AN ECONOMIC ANALYSIS OF INTERFUEL COMPETITION

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JEFFREY MICHAEL DOYLE

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Milton H. Steinmueller
Major professor

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ABSTRACT

AN ECONOMIC ANALYSIS OF INTERFUEL COMPETITION

By

Jeffrey Michael Doyle

Interfuel competition is a complex problem requiring a wide variety of analytical approaches. The problem is defined by examining the fundamental relationships between economic theory, thermodynamics and energy policies concerning fuel substitution dynamics. Relatively simple price-substitution questions are complicated by a myriad of problems--social, economic and thermodynamic. Existing pricing policies have failed to take into account basic scarcity, ecological and thermodynamic constraints.

Consequently today's energy supply and demand functions are not sufficiently responsive to price changes to avoid short-run problems. The long-term economic dimension of the problem is best analyzed in terms of adjusting the rate of conversion of low entropy into high entropy. Additionally, there are immutable technical constraints on the rate at which transition to alternate sources can be carried out. This is reflected in the declining marginal productivity of capital and energy and suggests that we should seriously question the effectiveness of increasingly capital-intensive technologies.

The "economics of interfuel competition" had to be constructed from a variety of other studies. The methodological approach was to provide a unified analytical view of interfuel competition by first

providing a traditional economic analysis, utilizing and integrating existing theoretical constructs and then adding qualifications and refinements with each new chapter. Previous economic studies have confronted the problem indirectly via uncoordinated analyses of scarcity, resource quality, market structure and elasticity of supply and substitution--ignoring until very recently ecological and thermodynamic constraints. Consequently a primary element of this study is an analysis of the validity and efficacy of modern economic theory as an energy problem-solver. While it is primarily a theoretical study, theory is linked to policy in many stages, especially when alternate energy policies are considered--including strategies to deal with the OPEC cartel.

The implications of the preceding analysis are disturbing. Since economics and the pricing system currently do not adequately take account of differentials in energy quality predicated by the first and second laws of thermodynamics, the result has been a drastic reduction in the marginal productivity of capital and energy. This conflict between the "laws" of economics and thermodynamics must be reconciled if economic reasoning (and pricing) is to prevent catastrophe in the future.

The breakdown in congruity between the "laws" of economics and thermodynamics is the key element in the failure of economic theory to deal by itself with energy problems. The link between thermodynamics (especially entropy) and economic value is so strong that it cannot continue to be ignored in energy policy and pricing. Declining capital productivity in the energy industries signals that this conflict between existing practices and thermodynamic realities is already being felt and challenges the assumption that technology can overcome all obstacles.

Jeffrey Michael Doyle

The key role for economics in the future should be to devise pricing practices that more effectively match energy sources to tasks. A valuable first step would be to gain acceptance of the theoretical and practical importance of shifting the focus of attention from labor-saving (capital- and energy-intensive) substitutions to energy-resource-saving substitutions.

In sum, we must re-examine the operation of the whole system (economic, political and cultural) which governs the development and use of energy. Remember, however, the important difference between recognizing a problem and enacting the required policies. It is not sufficient that experts from a wide range of disciplines accept these findings. The key problem for the future is how do we gain popular acceptance of these harsh realities before it is too late.

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CHAPTER I

INTRODUCTION

Problem Setting

"That man will face a series of particular scarcities as a result of growth is a foregone conclusion; that these will impose a general scarcity--increasing cost--is not a legitimate corollary."

Harold J. Barnett and Chandler Morse
in Scarcity and Growth, p. 244

The above conclusion of Barnett and Morse, reached fourteen years ago, is today even more important as a focal point for public policy regarding the use of our natural resources. This is especially true for energy--a commodity for which a substitute cannot be found. Different forms of energy may be substituted for each other but energy itself has no substitute.

Whether mankind can perpetually succeed in finding new sources of energy and also new modes of harnessing them to his benefit is currently unknown. Historically, resource problems have been characterized by continual accommodation and adjustment to an ever-increasing resource-quality spectrum. In the capitalist economies of the world these adjustments are primarily market adjustments. Logically, the most important question for social policy becomes how to take advantage of the beneficial aspects of the price system while remaining cognizant of its shortcomings--in terms of both efficiency and equity.

