.347

Sensitivity Analyses for Braidiwood Set

(A)		(B)	(C)	(D)	(E)	(F)
					50-Year Dynamic	
Group	Plant Name	Gen Cap. MW	Cost Per KW	Static O/I Ratio	O/I Ratio	Avg. Ann. Net Energy (Quads)
1	Braidiwood (Twin):					
	21436 Btu's/$82	2240	1113	1.9641	1.6582	11.15
	28266 Btu's/$82			1.4895	1.2702	5.89
	34324 Btu's$/82			1.2266	1.0460	1.22

(Similarly for Catawba, LaSalle, McGuire, and Watts Bar.)

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1982).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Bellefonte (Twin) Scottsboro, AL Tennessee Valley Auth.	2426	1484.00	1.2256	0.200
Byron (Twin) Byron, IL Commonwealth Edison Co.	2426	1484.00	1.2256	0.200
Comanche Peak (Twin) Glen Rose, TX TX Utilities Gen. Co.	2222	1484.00	1.2256	0.183
St Lucie Ft Pierce, FL FL Power & Light Co.	810	1484.00	1.2256	0.069
Virgil C. Summer Braoad River, SC SC Electric/Gas Co.	900	1484.00	1.2256	0.074

Sensitivity Analysis for Bellefonte Set

(A) Group	Plant Name	(B) Gen Cap. MW	(C) Cost Per KW	(D) Static O/I Ratio	(E) 50-Year Dynamic O/I Ratio	(F) 50-Year Dynamic Avg. Ann. Net Energy (Quads)
2	Bellefonte (Twin):					
	21436 Btu's/$82	2426	1484	1.6162	1.3648	8.02
	28266 Btu's/$82			1.2256	1.0350	1.02
	34324 Btu's$/82			1.0093	0.8523	-5.19

(Similarly for Byron, Comanche Peak, St. Lucie, and Sumner).

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1982).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Palo Verde (Twin) Wintersburg, AZ Arizona Public Serv. Co.	2540	1484.00	1.0092	0.103
San Onofre (Twin) San Clemente, CA Southern CA Edison Co.	2200	1724.00	1.0092	0.089
Susquehanna (Twin) Barwick, PA PA Power & Light Co.	2100	1724.00	1.0092	0.085
A. W. Vogtle (Twin) Waynesboro, GA Georgia Power Co.	2200	1724.00	1.0092	0.089
Wolf Creek Burlington, KS Kansas Gas & Elec. Co.	1150	1724.00	1.0092	0.047

Sensitivity Analysis for Palo Verde Set

(A)		(B)	(C)	(D)	(E)	(F)
					50-Year Dynamic	
		Gen	Cost	Static		Avg. Ann.
		Cap.	Per	O/I	O/I	Net Energy
Group	Plant Name	MW	KW	Ratio	Ratio	(Quads)
3	Palo Verde (Twin)					
	21436 Btu's/$82	2200	1724	1.4500	1.2187	4.89
	28266 Btu's/$82			1.0092	0.9242	-2.23
	34324 Btu's$/82			0.9055	0.7611	-8.53

(Similarly for Son Onofre, Susquehanna, Vogtle, and Wolf Creek).

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1979).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Callaway (Twin) Fulton, MO Union Elec. Co.	2240	2018.00	0.9766	-0.024
Grand Gulf (Twin) Fort Gibson, MS MS Power & Light Co.	2500	2018.00	0.9766	-0.027
Millstone No. 3 Waterford, CT Northeast Nuclear Energy Co	1158	2018.00	0.9766	-0.012
Perry (Twin) North Perry, OH Cleveland Elec. Illuminatin	2410	2018.00	0.9766	-0.026
South Texas (Twin) Palacios, TX Houston Lighting & Power Co	2500	2018.00	0.9766	-0.027

Sensitivity Analysis for Callaway Set

(A) Group	Plant Name	(B) Gen Cap. MW	(C) Cost Per KW	(D) Static O/I Ratio	(E) 50-Year Dynamic O/I Ratio	(F) 50-Year Dynamic Avg. Ann. Net Energy (Quads)
4	Callaway (Twin)					
	21436 Btu's/$82	2240	2018	1.2878	1.0775	1.99
	28266 Btu's/$82			0.9766	0.8171	-6.19
	34324 Btu's$/82			0.8043	0.6729	-13.45

(Similarly for Grand Gulf, Millstone 3, Perry, and South Texas.)

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1979).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Clinton (Twin) Clinton, IL Illinois Power Co.	1866	2444.00	0.8404	-0.159
Enrico Fermi Newport, MI Detroit Edison Co.	1083	2444.00	0.8404	-0.092
Sharon Harris (Twin) Bonsai, NC Carolina Power & Light Co.	1800	2444.00	0.8404	-0.153
Limerick No. 1 Pottstown, PA Philadelphia Elec. Co.	1055	2444.00	0.8404	-0.090
Waterford No. 3 Taft, LA LA Power & Light Co.	1113	2444.00	0.8404	-0.095

Sensitivity Analysis for Clinton Set

(A) Group	Plant Name	(B) Gen Cap. MW	(C) Cost Per KW	(D) Static O/I Ratio	(E) 50-Year Dynamic O/I Ratio	(F) 50-Year Dynamic Avg. Ann. Net Energy (Quads)
5	Clinton (Twin)					
	21436 Btu's/$82	1866	2444	1.1082	0.9226	-1.93
	28266 Btu's/$82			0.8404	0.6997	-9.90
	34324 Btu's$/82			0.6921	0.5762	-16.92

(Similarly for Fermi, Harris, Limerick 1, and Waterford.)

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1979).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Hope Creek (Twin) Salem, NJ Public Service Elec./Gas	2144	2797.00	0.7534	-0.315
River Bend (Twin) St Francisville, LA Gulf States Utilities	1868	2797.00	0.7534	-0.274
Seabrook No. 1 Seabrook, NH Public Service Co. of NH	1200	2797.00	0.7534	-0.176
WPPS No. 2 Richland, WA WA Public Power Supply Sys.	1100	2797.00	0.7534	-0.161
William H. Zimmer No. 1 Moscow, OH Cinn. Gas & Elec. Co.	810	2797.00	0.7534	-0.119

Sensitivity Analysis for Hope Creek Set

(A) Group	Plant Name	(B) Gen Cap. MW	(C) Cost Per KW	(D) Static O/I Ratio	(E) 50-Year Dynamic O/I Ratio	(F) 50-Year Dynamic Avg. Ann. Net Energy (Quads)
6	Hope Creek (Twin)					
	21436 Btu's/$82	2144	2797	0.9934	0.8294	-5.64
	28266 Btu's/$82			0.7534	0.6252	-15.88
	34324 Btu's$/82			0.6204	0.5148	-24.97

(Similarly for River Bend, Seabrook 1, WPPS 2, and Zimmer.)

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1979).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Table B-4 Continued

SUMMARY, STATIC NET ENERGY ANALYSES
Based on 1984 Komanoff Capital Cost Estimates

(A) NAME LOCATION PRINCIPLE OWNER	(B) PLANT SIZE MEGAWATT	(C) $COST PER KILOWATT	(D) OUTPUT/ INPUT RATIO	LIFECYCLE NET ENERGY (QUADS)
Beaver Valley No. 2 Shippingport, PA Duquesne Light Co.	833	3411.00	0.6383	-0.212
Midland No. 2 Midland, MI Consumer's Power Co.	808	3411.00	0.6383	-0.205
Nine Mile Point No. 2 Scriba, NY Niagara Mohawk Power Corp.	1080	3411.00	0.6383	-0.274
Shoreham Brookhaven, NY Long Island Lighting Co.	846	3411.00	0.6383	-0.215

Sensitivity Analysis for Beaver Valley 2 Set

(A)		(B)	(C)	(D)	(E)	(F)
					50-Year Dynamic	
		Gen	Cost	Static		Avg. Ann.
		Cap.	Per	O/I	O/I	Net Energy
Group	Plant Name	MW	KW	Ratio	Ratio	(Quads)
7	Beaver Valley 2					
	21436 Btu's/$82	833	3411	0.8147	0.6956	-4.50
	28266 Btu's/$82			0.6383	0.5275	-9.22
	34324 Btu's$/82			0.5257	0.4344	-13.40

(Similarly for Midland 2, Nine Mile Pt. 2, and Shoreham)

Notes: Column B shows Generating Capacity in Megawatts.
Column C shows Cost per Installed Kilowatt ($1979).
Column D shows Static Net Energy Analysis Output/Input Ratio.
Column E shows 50-Yr. Dynamic Output/Input Ratio.
Column F shows Average annual net energy over 50-yr period.
All Calculations related to $1982 for E/GNP coefficients.