Purpose and Hypothesis

Unfortunately the capacity of scientific progress to create new problems for society appears to have outrun the capacity of social progress to solve them. The crucial question is whether requisite changes in our economic mechanisms of choice will keep pace with the dynamic development of the scope of choice. Will existing economic structures in the capitalist economies be up to this task? This study will attempt to show that current economic mechanisms, based on existing (neoclassical) economic theory, are inadequate to deal with the problems of energy. The scope of existing neoclassical theory is simply too narrow to deal with multi-faceted energy crises.

These are strong charges, certain to invite counter-attack. However, the intent is not to imply that all hope is lost if we continue to look at energy problems from an economic perspective. Rather, there is promise that a broadening of our economic approach to energy will provide great hope for the future.

Introduction to Energy Analysis

The command over energy, especially inanimate energy, is a crucial variable in any social production function. Energy can legitimately be described as the driving force of a modern industrial economy and the key to other resource's availability. Energy involves two basic forms of physical energy: heat and work. The crucial distinction between these two forms will be discussed later in this study (in the chapter relating thermodynamics and economics). Also, in this following chapter, the concept of entropy will be introduced as a partial index of energy quality.

In the broadest "macro" sense there are three basic energetic factors: 1) solar energy, 2) human energy, and 3) physical energy. Substitution of energetic factors for one another logically depends upon relative availability and (it is presumed) relative price levels. Fuel substitution might appear at first glance to be a relatively simple process; cheaper fuels are substituted for more expensive ones. As this study will indicate, however, the process is considerably more complicated than this simple model suggests.

The chief characteristic of the U.S. energy industry has been the orderly shift from one fuel to another (from wood to coal, coal to oil and natural gas, oil and natural gas to nuclear, etc.). These changes were accomplished with little economic impact since all fuels used to be low in cost. With low cost energy a universal assumption, an energy intensive society was created.

However, between 1962 and 1972 all rational producers who were financially capable preferred to invest much of their time and money to find cheap oil reserves in the Middle East rather than the more expensive reserves in North America. Thus, the <u>distribution</u> of reserves had shifted. But did this alone "cause" the energy crisis? Is this the entire problem?

Energy problems have mostly taken the form of rapidly growing demands and slow-growing or lessening supplies, both of which are the normal economic signals for rising prices. Energy production is heavily dependent upon limited resources, so that depleting the known reserves faster means an increasingly costly search for more reserves or turning to more expensive substitutes.

Currently there is an awareness of a potentially precipitous decline in fluid fossil fuels with no scientific assurance that near substitutes can be made available in the quantities upon which the industrialized world has grown dependent. There is also justifiable concern that because of environmental limitations and the technological, economic and social delays intrinsic in our systems of production and consumption, it will not be possible to develop and implement our known alternative technologies fast enough to compensate for the decline of fossil fuels.[1]

Robert M. Solow states that "the energy crisis is best described as a crisis arising from inappropriate policies compounded by what has been described as the transitional problems of absorbing environmentalism into the set of shared public values."[2] John Kenneth Galbraith asserts that "blackouts and energy crises stem from the failure to match performance in various sectors of the economy."[3] Dr. Paul Davidson, professor of economics, Rutgers University, feels that the growth of monopoly power and not a Malthusian shortage of resources has caused the energy crisis.[4] These three are a mere sample of the diversity of opinion regarding the "cause" of the energy crisis.

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[1]Herman E. Koenig and Thomas C. Edens, Resource Management in a Changing Environment: With Applications to the Rural Sector (DMRE-76-15, Michigan State University, September 1976), p. i.

[2]U.S. Congress, Joint Economic Committee, Resource Scarcity, Economic Growth, and the Environment, before the Subcommittee on Priorities and Economy in Government, 93d Cong., 1st sess., 1974, p. 136.

[3]Professor Galbraith considers energy crises to be merely a part of the more general problem of unequal development and inequality between economic sectors. For an expanded discussion, see his book, Economics and the Public Purpose (New York: Houghton Mifflin Company, 1973).

[4]Resource Scarcity, Economic Growth, and the Environment, p. 78.

What is accepted by most authorities is that fuel and energy shortages arise partly because of technological lags in responding to shrinking supplies of low sulphur coal and petroleum and partly because environmental regulators did not correctly foresee or else ignored the consequences of imposing stringent pollution abatement standards too quickly. The recognition that solutions to problems of environmental absorption are qualitatively different from those problems associated with the supply of non-renewable resources is critical. (The assimilative capacity of the environment is continuous.) Ideally, non-renewable resource use should be restricted and extended via utilization of continuous energy resources.

Central to the problems of energy in general and interfuel competition in particular are two concurrently occurring processes: 1) the growth of the monopoly power of the OPEC cartel, and 2) development of conglomerate multi-national energy companies who control substantial quantities of substitute domestic fuel supplies. These will be analyzed in detail later in this study; they are mentioned at this point only to complement the general discussion of the energy problem.

The Complexity of Interfuel Competition Analysis

Interfuel competition is a complex issue requiring a wide variety of analytical approaches. One factor to be considered is the reliability of energy supply--we should diversify by region and type of fuel. This would allow us more flexibility in energy, environmental and foreign policy. Another factor is the cost to society for energy. If competition is absent increased prices do not always lead to increased production--just higher profits. This of course is at least a partial function of the market structure and technology that is in existence.

Other factors are economic and regional inequities. The poor pay the largest percentage of their income for basic energy and this fact must be considered. However, it is usually preferred that lump sum transfers to the poor be used rather than distorting allocative efficiency by considerations of equity. Two final considerations of inter-fuel competition are: minimizing international problems due to energy, and safeguarding the quality of the environment (designing technologies with environmental quality as a constraint for example).[5]

The preceding are often in conflict and must be compromised. They must also be harmonized with other social goals. Consequently, a variety of approaches are required to deal with this multi-faceted problem. Traditional neoclassical (Marshallian) analyses of pricing and output decisions (i.e., market adjustments) are useful and essential. Also required are industrial organization-market structure analyses. Allocation through time depletion studies are indispensable, especially in judging whether existing economic structures are adequate. Traditional resource economic studies such as those of S. V. Ciriacy Wantrup, Anthony Scott and Barnett and Morse are also relevant and applicable.

Perhaps most useful, however, are the revisionist analyses of John Kenneth Galbraith and Joseph Schumpeter as regards the role of

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[5]For an excellent extended discussion of the magnitude of the energy problem see, Skeptic--The Forum for Contemporary History, A Special Issue on the Problem of Energy, Jan.-Feb. 1975, and Energy: The Policy Issues, ed. Gary Eppen (The University of Chicago Press, 1975).

the economic system in dealing with problems of technology and economic performance.[6] Similarly, the work of Professors A. Allan Schmid and Robert A. Solo at Michigan State University has been most helpful. Finally, the conceptual integration of economics and thermodynamics is essential to a real understanding of the problems of interfuel competition.

The study of interfuel competition requires an analysis of the interaction of environment, energy and economy. The chief difficulties lie in the interface between energy, technology and economic structure. Past studies of interfuel competition have focused primarily upon market structure, anti-trust and monopoly aspects of the problem. Unfortunately, the nature of the problem demands a variety of approaches as outlined earlier. However, these structural studies (up until very recently) have analyzed economic structure from the perspective of a single fuel. This tends to obscure the fact that competition in energy production takes two forms: interfuel and intrafuel.

Interfuel competition exists where fuels are interchangeable enough to support the conclusion that they trade in a single energy market. The determination of whether there is a relevant energy market (i.e., the degree of fuel interchangeability) rests upon interpretation of the cross-elasticity of demand for these factors. The greatest degree of fuel interchangeability today is in the electric utility sector--hence much of the following analysis is directly applicable to problems of the utilities.

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[6] Galbraith, Economics and the Public Purpose, and Joseph A. Schumpeter, Capitalism, Socialism and Democracy (New York and London: Harper and Brothers, 1942).

Intrafuel competition exists where a single energy source dominates and no potential substitutes exist. Transportation sector's reliance upon liquid fossil fuels is an excellent example. It is crucial that policy-makers recognize the difference between these two forms of competition. Some activities may be anti-competitive in terms of intrafuel competition but at the same time have little impact on interfuel competition.