Source: Columns B & C from Charles E. Komanoff, "Assessing the High Costs of Nuclear Power Plants," Public Utilities Fortnightly, p.36.
Columns D & E Calculated using table B-1 Model
Dynamic net-energy calculations combine models of tables B-1 and B-2.

Appendix C

WIND ENERGY SYSTEMS

Detailed Explanation of Net-Energy Models

Static Net-Energy Model

In the following section paragraph numbers correspond to the line numbers of each table. cell C1, refers to column C, line 1, and so forth.

Line 1 - Expected Life

Wind machines were assumed to last 25 years (cell C1). This was the estimate furnished by the manufacturers. Transmission and distribution systems were also expected to last 25 years.

Line 2 - Efficiency Factor

A factor of 50% (cell C2), was adopted and the number is considered to be a conservative figure because of the reasoning developed in Chapter 6. U. S. utilities are only using about 40% of theoretical potential capacity (See Chapter 6). This represents a decrease from a high of 57% achieved in 1956 (See Table 6.1)

Line 3 - Kilowatts of Capacity

As furnished by the manufacturer.

Line 5 - Kilowatt-Hours Generated

The number in cell E was calculated by multiplying the expected life (25 years, cell C1) times a 50% Capacity Factor times the estimated annual output of the WECS (cell C5). The estimated annual output was furnished by the manufacturer.

Table C-1

ENERGY SCIENCES 200-KILOWATT WECS
12 MPH Average Wind
Capital Cost Reduced 25% Zero Other Cost

(A) LINE	(B) ITEM	(C) VARIABLE	(D) EQUATION	(E) RESULTS
1	Expected Life, Yrs.:	25.0000		
2	Efficiency Factor	0.5000		
3	Kilowatts of Capacity:	200.0000		
4	kWh's Generated			
5	@ 12 MPH:†	3.5000e05	C1*C2*C5 =	4375000.0000
6	Installed Cost:	712.5000	C3*C6 =	142500.0000
7	Other Plant Cost:			0.0000
8	Front-End Cost:		E6+E7 =	142500.0000
9	Fixed Charge:	0.0950	C1*E8*C9 =	338437.5000
10	Decommissioning Cost:			0.0000
11	O. & M. Cost:	1425.0000	C1 *C11=	35625.0000
12	Lifecycle Cost:		SUM(E9>E11)=	374062.5000
13	Distributive Cost:		E12-E6 =	231562.5000
14	Output in Btu's:	3413.0000	E5*C14 =	1.4931e10
15	Front-End Input Ener:	2.8116e04	E8*C15 =	4.0065e09
16	Distrib. Input Ener:	2.8116e04	E13*C16 =	6.5106e09
17	Total Input Energy:		E15+E16 =	1.0517e10
18	Output/Input Ratio:		E14/E17 =	1.4197
19	Net Energy		E14-E17 =	4.4140e09

Note: The notation 1.0517e10, for example, is engineering notation where 'e10' means decimal point is actually 10 places to the right.
† includes so-called Other Costs, which includes trans. & Distr.

Selected variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 19

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C2*C4, for example, means that the quantity in column C, line 2 is multiplied times the quantity at column C, line 4.

SUM(E8>E10) means that the quantities in column E from lines 8 through 10 are added together.

E14/E17 is notation to mean that cell E14 is divided by cell E17.

Line 18 shows the Output/Input Ratio to be 1.4197 to 1

Line 19 shows that over its 30-year lifecycle a Komanoff Base-Case plant would yield 4.4140e09 British thermal units of net energy, where "e09" means that the decimal point is 9 places to the right. Also, 4.4140e09 = .000004414 quads

Line 6 - Installed Cost

The cost of the production plant (cell E6) was furnished by the manufacturer. Cell C6 shows that the per-kilowatt capacity cost is arrived at by dividing total production plant cost by the Kilowatts of capacity (cell C3).

Line 7 - Other Plant

These costs (cell E7) were calculated by taking 50% of Installed Cost (cell E6). This is believed to be a conservative procedure because, as discussed in chapter 6, this cost has been approximately 160% to 170% of Generating Plant Cost for U. S. utilities. The rationale for charging wind energy systems with a portion of the electric utility grid was discussed in chapters 6 and 8. Most wind systems are being marketed on the basis of inter-connection with the central power station utility grid system and therefore must be charged with a share of that energy cost.

Line 8 - Front-End Cost

The number in cell E8 is calculated for the purposes of making dynamic net-energy calculations and represents those costs incurred before any electricity is generated and is the result of summing cell E6 plus E7.

Line 9 - Fixed Charge

A real rate of 9.5% (cell C9) was used to calculate total real economic cost of Production Plant, and Other Plant, including transmission and distribution costs[1]. This is slightly lower than the constant used by Komanoff for coal plants (i.e. .0978). Fixed-charge cost (cell E8) was arrived at by multiplying the Expected Life of 25 years (cell C1) by Front-End Cost (cell E7) by the fixed-charge rate of .0950 (cell C9). The total fixed-charge cost also accounts for amortization of the initial capital cost.

Line 10 - Decommissioning Cost

It was assumed that the Decommissioning Cost would equal the salvage value of the plant and therefore was zero.

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[1] "Real" cost means corrected for inflation. A "real" interest rate of 3.8% was used by Komanoff in his calculations and is a part of the fixed charge cost, and is assumed (approximately) in these calculations.

Line 11 - Operations and Maintenance Cost

A uniform annual Operation and Maintenance (O&M) charge of 1% of capital cost was used throughout the WECS analyses. The number in E11 was obtained by multiplying 1% times Installed Cost times twenty-five years. This is believed to be a generous (low) estimate and the results are robust accordingly.

Line 12 - Total Life-Cycle Cost

The total is the result of summing of cells E9 through E11.

Line 13 - Distributive Cost

This is a term adapted to identify those costs that are to be distributed over the generating life of each plant (as opposed to Front-End Costs). It is obtained by subtracting Front-End Costs (C8) from the Total Life-Cycle Cost (C12).

Line 14 - Output in Btu's

The number is calculated by multiplying a constant of 3413 (Btu's per kilowatt hour) by the total number of kilowatt-hours generated (cell E5) during the life of the facility. There are 3413 Btu's, thermal, available from one kilowatt-hour of electricity.

Line 15 - Front-End Energy Input

This number (Btu's) is arrived at by multiplying the total Life-Cycle Cost (cell E12) times a factor of 28,116 Btu's per dollar of Gross National Product ($1983). The underlying rationale for this procedure was developed in chapters 5 and 6. It will be noted that this Energy/GNP ratio is smaller than that used for the nuclear calculations and is the mean value for the ratios between 1947 and 1983 ($1983). An Energy/GNP ratio of 35,791 Btu's/$ for nuclear plants was related to 1979 dollars. The costs for wind machines are for 1983 dollars (the year of the survey).

Line-16 - Distributive Input Energy

This number (Btu's) is arrived at by multiplying distributive dollar cost (cell E13) times 28,116 Btu's per dollar.

Line 17 - Total-Input Energy

The number is obtained by summing E15 + E16.

Line 18 - Output/Input Ratio

The ratio is calculated by merely dividing Total-Output Energy (cell E14) by Total-Input Energy (cell E17).

Dynamic Model Explained

A line-by-line explanation of the model follows and paragraph numbers correspond to line numbers in each analysis.

Line 1 - Construction Time

For ease of analysis, it was assumed that it would take a year to install any set (1 to 1 million) of wind machines selected.

Line 2 - Cycle

50-Year and 100-Year Construction and Operation Cycles were chosen. Any number can be inserted in the model, however.

Line 3 - Years of Generation

Since it takes one year to construct and install a set, then the Years of Generation (line 2) is obtained by subtracting one from Cycle in Years (cell C2).