Interfuel competition seems to have played a beneficial role for consumers during the 1960's when sources of supply were plentiful. In the 1960's interfuel competition was an important market regulator. Even if the coal, oil or uranium industries were not highly competitive within their separate industries, the growing competition among them resulted in fair prices to consumers. Interfuel competition appears to have flourished while the ownership of the different branches of the energy industry remained distinct.[7] The situation is now much less certain. Mergers and horizontal integration may not violate existing anti-trust legislation but the threat to economic performance is nonetheless a real one.

The impact of mergers and horizontal integration upon economic performance will be discussed in greater detail in the chapter on market structure and technology. What is pertinent to discuss at this point is the related question: Who should develop new energy sources? Existing "energy" companies (primarily big oil companies) have considerable advantages of technical competency, access to capital and organizational skill.

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[7]S. David Freeman, Energy: The New Era (New York: Random House, 1974), p. 154.

However, coexisting with these advantages is the ever-present danger of monopoly power (with its effects upon technical change, prices, profits, output, efficiency and growth) and the possibility that large economic entities would hesitate to develop new energy sources that would threaten the value of their existing oil reserves. That is, uncertainty currently exists as to whether existing fuel companies will delay the advent or introduction of synthetic fuels in order to protect their own interests. Ideally, the production rates of alternate energy sources should not be controlled by organizations which have a vested interest in maintaining monopoly prices in fossil fuels or in speculating via withholding production.

Realistically, however, we must recognize that tradeoffs between economic (market) structure and energy goals may be required. Static economic efficiency or theoretically optimum market structures are not universally adaptable to all performance categories. What is "optimum" for one performance goal may not be for another (such as creation of alternate energy sources). Additionally, we must consider not only the effects of economic structure upon energy production technologies but also the effects of various energy production technologies upon economic structure (life styles and society may drastically change).

The choice of which fuel is "best" for a given task cannot be made without reference to the length of the planning period involved. Today's energy supply and demand functions are not sufficiently responsive to price changes to avoid short-run problems.

On the demand side of the issue, people have significant investments in large fuel consumptive homes and automobiles. The decision whether to sell these items because of increasing energy prices is strongly influenced by consumer uncertainty regarding the relative worth of their current investments compared to rising operating (energy) costs. The latter, of course, ignores the effects of rising fuel prices on the value of those investments. On the supply side, response is slow because of long lead times, capital requirements and risk-aversion factors.

Fears about energy shortages in the very long term appear to be exaggerated, provided the pollution problems associated with energy can be overcome. It is a distinct possibility that the earth's capacity to assimilate wastes will become a constraint before there is any question of literally "running out" of energy. Perhaps even more serious for proponents of alternate energy resources is the fact that non-acknowledgement of the residuals problem could become so serious as to set an effective limit to the adoption of new energy technologies. There are plenty of domestic energy reserves; the real question is at <u>what price</u> (private, social and environmental) can they be made available.?

As mentioned before, there is a strong relationship between fuel interchangeability and the extent of interfuel competition. Some persons contend that all forms of primary energy--oil, natural gas, coal, oil shale, uranium, geothermal, steam, solar, wind and tar sands--are sufficiently interchangeable so that it is appropriate to lump everything into one large so-called energy market.

Others argue that a more refined analysis indicates that the degree of interchangeability among the various forms of primary energy fluctuates, depending upon the types of energy being considered and the context of the analysis. For example, it seems reasonably clear that fuel oil, natural gas, coal and uranium are, to a considerable extent, reasonably interchangeable insofar as the electric power industry is concerned (i.e., a strong cross-elasticity of demand would exist among these fuels).

However, there are other factors affecting the degree of interchangeability besides "purely economic" ones. Among these are waste disposal problems, nuclear safety and environmental restrictions. Additional problems include the effects of transportation costs and the fact that many of the alternate energy forms are useable only if commercially feasible technology can or will be developed.[8] The latter problem of course hinges on the performance impact of the particular market structure in existence and the operator's perception of user costs (a concept to be discussed later in this chapter).

It would be useful at this juncture to quickly reassess the central problems involved in analyzing interfuel competition. One crucial factor is the impossibility of gauging even the approximate size of fuel reserves for the long term (or even what will be "fuel" in the distant future). A related issue is that intertemporal allocation and interfuel substitution problems are complicated by the fact that fossil fuels can alternatively be used as inputs to the chemicals and plastics industries.

Next, there are considerable difficulties in gauging future substitution possibilities, especially when one recognizes that much of the easily accessible fuel is already consumed and concern for the

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[8]U.S. Congress, Senate Committee on the Judiciary, Interfuel Competition, before the subcommittee on Anti-trust and Monopoly, U.S. Senate on S.489, 94th Cong., 1st sess., 1976, p. 346.

environment is a growing constraint. Two final considerations are the difficulty of gauging how demand will respond to price changes and the risk that new technologies which now appear promising will prove socially unnacceptable or unfeasible to introduce commercially.[9]

Role of Economic Theory

Given the preceding myriad of problems, what can economic theory offer to deal with the questions of interfuel competition and the OPEC cartel? The first point to be stressed is that we cannot deal effectively with the power of the OPEC nations until we understand the fundamental relationships between economics, energy and thermodynamics. The following chapters will explain why public policy must, of necessity, take a broader view than that currently offered by traditional economic theorists. To achieve any degree of energy independence, we must first understand the "economics of interfuel competition"--a field that has been defined and analyzed to date only in fragmented fashion.

A fundmental parameter is the elasticity of demand for resources. Since the demand for resource inputs is largely a derived demand, it is clear that elasticity of demand depends on the elasticity of substitution between resources and other inputs and the prices of all inputs. There are two elasticities of demand that are relevant in this study--one for energy in all forms--another for energy in a particular form. As emphasized in the opening paragraph of this study, there is substitutability for fuels but none for energy itself.

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[9]See Skeptic and Energy: The Policy Issues for an excellent overview of the central problems.

Economic theory, via the concepts of demand and supply elasticity and elasticity of substitution, suggests that the best way to break the power of the OPEC cartel is to create conditions which will cause the demand for OPEC oil to become elastic. A price elastic demand for a product whose current prices are substantially above real production costs and where additional low cost supplies are technologically available will unleash forces which will reduce monopoly power. The key to the preceding strategy is of course the availability of low-cost substitutes--thus the focus on interfuel substitution and competition.

Many suggested policies (such as a large gas tax, rationing and import quotas) in the absence of an embargo or true Malthusian shortage are at variance with the preceding arguments. Such policies assume that by merely driving up the price to the consumer in order to reduce the quantity demanded of imported oil--but without altering the price elasticity of demand--the cartel will break.

Since such a policy does not directly change the demand curve for OPEC oil (except perhaps in the extreme long run), it merely requires consumers to move along a short run price inelastic demand curve. In other words, we should remember the distinction in economic theory between a "change in demand" and a "change in the quantity demanded."

Induced demand elasticity is a function of the number of available substitutes and the user cost perceptions of economic operators. Theoretically, two conditions are necessary to force a price elastic demand curve for OPEC oil. First, substitute energy sources should be made available at less than the cartel price. Second, the substitute's production rates should not be controlled by managers who have a vested interest in maintaining monopoly prices in fossil fuels or in speculating via withholding production.

Our goal should be to encourage the expectation of a decline in the price of OPEC crude oil by (say) 1980. If the OPEC producers anticipate lower prices for their oil in the future, they will logically try to produce and sell more now. This strategy, however, is a two-edged sword. On one side is the fact that increased current supplies will tend to lower world prices of crude oil. This will make it extemely difficult for inherently higher priced synthetic fuels to become commercially available--hence we still would remain tied to OPEC's supplies. On the other hand, our national economy would definitely benefit from lower world oil prices (a better balance of payments situation would be possible).

Remember, however, another goal--that of making substitute fuels available at less than the cartel price (in terms of dollars per BTU for example). Suppose the supplier of a substitute energy source also has an economic interest in OPEC petroleum reserves because it is a conglomerate energy company with an OPEC concession or other oil reserves. Then it will anticipate a positive user cost[10] in producing the substitute if the production of this substitute reduces potential profits from its oil reserves. This positive user cost will raise the supply price (above resource costs) of marketing the substitute.