Line 4 - Number Constructed

The number to be constructed each year is entered as a variable in cell C4, in the example case it is 5.0000e5 which is scientific notation for 500,000.

Line 5 - Annual Output

This is the annual output of one set of machines. The number in Cell C5 is obtained from cell E14 of the Static Net Energy Analysis model (table C-1). The annual output of one set of machines is obtained by dividing the Life-Cycle Output of a single machine (C5) by 25 years and multiplying the results times the number of machines constructed each year (C4).

Table C-2

100-YEAR DYNAMIC NET ENERGY ANALYSIS
Energy Sciences 200-Kilowatt WECS
Capital Cost Reduced 25%, Zero Other Plant Cost

(A) Line No.	(B) Item	(C) Variable	(D) Calculation:	(E) Result
1	Const. Time:	1 Year		
2	Cycle:	100 Years		
3	Years of Generation:	99 Years		
4	No. Constr. Per Year:	500,000 WECS		
5	Annual Output, 1 Set (From E13, Static):	1.4931e10	(C5/25)*C4 =	2.9862e14
6	Front-End Input Energy (From E14, Static):	4.0065e09	C2*C4*C6 =	2.0032e17
7	Ann. Distr. Input Energy (C7 From E15, Static):	6.1506e09	(C7/25)*C4 =	1.2301e14
8	Accumulated WEC Years:	2.1750e03	=SUM(1,2,3...99) -SUM(1,2,3...74)	
9	Life-Cycle System Output:	(Btu's)	E5*C8 =	6.4949e17
10	Life-Cycle System Input:	(Btu's)	(E7*C8)+C6 =	4.6787e17
11	Output/Input Ratio:		E9/E10 =	1.3881
12	Net Energy, End Period:	(Btu's)	E9-E10 =	1.8162e17
13	No. Windmills On-Line End 100 Years:		25*C4 =	1.2500e07
14	Ann. Net Energy:		E12/C2 =	1.8162e15
15	Total No. Constructed:		C3*C4 =	4.9500e07
16	Total No. Decommissioned:		(C3-25)*C4 =	3.7000e07

Notes: Generally, variables are shown in column C, although it will be seen that sometimes a number in column E is used in subsequent calculations.

Equations are shown in column D for results in column E.

Calculations start at line 4 and proceed, in sequence, through line 16.

The notation C2 (cell C2), for example, refers to entry located at the intersection of column C and line 2.

C3*C4, for example, means that the quantity in column C, line 3 is multiplied times the quantity at column C, line 4.

SUM(1,2,3...99) means integers 1,2,3...99) are summed.

Sum(1,2,3...74), similarly. (accounting for decommission yrs.)

E9/E10 means that cell E12 is divided by cell E12.

E14 shows annual net energy of 1.8162e15 Btu's of energy/yr. where "e15" is scientific notation meaning decimal is 15 places to right. 1.8.62e15 = 1.8162 quads.

Model fits computer software known as electronic spread sheet.

Line 16 shows that 37 million wind machines would be decomm.

Information in cells C5, C6, & C7 taken from table 8.3.

Line 6 - Front-End Input Energy

The number in cell C6 is obtained from cell E15, of the Static Net Energy model (Table C-1). To obtain the total amount for the 50-year cycle, cell C6 is multiplied by the life-cycle years (cell C2) times the number of WECS constructed per year (cell C4).

Line 7 - Annual Distributive Input Energy

The quantity shown in E7 is that amount of energy cost that is distributed over the life-cycle of the total system. Each year interest charges are incurred, dividends and taxes must be paid, and maintenance and operational costs are incurred. The Distributive Cost for one WEC is obtained from cell E15 the static model (Table C-1). This number is then divided by 25 years (life-span of a single machine/set) and then the result is multiplied by the number of WEC's constructed each year. The number in cell E7 is an annual amount of distributable energy that is incurred by each set of WECs constructed, each year.

Line 8 - Accumulated Alpha Units

This is an adapted term to identify the accumulated system-years after each set is constructed. The intuitive model was shown as Figure 7.1 and is further illustrated in Figure B-1. The number in cell C8 is calculated in the same manner as in Chapter 7 as that for nuclear reactors. The number in cell C8 is obtained by summing integers (e.g., 1,2,3 . . .99) and subtracting 1,2,3, . . .74). The foregoing would apply to any 100-year dynamic model for a set of machines constructed in a 1-year time span and that will last 25 years. Subtracting out the last series of integers accounts for the alpha units that are related to that space in the model (triangle, if you will) that is related to retired machines (see Figure C-1.)

Line 9 - Life-Cycle System Output

The number (cell E9) is obtained by multiplying Annual Output Energy of one set of machines (cell E5) times Accumulated Alpha Years (cell C8).

Line 10 - Life-Cycle System Input

This number is obtained by first multiplying the Distributive Input-Energy (E7) times the Accumulated WEC years (C8) and adding the Front-End Energy (cell E6).

Line 11 - Output /Input Ratio

The ratio is obtained by dividing cell E9 by cell E10.

Line 12 - Net Energy

Net-energy is obtained by merely subtracting total system input (cell E10) from total system output (cell E9).

Line 13 - Number of Windmills On-Line

This is obtained by multiplying the annual No. Constructed Per Year times 25 years. It is assumed that it takes a year to construct and install the "set" and that System Life on one set of wind machines is 25 years. Therefore, the maximum that can be operating at one time is twenty-five years times the annual construction rate. Incidentally, the input and output results are scalar -- i.e., you can double or quadruple the rate of construction and the Output/Input Ratio does not change, **ceteris paribus.**

Line 14 - Annual Net-Energy

This is obtained by dividing Net Energy, End Period (cell E12) by Cycle in Years (cell C2), in this case 100 years.

Line 15 - Total Number Constructed

The number is obtained by multiplying the Number Constructed per Year times (C4) times Cycle in Years.

Line 16 - Total Number Decommissioned

This is obtained by subtracting 25 Year (life of a single set) from Years of Generation (cell C3) and multiplying the result by the annual rate of construction.

Table C-3

SUMMARY, ENERGY SCIENCES, INC.
Wind Energy Conversion Systems
Static Net Energy Analyses

(A) Line No.	(B) Variable Conditions:	(C) Static O/I Ratio
	68-Kilowatt Wind Machine:	
1.	12 MPH, 100,000 kWh ann:	0.4538
	a. Install Cost @ 50%:	0.6044
	b. Plus Zero Trans. & Distr.	0.9067
2.	14 MPH, 193,000 kWh ann:	0.8750
3.	18 MPH, 250,000 kWh ann:	1.1334
	200-Kilowatt Wind Machine:	
4.	12 MPH, 350,000 kWh ann.:	0.7098
	a. Install. Cost @ 50%:	0.9465
	b. Plus Zero Trans & Distr.:	1.4197†
5.	14 MPH, 500,000 kWh ann.:	1.0141
6.	18MPH, 800,000 kWh ann.:	1.6225

Sensitivity Analyses at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
1.	Energy Sciences Inc:			
	a. 200-KW MACH:			
	21333 Btu's/$1979	0.9355	1.2474	1.8711
	28116 Btu's/$1979	0.7098	0.9465	1.4197
	34172 Btu's/$1979	0.5845	0.7794	1.1691
	b. 68-KW MACH:			
	21333 Btu's/$1979	0.5915	0.7966	1.1950
	28116 Btu's/$1979	0.4533	0.6044	0.9067
	34172 Btu's/$1979	0.3733	0.4978	0.7467

Table C-4

SUMMARY, BOEING COMPANY
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A) Line No.	(B) Mean Value Wind Conditions:	(C) Input Ratio
1.	17 MPH, 8.26 Mil. kwh ann.:	0.5998
a.	Install. Cost @ 75%:	0.7998
b.	Plus Zero Trans. & Distr.:	1.1997

Sensitivity Analyses at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
	Boeing Co:			
	2500-KW Mach:			
	21333 Btu's/$1979	0.6708	0.8944	1.3416
	28116 Btu's/$1979	0.5089	0.6786	0.1017
	34172 Btu's/$1979	0.3852	0.5137	0.7705

Table C-5

SUMMARY, CARTER WIND SYSTEMS
Wind Energy Conversion Systems
Static Net Energy Analyses

(A) No.		(B) Wind Condition	(C) Static I/O Ratio
		25-Kilowatt Wind Machine:	
1.		12 MPH, 36,750 kWh Annually	0.4568
	a.	Installed Cost 50%:	0.6091
	b.	Zero Trans. & Distr. Cost:	0.9136
2.		14 MPH, 50,500 kWh Annually	0.6217
3.		18 MPH, 79,000 kWh Annually:	0.9820
		200-Kilowatt Wind Machine:	
4.		12 MPH, 294,000 kWh Annually:	0.4531
	a.	Installed Cost 50%:	0.6042
	b.	Zero Trans. & Distr. Cost:	0.9063
5.		14 MPH, 404,000 kWh Annually	0.6227
6.		16 MPH, 520,000 kWh Annually	1.0546
7.		18 MPH, 636,000 kWh Annually	1.2899

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
3.	Carter Wind Systems			
	a. 200-KW Mach:			
	21333 Btu's/$1979	0.6029	0.7963	1.1945
	28116 Btu's/$1979	0.4531	0.6042	0.9063
	34172 Btu's/$1979	0.3732	0.4976	0.7464
	b. 25-KW Mach:			
	21333 Btu's/$1979	0.6021	0.8028	1.2042
	28116 Btu's/$1979	0.4568	0.6091	0.9136
	34172 Btu's/$1979	0.3458	0.4610	0.6916

Table C-6

SUMMARY, BERGEY WINDPOWER COMPANY
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Static I/O Ratio
	10 KWe Machine:	
1.	10 MPH, 13,800 kwh ann.:	0.2727
2.	12 MPH, 18,000 kwh ann.:	0.3557
a.	75% Install Cost:	0.4742
b.	Zero Trans. & Distr.:	0.7114
3	14 MPH, 22,500 kwh ann.:	0.4446
4.	16 MPH, 27,000 kwh ann.:	0.5335
5.	18 MPH, 29,000 kwh ann.:	0.5731
	1.4 KWe Machine:	
6.	10 MPH, 1060 kwh ann.:	0.0680
7.	12 MPH, 1800 kwh ann.:	0.1156
a.	75% of Install Cost	0.1541
b.	Plus Zero Trans. & Distr:	0.2312
8.	14 MPH, 2600 kwh ann.:	0.1669

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
4.	Bergey Windpower Co.			
	a. 10-KW Mach:			
	21333 Btu's/$1979	0.4668	0.6251	0.7032
	28116 Btu's/$1979	0.3557	0.4742	0.5335
	34172 Btu's/$1979	0.2143	0.2857	0.4286
	b. 1 4-KW Mach:			
	21333 Btu's/$1979	0.1451	0.1934	0.2902
	28116 Btu's/$1979	0.1101	0.1468	0.2202
	34172 Btu's/$1979	0.0833	0.1111	0.1666

Table C-7

SUMMARY, WINDWORKS, INC.
12-Kilowatt WECS
Static Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
1.	10 MPH, 26,000 kWh Annually	0.2504
2.	12 MPH, 38,000 kWh Annually	0.3660
	a. Installed Cost @ 75%:	0.4881
	b. Zero Trans. & Distr. Cost:	0.7321
3.	14 MPH, 49,000 kWh Annually	0.4720
4.	16 MPH, 58,000 kWh Annually:	0.5587

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
5.	12-KW Mach:			
	21333 Btu's/$1979	0.4825	0.6433	0.9650
	28116 Btu's/$1979	0.3660	0.4881	0.7321
	34172 Btu's/$1979	0.2771	0.6433	0.5542

Table C-8

SUMMARY, HAMILTON STANDARD COMPANY
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A)	(B)	(C)
Line No.	Wind Condition:	Output/ Input Ratio
1.	12 MPH, 7 Million kwh ann.:	0.3371
	a. Install. Cost @ 75%:	0.4495
	b. Plus Zero Trans. & Distr.:	0.6743
2.	14 MPH, 10 Mil. kwh ann.:	0.4817
3	16 MPH, 15 Mil. kwh ann.:	0.7225
4.	18 MPH, 17.4 Mil kwh ann.:	0.8381

Sensitivity Analysis at Varying E/GNP Ratios

(A)	(B)	(C)	(D)	(E)
NO.		Static O/I Ratio (100%)	Static O/I Ratio (75%)	Static O/I Ratio (Zero T&D)
6	Hamilton Standard:			
	4000-KW Mach:			
	21333 Btu's/$1979	0.4444	0.5925	0.8888
	28116 Btu's/$1979	0.3371	0.4495	0.6743
	34172 Btu's/$1979	0.2552	0.3403	0.5105

Table C-9

SUMMARY, JACOBS WIND ENERGY SYSTEMS
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
	10 kWe Wind Machine:	
1.	10 MPH, 10,347 kwh ann.:	0.1733
2.	12 MPH, 16,852 kwh ann.:	0.2823
	a. @ 75% Install. Cost:	0.3764
	b. Zero Trans. & Distr.:	0.5647
3	14 MPH, 24,070 kwh ann.:	0.4057
	17.5 kWe Wind Machine:	
4.	10 MPH, 15,579 kwh ann.:	0.1500
5.	12 MPH, 25,772 kwh ann.:	0.2482
	a. 75% Installed Cost:	0.3310
	b. Plus Zero Trans. & Distr.	0.4965
6.	14 MPH, 37,517 kwh ann:	0.3613

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
7	Jacobs:			
	a. 17.5-KW Mach:			
	21333 Btu's/$1979	0.3272	0.4363	0.6544
	28116 Btu's/$1979	0.2482	0.3310	0.4965
	34172 Btu's/$1979	0.1877	0.2506	0.3759
	b. 10-KW Mach:			
	21333 Btu's/$1979	0.3721	0.4961	0.7442
	28116 Btu's/$1979	0.2823	0.3764	0.5647
	34172 Btu's/$1979	0.2137	0.2849	0.4274

Table C-10

SUMMARY WTG, INC.
Wind Energy Conversion Systems
Static Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
	300-Kilowatt Wind Machine:	
1.	12 MPH, 273,000 kWh Annually:	0.2504
a.	Installed cost @ 75%:	0.3339
b.	Plus Zero Trans & Distr.:	0.5009
2.	14 MPH, 429,000 kWh Annually:	0.3936
3.	18 MPH Wind:	0.4014
	750-Kilowatt Wind Machine:	
4.	12 MPH, 580,000 kWh Annually:	0.2591
a.	Installed Cost @ 75%:	0.3455
b.	Plus Zero Trans. & Distr.:	0.5182
5.	14 MPH, 951,000 kWh Annually:	0.4249
6.	16 MPH, 1,350,000 kWh Ann.	0.6031
7.	18 MPH, 1,771,000 kWh Ann.	0.7912

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
8.	WTG, Inc.			
	a. 750-KW Machine:			
	21333 Btu's/$1979	0.3415	0.4533	0.6830
	28116 Btu's/$1979	0.2591	0.3455	0.5182
	34172 Btu's/$1979	0.1961	0.2615	0.3923
	b. 300-KW Mach:			
	21333 Btu's/$1979	0.4951	0.4401	0.6602
	28116 Btu's/$1979	0.2504	0.3339	0.5009
	34172 Btu's/$1979	0.1896	0.2528	0.3792

Table C-33

Table C-11

SUMMARY HUMMINGBIRD WINDPOWER
Wind Energy Conversion Systems
Static Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
1.	10 MPH, 4800 kWh Annually:	0.1233
2.	12 MPH, 8500 kWh Annually:	0.2183
	a. Installed cost @ 75%:	0.2911
	b. Plus Zero Trans. & Distr.:	0.4367
3.	14 MPH, 12,600 kWh Annually:	0.3237
4.	18 MPH, 20,500 kWh Annually:	0.5266

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
9.	Hummingbird:			
	6-KW Mach:			
	21333 Btu's/$1979	0.2878	0.3837	0.5756
	28116 Btu's/$1979	0.2183	0.2911	0.4367
	34172 Btu's/$1979	0.1653	0.2204	0.3306

Table C-12

SUMMARY BERTOIA STUDIOS, LTD.
Wind Energy Conversion Systems
Static Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
1.	10 MPH, 4000 kwh ann.:	0.1185
2.	12 MPH, 6500 kwh ann.:	0.1926
a.	Install. Cost 75%:	0.2569
b.	Plus Zero Trans. & Distr.	0.3853
3	14 MPH, 8000 kwh ann.:	0.2371

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
10	Bertoia Studios			
	3-KW Mach:			
	21333 Btu's/$1979	0.2539	0.3385	0.5078
	28116 Btu's/$1979	0.1926	0.2569	0.3853
	34172 Btu's/$1979	0.1458	0.1944	0.2917

Table C-13

SUMMARY, FLOWIND INC.
Wind Energy Conversion Systems
Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
1	14 Miles Per Hour	.3691
2	@ 75% of capital cost	.4920
3.	less Trans. & Distr.	.7380

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
11.	Flowind Inc.			
	170-KW Mach @ 14 MPH			
	21333 Btu's/$1979	0.7885	0.6648	0.9972
	28116 Btu's/$1979	0.3988	0.5044	0.7566
	34172 Btu's/$1979	0.3019	0.3818	0.5728

Note: An example of this type of wind machine is is located on the east side of Inter-state 35 approximately 1 mile north of Norman, OK.