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[10]User costs are positive and there will be a deceleration of current production when the expected difference between future prices and costs (i.e., properly discounted future profits) has increased. In other words, we can expect decreasing current production when expectations of future profits increase. Negative user costs, on the other hand, would lead to expectations of decreasing future profits and consequently increasing current exploitation.

In these circumstances this positive user cost of substitutes internalizes a cost that in a competitive economy would be external to an independent producer of a substitute energy source. Independent producers of domestic oil, shale, tar sands, coal and uranium would not care if they inflicted capital losses on the value of foreign underground reserves of petroleum by providing a cheaper energy source. Thus, in the absence of developed futures markets, producer's subjective expectations of the user costs inherent in all raw materials are major determining factors in the time rate of exploitation of energy resources.[11]

The preceding discussion of OPEC and economic strategy was meant to serve as a real world referent for the technical chapters that follow. In the final chapter of this study (concerned with policy implications of the technical analysis) the problems introduced here will again be discussed. The emphasis in the concluding chapter will, however, be upon the limitations and potentialities of economics in dealing with energy issues.

Thermodynamics--The "Science of Energy"

The final topic we will briefly discuss in this introductory chapter is thermodynamics--the "science of energy." Ideally, the characteristics of the tasks (we wish energy to perform) should determine the thermodynamic quality of the energy that can best be applied to them. By thermodynamically matching energy sources to tasks, we can avoid the enormous waste of using high quality energy for low quality tasks and minimize the growing economic and social (pollution) costs of

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[11]For an extensive discussion of user costs, especially regarding the absence of futures markets, see "Oil: Its Time Allocation and Project Independence" by Paul Davidson, Laurence H. Falk and Hoesung Lee in Interfuel Competition Hearings, 1974, pp. 451-68.

energy production.

For example, when oil is burned in a furnace at 500°F. to warm a room to 70°F., we are using high quality energy to accomplish a task that could be done just as well by a low-quality energy source--such as waste heat rejected by a power plant. High quality energy refers to energy delivered at high temperatures having great capability of performing "work" ("work" defined as force exerted through distance).

As energy flows from a hot entering status to its cooler final status, total energy in a whole system remains constant (the first law of thermodynamics). However, the ability of that energy to do work is irretrievably lost (the second law of thermodynamics--the "entropy law"). Entropy can thus be defined as a measure of the unavailibility of energy for work. What is crucial for energy policy is that economics and the pricing system currently do not take account of these differentials in energy quality.

Conventional fuels almost always generate energy at temperatures much above those needed for most energy-requiring tasks so that the thermodynamic quality of the energy is wastefully downgraded in the process. The inevitable result is thermal pollution. In contrast, solar energy can readily be brought up to any desired temperature by concentrating it. Then it can be matched thermodynamically to any given task (without the risk of nuclear radiation or waste or other types of pollution).

The complex and subtle interrelationships between energy, economics and thermodynamics will be discussed in considerable detail in a later chapter. At this point, however, it may be useful to tentatively introduce a few ideas to consider before entering the technical chapters.

Barry Commoner posits in "The Poverty of Power: Energy and the Economic Crisis" that solar energy is more than a superior economic alternative to conventional energy sources; it is also an antidote to their catastrophic economic effects.[12] Unlike conventional energy sources, the use of solar energy does not automatically increase its future costs (through scarcity effects and increasing capital costs of pollution control, for example). In marked contrast to conventional sources, solar energy is renewable, not subject to diminishing returns (at least in the sense of increasing costs due to depletion), is technologically simple and is compatible with the environment.

One need not accept Commoner's argument without reservations, however. There are considerable economic, social and institutional problems involved with the widespread adoption of solar power. Perhaps the greatest potential (I believe) lies in the successful development of multi-source energy systems that are not dependent upon any one energy source. This is one area where solar power may reach its earliest practical usefulness--as a supplement (not a replacement)--for existing conventional energy sources.

Method of Analysis

Hopefully, the preceding brief introductory remarks have provided sufficient background for the main thrust of this study--an analysis of the validity and efficacy of modern economic theory as an energy problem solver. First, we shall examine traditional theory in practice (how it confronts problems of interfuel competition and the broader problems of

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[12] Barry Commoner, The Poverty of Power: Energy and the Economic Crisis (New York: Alfred A. Knopf, Inc., 1976), p. 218.