Table C-14

SUMMARY, DAF INDAL, LTD.
Wind Energy Conversion Systems
Net Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) Output/ Input Ratio
	50-Kilowatt WECS:	
	14 MPH Average Wind:	0.1300
	a. Installed Cost @ 75%:	0.1734
	b. Plus Zero Trans & Distr.:	0.2601
	500-Kilowatt WECS:	
	14 MPH Average Wind	0.3029
	a. Installed Cost @ 75%:	0.4039
	b. Plus Zero Trans. & Distr.:	0.6059

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
12	DAF Indal Ltd.			
	a. 500-KW Mach:			
	21333 Btu's/$1979	0.3993	0.5324	0.7986
	28116 Btu's/$1979	0.3029	0.4039	0.6059
	34172 Btu's/$1979	0.2293	0.3057	0.4586
	b. 300-KW Mach:			
	21333 Btu's/$1979	0.1714	0.2285	0.3428
	28116 Btu's/$1979	0.1300	0.1734	0.2601
	34172 Btu's/$1979	0.0984	0.1312	0.1969

Table C-15

SUMMARY, NORTH WIND POWER COMPANY
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) O/I Ratio
	2 kWe Wind Machine:	
1.	10 MPH, 4,800 kwh ann:	0.1887
2.	12 MPH, 7,200 Kwh ann.:	0.2831
a.	Install Cost @ 75%:	0.3775
b.	Plus Zero Trans. & Distr.	0.5662
3.	14 MPH, 9,000 kwh ann.:	0.4718
	16 kWe Wind Machine:	
4.	10 MPH, 20,000 kwh ann.:	0.2798
5.	12 MPH, 30,000 kwh ann.:	0.4198
a.	Install. Cost @ 75%	0.5597
b.	Zero Trans. & Distr.:	0.8396
6.	14 MPH, 43,000 kwh ann.:	0.6017

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
13	North Wind:			
	a. 16-KW Mach:			
	21333 Btu's/$1979	0.5531	0.7375	1.1063
	28116 Btu's/$1979	0.4197	0.5596	0.8394
	34172 Btu's/$1979	0.3177	0.4236	0.6354
	b. 2-KW Mach:			
	21333 Btu's/$1979	0.3731	0.4975	0.7462
	28116 Btu's/$1979	0.2831	0.3775	0.5662
	34172 Btu's/$1979	0.2143	0.2857	0.4286

Table C-15

SUMMARY, NORTH WIND POWER COMPANY
Wind Energy Conversion Systems
Static Net-Energy Analyses

(A) Line No.	(B) Wind Condition:	(C) O/I Ratio
	2 kWe Wind Machine:	
1.	10 MPH, 4,800 kwh ann:	0.1887
2.	12 MPH, 7,200 Kwh ann.:	0.2831
a.	Install Cost @ 75%:	0.3775
b.	Plus Zero Trans. & Distr.	0.5662
3.	14 MPH, 9,000 kwh ann.:	0.4718
	16 kWe Wind Machine:	
4.	10 MPH, 20,000 kwh ann.:	0.2798
5.	12 MPH, 30,000 kwh ann.:	0.4198
a.	Install. Cost @ 75%	0.5597
b.	Zero Trans. & Distr.:	0.8396
6.	14 MPH, 43,000 kwh ann.:	0.6017

Sensitivity Analysis at Varying E/GNP Ratios

(A) NO.	(B)	(C) Static O/I Ratio (100%)	(D) Static O/I Ratio (75%)	(E) Static O/I Ratio (Zero T&D)
13	North Wind:			
	a. 16-KW Mach:			
	21333 Btu's/$1979	0.5531	0.7375	1.1063
	28116 Btu's/$1979	0.4197	0.5596	0.8394
	34172 Btu's/$1979	0.3177	0.4236	0.6354
	b. 2-KW Mach:			
	21333 Btu's/$1979	0.3731	0.4975	0.7462
	28116 Btu's/$1979	0.2831	0.3775	0.5662
	34172 Btu's/$1979	0.2143	0.2857	0.4286

AVERAGE WIND SPEEDS

Average Wind speeds are shown for 105 selected cities in the United States. Measurements of column A are average wind speeds reported by the National Climatic Center and are at 10 meters (approx 30 ft.) above the surface.[1]

Column B are the estimated average wind speeds at 50 feet above the surface using the "1/7 Power Rule" equation.[2]

Column C are the estimated average wind speeds at 100 ft above the surface using the "1/7 Power Rule" equation.[3]

It will be noted that only 17 of the 105 cities would have average wind speeds in excess of 14 miles-per-hour on wind machine towers extending to 100 ft. above the surface. Only 46 cities have average wind speeds in excess of 12 miles-per-hour.

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[1]Donald Marier, Wind Power for the Homeowner, (Emmaus, PA: Rodale Press, 1981),pp. 286-300. Data taken from National Climatic Center, "Comparative Climatic Data for the United States: Through 1979, (Ashville, NC: National Climatic Center, 1979).

[2]Donald Marier, Wind Power for the Homeowner, (Emmaus, PA: Rodale Press, 1981), pp.302-303

[3]Ibid.

Table C-16

AVERAGE WIND SPEEDS
Selected Cities in The United States
Through 1979

City	(A) Wind 30 ft.	(B) Wind 50 ft.	(C) Wind 100 ft.
HUNTSVILLE, AL	8.1	8.50	9.63
MOBILE, AL	9.1	9.55	10.82
ANCHORAGE, AK	6.7	7.03	7.97
COLD BAY, AK	16.9	17.74	20.11
KODIAK, AK	10.7	11.23	12.73
FORT SMITH, AR	7.6	7.98	9.04
LITTLE ROCK, AR	8.1	8.50	9.63
FLAGSTAFF, AZ	7.4	7.77	8.80
PHOENIX, AZ	6.3	6.61	7.49
LOS ANGELES, CA	6.2	6.51	7.37
SAN FRANCISCO, CA	10.5	11.02	12.49
RED BLUFF, CA	8.7	9.13	10.35
COLORADO SPRINGS, CO	10.4	10.92	12.37
DENVER, CO	9.0	9.45	10.71
BRIDGEPORT, CT	12.0	12.60	14.28
HARTFORD, CT	8.8	9.24	10.47
WASH., D.C. (DULLES)	7.0	7.35	8.33
WASH., D.C. (INT'L)	9.0	9.45	10.71
JACKSONVILLE, FL	8.1	8.50	9.63
MIAMI, FL	9.2	9.66	10.94
KEY WEST, FL	12.1	12.70	14.39
ATLANTA, GA	9.1	9.55	10.82
SAVANNAH, GA	8.0	8.40	9.52
HONOLULU, HI	11.8	12.39	14.04
HILO, HI	7.1	7.45	8.44
BOISE, ID	8.9	9.34	10.59
POCATELLO, ID	10.3	10.81	12.25

Table C-16 Continued

City	(A) Wind 30 ft.	(B) Wind 50 ft.	(C) Wind 100 ft.
CHICAGO, IL (O'HARE)	10.4	10.92	12.37
PEORIA, IL	10.2	10.71	12.13
FORT WAYNE, ID	10.3	10.81	12.25
INDIANAPOLIS, ID	9.7	10.18	11.54
DES MOINES, IA	11.0	11.55	13.09
SIOUX CITY, IA	10.9	11.44	12.97
DODGE CITY, KS	14.0	14.70	16.66
TOPEKA, KS	10.3	10.81	12.25
LEXINGTON, KY	9.1	9.55	10.82
LOUISVILLE, KY	8.4	8.82	9.99
NEW ORLEANS, LA	8.7	9.13	10.35
SHREVEPORT, LA	8.7	9.13	10.35
CARIBOU, ME	11.2	11.76	13.32
PORTLAND, ME	8.8	9.24	10.47
BALTIMORE, MD	9.4	9.87	11.18
BOSTON, MA	12.6	13.23	14.99
BLUE HILL OBSERV., MA	15.4	16.17	18.32
DETROIT, MI (CITY)	10.2	10.71	12.13
GRAND RAPIDS, MI	10.0	10.50	11.90
DULUTH, MN	11.3	11.86	13.44
MINNEAPOLIS, MN	10.5	11.02	12.49
JACKSON, MS	7.4	7.77	8.80
MERIDIAN, MS	6.0	6.30	7.14
KANSAS CITY, MO	10.4	10.92	12.37
ST LOUIS, MO	9.5	9.97	11.30
BILLINGS, MT	11.4	11.97	13.56
GREAT FALLS, MT	13.0	13.65	15.47
GRAND ISLAND, NB	12.0	12.60	14.28
OMAHA, NB	10.8	11.34	12.85

Table C-16 Continued

City	(A) Wind 30 ft.	(B) Wind 50 ft.	(C) Wind 100 ft.
LAS VEGAS, NV	9.0	9.45	10.71
RENO, NV	6.4	6.72	7.61
CONCORD, NH	6.8	7.14	8.09
MT. WASHINGTON, NH	35.0	36.75	41.65
ATLANTIC CITY, NJ	10.5	11.02	12.49
NEWARK, NJ	10.2	10.71	12.13
ALBUQUERQUE, NM	9.0	9.45	10.71
ROSWELL, NM	8.7	9.13	10.35
NEW YORK, NY (JFK)	12.2	12.81	14.51
BUFFALO, NY	12.3	12.91	14.63
SYRACUSE, NY	9.8	10.29	11.66
ASHVILLE, NC	7.8	8.19	9.28
RALEIGH, NC	7.8	8.19	9.28
BISMARCK, ND	10.4	10.92	12.37
FARGO, ND	12.6	13.23	14.99
CLEVELAND, OH	10.8	11.34	12.85
DAYTON, OH	10.2	10.71	12.13
OKLA. CITY, OK	12.7	13.33	15.11
TULSA, OK	10.6	11.13	12.61
EUGENE, OR	7.6	7.98	9.04
PORTLAND, OR	7.9	8.29	9.40
PHILADELPHIA, PA	9.6	10.08	11.42
PITTSBURG, PA	9.3	9.76	11.06
SAN JUAN, PR	8.8	9.24	10.47
PROVIDENCE, RI	10.7	11.23	12.73
CHARLESTON, SC	8.8	9.24	10.47
COLUMBIA, SC	6.9	7.24	8.21
RAPID CITY, SD	11.3	11.86	13.44
SIOUX FALLS, SD	11.2	11.76	13.32

Table C-16 Continued

City	(A) Wind 30 ft.	(B) Wind 50 ft.	(C) Wind 100 ft.
KNOXVILLE, TN	7.2	7.56	8.56
MEMPHIS, TN	9.1	9.55	10.82
AMARILLO, TX	13.7	14.38	16.30
DALLAS-FT WORTH, TX	10.8	11.34	12.85
HOUSTON, TX	7.7	8.08	9.16
EL PASO, TX	9.4	9.87	11.18
SALT LAKE CITY, UT	8.8	9.24	10.47
BURLINGTON, VT	8.8	9.24	10.47
NORFOLK, VA	10.6	11.13	12.61
RICHMOND, VA	7.5	7.87	8.92
SEATTLE (INT'L) WA	9.2	9.66	10.94
SPOKANE, WA	8.7	9.13	10.35
CHARLESTON, WV	6.4	6.72	7.61
PARKERSBURG, WV	6.3	6.61	7.49
MADISON, WI	9.9	10.39	11.78
MILWAUKEE, WI	11.7	12.28	13.92
CASPER, WY	13.0	13.65	15.47
CHEYENNE, WY	13.2	13.86	15.70

Notes: Column C is Column B multiplied by 1.05
Column D is Column B multiplied by 1.19
Based on the "1/7 power rule" equation:

$$\left| \frac{H}{Ho} \right|^{1/7} = \frac{V}{Vo}$$

where:
H = Height at which wind speed V is to be estimated
Ho = Height at which wind speed Vo is measured
V = Wind speed at Height H
Vo = Wind speed at Height Ho

Source: Donald Marier, Wind Power for the Homeowner, Emmaus, PA: Rodale Press, 1981), pp. 286-300. Data taken from National Climatic Center, "Comparative Climatic Data for the United States: Through 1979, (Ashville, NC: National Climatic Center, 1979).

SELECTED UTILITY CROSS-SECTIONAL UTILITY DATA

The cross-sectional data that was used in Chapter 6 is shown in this appendix.

Table D-1 shows basic data for 101 selected, privately-owned, large, United States, utilities, generally with generating capacity greater than 1,000 megawatts of installed capacity. Some exceptions were made with slightly smaller utilities if they had some nuclear capacity as a part of their portfolio. Table D-1 shows basic data on Total Generating Capacity (in megawatts), Nuclear Generating Capacity (in megawatts), reported Net Generation in millions of kilowatt hours. Column E of table D-1 shows the ratio of installed nuclear generating capacity to total capacity. Column F is obtained by multiplying column B times 8760 hours. The Efficiency Factor (column G) for each utility is obtained by dividing column D by column F, which shows the ratio of total, theoretical generating potential to what was actually generated.

Table D-2 is similiar information, except an additional column is added which shows individual calculations of arriving at the nuclear duty cycle:

$$F = \frac{(1 - e - x)}{(1 - 2x)}$$

Where, e = the Efficiency Factor for each utility,
x = fraction of total capacity that is nuclear capacity.

Table D-1

SELECTED DATA, LARGE PRIVATELY-OWNED U.S. UTILITIES (1983)

#	(A) UTILITY	(B) TOTAL CAPAC MW	(C) NUCLEAR CAPAC MW	(D) NETGEN MW HOURS	(E) NUCLEAR CAPAC RATIO	(F) MAXGEN (8760 x Col.C)	(G) EFFIC FACTOR (C/F)
1	ALA POWER CO	8881	1777	37244	0.2000	77797	0.4787
2	S. ELEC GEN CO	1082	0	5522	0.0000	9478	0.5825
3	ARIZON PSC	3364	0	13835	0.0000	29468	0.4694
4	TUCSON EPC	1838	0	5563	0.0000	16100	0.3455
5	AR P&L	5457	1845	18034	0.3380	47803	0.3772
6	PG&E	11865	0	40856	0.0000	103937	0.3930
7	SAN DIEGO EL	2517	315	6276	0.1251	22048	0.2846
8	S CAL EDISON	14363	1206	40082	0.0839	125819	0.3185
9	PSC COLO	3816	342	12959	0.0896	33428	0.3876
10	CT L&P	4546	1273	12762	0.2800	39822	0.3204
11	UNITED ILLUM	1251	0	5393	0.0000	10958	0.4921
12	DELMARVA	2481	346	10603	0.1394	21733	0.4878
13	POTOMAC E&P	5814	0	17749	0.0000	50930	0.3484
14	FL PC	6365	721	19046	0.1132	55757	0.3415
15	FL P&L	14104	2370	43417	0.1680	123551	0.3514
16	GULF POWER	2257	0	7712	0.0000	19771	0.3900
17	TAMPA ELEC	20234	0	11730	0.0000	177249	0.0661
18	GA POWER CO	12926	852	50567	0.0659	113231	0.4465
19	HAWAII ELEC	1189	0	5541	0.0000	10415	0.5319
20	IDAHO POWER	2498	0	14641	0.0000	21882	0.6690
21	CEN ILL LIGHT	1538	0	4945	0.0000	13472	0.3670
22	CEN ILL PSC	3152	0	10488	0.0000	27611	0.3798
23	COMMWEALTH EDIS	18822	6473	57153	0.3439	164880	0.3466
24	ELEC ENERGY	1100	0	5161	0.0000	9636	0.5355
25	ILL POWER	3948	0	15829	0.0000	34584	0.4576
26	INDIANA/KENTUCK	1304	0	8506	0.0000	11423	0.7446
27	INDIANA/MICH	3902	2285	18040	0.5855	34181	0.5277
28	INDIANAPOLIS P&	2698	0	11349	0.0000	23634	0.4801
29	NO INDIANA PS	3515	0	10036	0.0000	30791	0.3259
30	PS OF INDIANA	6162	0	24309	0.0000	53979	0.4503
31	S INDIANA G&L	1079	0	4113	0.0000	9452	0.4351
32	IOWA ELEC & PWE	1180	418	3231	0.3542	10336	0.3125
33	IOWA ILL G&L	1681	414	5309	0.2462	14725	0.3605
34	IOWA P&L	1413	0	3180	0.0000	12377	0.2569
35	IOWA PSC	1500	0	3081	0.0000	13140	0.2344
36	KANSAS G&L	2292	0	6806	0.0000	20077	0.3389
37	KANSAS P&L	2991	0	8808	0.0000	26201	0.3361
38	KENTUCKY POWER	1097	0	5414	0.0000	9609	0.5633
39	KENTUCKY UTILIT	2942	0	9899	0.0000	25771	0.3841
40	LOUISVILLE G&E	3007	0	8195	0.0000	26341	0.3111
41	GULF STATES	7177	0	25352	0.0000	62870	0.4032