OPEC). Next, an in-depth examination of market structure and technical change will be provided.

The next phase will be a chapter devoted specifically to a critique of existing theory as an energy problem solver. An additional chapter will continue this critique via a discussion of the role of thermodynamics and entropy and their fundamental relationships to energy and economics. This study will conclude with a chapter concerned with the policy implications of the preceding analyses.

Limitations of This Study

There are a number of undiscussed assumptions and general limitations of this analysis. Population size and demands are not considered--either conceptually or dynamically via empirical examination. Similarly the impacts of the overall structure of the economy and the organization of society upon interfuel competition are not analyzed.

Another important limitation is that the interrelationship between energy production and pollution is not fully discussed. Pollution is a ceteris paribus constraint--i.e., a constraint that is recognized but the analysis proceeds as if it were a constant.

Finally, this study ignores completely the macro-economic dimensions and policy implications of interfuel competition and fuel-substitution dynamics. The preceding limitations were necessary to make the problem analytically manageable and conceptually precise but should be examined in future research.

CHAPTER II

A "TRADITIONAL" ECONOMIC ANALYSIS OF INTERFUEL COMPETITION

This chapter will provide an economic analysis of interfuel competition utilizing existing constructs from traditional theory. The following chapter will continue this type of analysis, focusing narrowly upon the relationship between market structure and technological innovation.

Introduction

The history of economic exploitation of non-renewable resources over the past 200 years is, in general, one of decreasing costs and increasing reserves. However, the direct energy or work costs of recovery have been rising, slowly for a while, then more rapidly as resource quality declines.

This seeming paradox of decreasing total costs and increasing work costs is explained by a long record of decreasing total costs of energy used for extraction and processing. Now that energy resources are beginning to cost more "in work" (the efficiencies of energy conversion appear to be nearing limits dictated by the strength of materials and the laws of thermodynamics) and also since the work costs of recovery are increasing, the nature of the limits to exploitation are beginning to be realized.

The limits to exploiting new (alternate) energy resources are threefold: 1) an ultimate limit defined by net energy constraints--that is, where it takes more energy to procure the energy than the energy source itself provides, 2) limits of comparable utility where cheaper substitutes are found (cheaper in the sense of net energy costs), and 3) where society is unwilling to pay the cost of exploitation even though an energy saving or surplus might be recognized--because it is felt that the exploitation would lower the level of living more than would foregoing use of the resource, e.g., strip mining, for example.[1]

Role of the Price System in Energy Analysis

The market adjustment process serves as a computing device, in effect, for making allocations within the economy provided that input signals (resource and residual prices) reflect the dynamics of resource depletion and the limitations of natural environments to accept residuals. The key to Neoclassical market adjustments is "proper" substitutions resulting from the pricing and output decisions of economic operators.

The peacetime price system (with varying amounts of government intervention) strives to achieve the rough effect of allocating resources so that their marginal product is equal in each of their uses. In our case for example, factors may be switched from one use (fuel) to another use (petrochemical) until the last unit might be indifferently employed.

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[1]Earl Cook, "Limits to Exploitation of Nonrenewable Resources," Science 191 (February 1976): 677-82.

Theoretically the price system should resolve a multitude of energy problems. A rise in price invokes at least four processes: 1) it reduces demand for resources, 2) it provides incentive to substitute cheaper materials for superior and "dearer" ones, 3) it provides incentives for exploration, and 4) it guides scientific and engineering effort to technical areas that are likely to generate large savings in costs.[2] As we shall see throughout this study, reality does not always coincide with theory.

We should not ignore or underestimate (as have a number of "doomsday" theorists) the human ability to make adjustments in technology, resource substitution and consumption habits. Many of the "computer-centered" systems approaches to resource problems ignore (in the design of the computer simulations) the effectiveness of the price system in altering supply and demand functions.[3] We must also be careful to avoid the "fallacy of endless substitution"--as Professor Robert Solow of M.I.T. warns. Substitution is _the_ key factor supporting technical progress (even as resources become increasingly scarce) and as such must be carefully analyzed regarding its potentialities in different contexts.

Traditional economic analyses of energy (and of interfuel competition in particular) have relied heavily upon a number of historically established precedents. One factor is that in the fuels market there is

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[2]_Resource Scarcity, Economic Growth and the Environment_, p. 28.