Table D-1, Continued
Table D-1, Continued

SELECTED DATA, LARGE PRIVATELY-OWNED U.S. UTILITIES (1983)

#	(A) UTILITY	(B) TOTAL CAPAC MW	(C) NUCLEAR CAPAC MW	(D) NETGEN MW HOURS	(E) NUCLEAR CAPAC RATIO	(F) MAXGEN (8760 x Col.C)	(G) EFFIC FACTOR (C/F)
42	LA P&L	4850	0	12922	0.0000	42486	0.3041
43	NEW ORLEANS PSC	1295	0	2154	0.0000	11344	0.1898
44	CENT LA ELEC	1551	0	4240	0.0000	13586	0.3120
45	CENT MAINE PWR	1014	0	2913	0.0000	8882	0.3279
46	BALTIMORE G&E	5250	1828	19027	0.3481	45990	0.4137
47	POTOMAC EDISON	1935	0	10289	0.0000	16950	0.6069
48	BOSTON EDISON	2767	687	12775	0.2482	24238	0.5270
49	NEW ENGLAND POW	3660	0	13050	0.0000	32061	0.4070
50	WEST MASS ELEC	816	298	2374	0.3651	7148	0.3321
51	MICH CONSUMER'S	6756	887	20217	0.1312	59182	0.3416
52	DETROIT EDISON	10137	0	30992	0.0000	88800	0.3490
53	MINN P&L	1448	0	5136	0.0000	12684	0.4049
54	NO STATES PWR	5990	1755	23617	0.2929	52472	0.4500
55	MISS POWER	2267	0	6097	0.0000	19858	0.3070
56	MISS P&L	2989	0	5446	0.0000	26183	0.2079
57	KC P&L	3354	0	9191	0.0000	29381	0.3128
58	UNION ELEC	7417	0	26182	0.0000	64972	0.4029
59	MONTANA PWR	1110	0	7037	0.0000	9723	0.7237
60	NEVADA PWR	1944	0	5028	0.0000	17029	0.2952
61	PSC NEW HAMP	1234	0	4469	0.0000	10809	0.4134
62	ATLANTIC CITY E	1416	346	5913	0.2443	12404	0.4766
63	JERSEY CENTRAL	2640	550	4271	0.2083	23126	0.1846
64	NJ PS&G	9936	1976	24593	0.1988	87039	0.2825
65	PSC NM	1457	0	7860	0.0000	12763	0.6158
66	CENT HUDSON G&L	1059	0	4446	0.0000	9276	0.4792
67	CON EDISON	9145	1013	24477	0.1107	80110	0.3055
68	NY LI LIGHT	3952	0	11703	0.0000	34619	0.3380
69	NY ST E&G	1886	0	10854	0.0000	16521	0.6569
70	NIAGARA MOHAWK	5794	642	19682	0.1108	50755	0.3877
71	ORANGE & ROCKLA	1023	0	2716	0.0000	8961	0.3030
72	ROCHESTER G&L	1252	517	5546	0.4129	10967	0.5056
73	CAROLINA P&L	8238	2185	32425	0.2652	72164	0.4493
74	DUKE POWER	13064	3887	59648	0.2975	114440	0.5212
75	CINN G&L	4419	0	16185	0.0000	38710	0.4181
76	CLEVELAND EL IL	4531	494	17153	0.1090	39691	0.4321
77	COLUMBUS & SOOH	2745	0	9321	0.0000	24046	0.3876
78	DAYTON P&L	2889	0	11157	0.0000	25307	0.4408
79	OHIO EDISON	5046	323	20439	0.0640	44202	0.4623
80	OHIO POWER	8807	0	43516	0.0000	77149	0.5640
81	OHIO VALLEY ELE	1086	0	6394	0.0000	9513	0.6721
82	TOLEDO EDISON	1834	468	7066	0.2551	16065	0.4398
83	OG&E	5773	0	22669	0.0000	50571	0.4482
84	PSO	3970	0	14501	0.0000	34777	0.4169

Table D-1, Continued

SELECTED DATA, LARGE PRIVATELY-OWNED U.S. UTILITIES (1983)

#	(A) UTILITY	(B) TOTAL CAPAC MW	(C) NUCLEAR CAPAC MW	(D) NETGEN MW HOURS	(E) NUCLEAR CAPAC RATIO	(F) MAXGEN (8760 x Col.C)	(G) EFFIC FACTOR (C/F)
85	PP&L	3898	30	19123	0.0076	34146	0.5600
86	PORTLAND GE	2006	821	6193	0.4092	17572	0.3524
87	DUQUESNE LIGHT	3522	439	11900	0.1246	30852	0.3857
88	MET EDISON	2177	916	4908	0.4207	19070	0.2573
89	PA ELEC	2365	0	11333	0.0000	20717	0.5470
90	PA P&L	7838	1037	37720	0.1323	68660	0.5493
91	PHILA ELEC	7614	1976	16020	0.2595	66698	0.2401
92	WEST PA PWR	3765	0	18107	0.0000	32981	0.5490
93	SC E&G	2933	0	12393	0.0000	25693	0.4823
94	TX CENTRAL P&L	3917	0	14909	0.0000	34312	0.4345
95	EL PASO ELEC	1051	0	2533	0.0000	9206	0.2751
96	HOUSTON L&P	12996	0	50989	0.0000	113844	0.4478
97	SW E&P	3873	0	13836	0.0000	33927	0.4078
98	SW PSC	3752	0	14689	0.0000	32867	0.4469
99	TX UTIL ELEC	18585	0	67707	0.0000	162804	0.4158
100	WEST TX UTIL	1093	0	4309	0.0000	9574	0.4500
101	UTAH P&L	3427	0	15250	0.0000	30020	0.5079

Source: Columns A, B, C, and D from Financial Statistics of Selected Electric Utilities 1983, Energy Information Administration Washington, D. C., Published February, 1985.

Notes: Column B = Total generating capacity in megawatts.
Column C = Nuclear generating capacity in megawatts.
Column D = Total Net Generation in megawatt hours.
Column E = Column C divided by column B.
Column F = 8760 hours times column B
Column G = Column D divided by column F.

Information used in chapter 6.

Table D-2

SELECTED DATA OF LARGE PRIVATELY-OWNED UTILITIES
With Generating Capacity More Than 1000 Megawatts

(A) Util. #	(B) Total. Capac. MW	(C) Nuclear Capac. MW	(D) Net.Gen. kWh (Million)	(E) % Cap. Nuclear	(F) Col B x 8760 kWh's	(G) Col D/ Col F E.F.	(H) (1-e-x) ------ (1-2x)†
1	8881	1777	37244	0.2000	77797	0.4787	0.5354
2	1082	0	5522	0.0000	9478	0.5825	0.4174
3	3364	0	13835	0.0000	29468	0.4694	0.5305
4	1838	0	5563	0.0000	16100	0.3455	0.6544
5	5457	1845	18034	0.3380	47803	0.3772	0.8790
6	11865	0	40856	0.0000	103937	0.3930	0.6069
7	2517	315	6276	0.1251	22048	0.2846	0.7872
8	14363	1206	40082	0.0839	125819	0.3185	0.7180
9	3816	342	12959	0.0896	33428	0.3876	0.6368
10	4546	1273	12762	0.2800	39822	0.3204	0.9080
11	1251	0	5393	0.0000	10958	0.4921	0.5078
12	2481	346	10603	0.1394	21733	0.4878	0.5168
13	5814	0	17749	0.0000	50930	0.3484	0.6515
14	6365	721	19046	0.1132	55757	0.3415	0.7048
15	14104	2370	43417	0.1680	123551	0.3514	0.7238
16	2257	0	7712	0.0000	19771	0.3900	0.6099
17	20234	0	11730	0.0000	177249	0.0661	0.9338
18	12926	852	50567	0.0659	113231	0.4465	0.5615
19	1189	0	5541	0.0000	10415	0.5319	0.4680
20	2498	0	14641	0.0000	21882	0.6690	0.3309
21	1538	0	4945	0.0000	13472	0.3670	0.6329
22	3152	0	10488	0.0000	27611	0.3798	0.6201
23	18822	6473	57153	0.3439	164880	0.3466	0.9912
24	1100	0	5161	0.0000	9636	0.5355	0.4644
25	3948	0	15829	0.0000	34584	0.4576	0.5423
26	1304	0	8506	0.0000	11423	0.7446	0.2553
27	3902	2285	18040	0.5855	34181	0.5277	0.6622
28	2698	0	11349	0.0000	23634	0.4801	0.5198
29	3515	0	10036	0.0000	30791	0.3259	0.6740
30	6162	0	24309	0.0000	53979	0.4503	0.5496
31	1079	0	4113	0.0000	9452	0.4351	0.5648
32	1180	418	3231	0.3542	10336	0.3125	1.1429
33	1681	414	5309	0.2462	14725	0.3605	0.7748
34	1413	0	3180	0.0000	12377	0.2569	0.7430
35	1500	0	3081	0.0000	13140	0.2344	0.7655
36	2292	0	6806	0.0000	20077	0.3389	0.6610
37	2991	0	8808	0.0000	26201	0.3361	0.6638
38	1097	0	5414	0.0000	9609	0.5633	0.4366
39	2942	0	9899	0.0000	25771	0.3841	0.6158
40	3007	0	8195	0.0000	26341	0.3111	0.6888

See footnote at bottom of last page of table D-2.

Table D-2 Continued

SELECTED DATA OF LARGE PRIVATELY-OWNED UTILITIES
With Generating Capacity More Than 1000 Megawatts

(A) Util. #	(B) Total. Capac. MW	(C) Nuclear Capac. MW	(D) Net.Gen. kWh (Million)	(E) % Cap. Nuclear	(F) Col B x 8760 kWh's	(G) Col D/ Col F E.F.	(H) (1-e-x) ------ (1-2x)†
41	7177	0	25352	0.0000	62870	0.4032	0.5967
42	4850	0	12922	0.0000	42486	0.3041	0.6958
43	1295	0	2154	0.0000	11344	0.1898	0.8101
44	1551	0	4240	0.0000	13586	0.3120	0.6879
45	1014	0	2913	0.0000	8882	0.3279	0.6720
46	5250	1828	19027	0.3481	45990	0.4137	0.7841
47	1935	0	10289	0.0000	16950	0.6069	0.3930
48	2767	687	12775	0.2482	24238	0.5270	0.4462
49	3660	0	13050	0.0000	32061	0.4070	0.5929
50	816	298	2374	0.3651	7148	0.3321	1.1227
51	6756	887	20217	0.1312	59182	0.3416	0.7147
52	10137	0	30992	0.0000	88800	0.3490	0.6509
53	1448	0	5136	0.0000	12684	0.4049	0.5950
54	5990	1755	23617	0.2929	52472	0.4500	0.6205
55	2267	0	6097	0.0000	19858	0.3070	0.6929
56	2989	0	5446	0.0000	26183	0.2079	0.7920
57	3354	0	9191	0.0000	29381	0.3128	0.6871
58	7417	0	26182	0.0000	64972	0.4029	0.5970
59	1110	0	7037	0.0000	9723	0.7237	0.2762
60	1944	0	5028	0.0000	17029	0.2952	0.7047
61	1234	0	4469	0.0000	10809	0.4134	0.5865
62	1416	346	5913	0.2443	12404	0.4766	0.5455
63	2640	550	4271	0.2083	23126	0.1846	1.0406
64	9936	1976	24593	0.1988	87039	0.2825	0.8610
65	1457	0	7860	0.0000	12763	0.6158	0.3841
66	1059	0	4446	0.0000	9276	0.4792	0.5207
67	9145	1013	24477	0.1107	80110	0.3055	0.7497
68	3952	0	11703	0.0000	34619	0.3380	0.6619
69	1886	0	10854	0.0000	16521	0.6569	0.3430
70	5794	642	19682	0.1108	50755	0.3877	0.6441
71	1023	0	2716	0.0000	8961	0.3030	0.6969
72	1252	517	5546	0.4129	10967	0.5056	0.4674
73	8238	2185	32425	0.2652	72164	0.4493	0.6079
74	13064	3887	59648	0.2975	114440	0.5212	0.4476
75	4419	0	16185	0.0000	38710	0.4181	0.5818
76	4531	494	17153	0.1090	39691	0.4321	0.5867
77	2745	0	9321	0.0000	24046	0.3876	0.6123
78	2889	0	11157	0.0000	25307	0.4408	0.5591
79	5046	323	20439	0.0640	44202	0.4623	0.5431
80	8807	0	43516	0.0000	77149	0.5640	0.4359
81	1086	0	6394	0.0000	9513	0.6721	0.3278
82	1834	468	7066	0.2551	16065	0.4398	0.6229

Table D-2 Continued

SELECTED DATA OF LARGE PRIVATELY-OWNED UTILITIES
With Generating Capacity More Than 1000 Megawatts

(A) Util. #	(B) Total. Capac. MW	(C) Nuclear Capac. MW	(D) Net.Gen. kWh (Million)	(E) % Cap. Nuclear	(F) Col B x 8760 kWh's	(G) Col D/ Col F E.F.	(H) (1-e-x) ------ (1-2x)†
83	5773	0	22669	0.0000	50571	0.4482	0.5517
84	3970	0	14501	0.0000	34777	0.4169	0.5830
85	3898	30	19123	0.0076	34146	0.5600	0.4390
86	2006	821	6193	0.4092	17572	0.3524	1.8377
87	3522	439	11900	0.1246	30852	0.3857	0.6522
88	2177	916	4908	0.4207	19070	0.2573	2.0302
89	2365	0	11333	0.0000	20717	0.5470	0.4529
90	7838	1037	37720	0.1323	68660	0.5493	0.4328
91	7614	1976	16020	0.2595	66698	0.2401	1.0403
92	3765	0	18107	0.0000	32981	0.5490	0.4509
93	2933	0	12393	0.0000	25693	0.4823	0.5176
94	3917	0	14909	0.0000	34312	0.4345	0.5654
95	1051	0	2533	0.0000	9206	0.2751	0.7248
96	12996	0	50989	0.0000	113844	0.4478	0.5521
97	3873	0	13836	0.0000	33927	0.4078	0.5921
98	3752	0	14689	0.0000	32867	0.4469	0.5530
99	18585	0	67707	0.0000	162804	0.4158	0.5841
100	1093	0	4309	0.0000	9574	0.4500	0.5499
101	3427	0	15250	0.0000	30020	0.5079	0.4920

Source of data in columns B, C, & D:
Department of Energy, Energy Information Administration, Washington, D. C., Published February 1985, _Financial Statistics of Selected Electric Utilities 1983_, Published February 1985.
Data in table used in chapter 6.
†See explantation at beginning of appendix D.
Utility # corresponds to the name of the utility in table D-1 .

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