[3]See for example, Donella H. Meadows, et al., _The Limits to Growth_ (New York: Universe Books, 1972) and H. S. D. Cole, et al., _Models of Doom: A Critique of the Limits to Growth_ (New York: Universe Books, 1973).

a particularly strong tendency to establish the price of fuel A on the basis of the equivalent cost per BTU of fuel B. More specifically, the price of alternative fuels is determined, to a great degree, by the price of crude oil. If the integrated oil companies should dominate the future synthetic fuels industry, we should be careful to analyze how synthetic fuel prices compare with those of crude oil-derived products (i.e., how do the production costs of synthetics compare with their selling price _and_ the market price of crude oil).[4]

Another precedent underlying economic analyses of energy is that _basic fuel_ represents only a small fraction of the ultimate cost to the consumer. A large percentage of the cost is in conversion, transportation and distribution within the marketing area. Additionally, energy industries are uniquely capital intensive and construction costs are a dominant factor. Some analysts, in fact, go so far as to state that the increased price of energy to the consumer stems largely from the increased cost of fuel and its conversion to electricity, gasoline or fuel oil and _not_ from increased profits.[5]

If interfuel competition were strictly subject to free market price dynamics, the scenario would be that espoused in the standard microeconomic text: No buyer or seller able to influence price or market outcome; surpluses or shortages causing price adjustments (and consequent interfuel substitutions); quantities offered for sale by producers equivalent to quantities demanded (purchased) by consumers. Any other market price will lead to either surplus or shortage, leading

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[4] _Interfuel Competition Hearings_, pp. 20-27.

[5] Freeman, p. 147.

to further price adjustments and interfuel substitutions. If "above normal" profits are being earned, new firms will enter, causing increased production, falling prices and a new equilibrium point where "normal" profits are being earned.[6]

Here firms battle not so much against each other as against rather nebulous market forces. The "winner" is determined from those firms which compete at the price established by all of these combined market forces. Thus, in small firm dominated markets, the adjustment process relies heavily upon interfirm resource mobility--an external resource reallocation dynamic is employed.

Empirical examination of the current structure of the energy industry indicates, however, that such a scenario is neither relevant nor applicable.[7] The following chapter will detail the rationale of the above statement, but it is sufficient at this stage to indicate that the large, capital intensive energy conglomerates are more properly analyzed as being part of the corporate sector of the economy than they are as small atomized units whose actions have little effect upon other operators (or market prices).

At this juncture what is important to note is that in the corporate sector, adjustments to changes in supply and demand more often

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[6]For a detailed discussion of free market price dynamics, see Walter Nicholson, Microeconomic Theory: Basic Principles and Extensions (Hinsdale, Illinois: The Dryden Press, Inc., 1972), pp. 265-90, or Robert R. Solo, Price Theory in Perspective (East Lansing, Michigan, Michigan State University Publication, 1974), pp. 121-51.

[7]A detailed empirical analysis is provided by Thomas D. Duchesneau, Competition in the U.S. Energy Industry (Cambridge, Mass.: Ballinger Publishing Company, 1975).

take the form of an internal reallocation of resources with greater emphasis upon intrafirm resource mobility. This of course is a by-product of the large corporations' predilection for long range planning and forecasting.[8]

Economics has no determinate theory of oligopoly pricing and the mechanical beauty and precision of the perfectly competitive model is inappropriate in our case. How then has economics (to date) attempted to deal with interfuel competition and our dependence upon OPEC?

To reiterate, previous attempts have been fragmented and narrowly focused. What should concern us is not esoteric refinement but at what rate different sources of supply will become available--in the sense of being economically feasible.

Synthesis of Analytical Models and Constructs

The preceding arguments were designed to demonstrate that relatively simple price-substitution questions are complicated by a myriad of problems concerned with market structure and economic performance. Analytically, we have two options: 1) immediately discuss market structure and its effect upon substitution processes, or 2) perform a more limited economic analysis of interfuel substitution, holding in abeyance the effects of market structure until later. I shall follow the latter path.

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[8]Excellent analyses of corporate capitalism are provided by Arthur A. Thompson, Jr., The Economics of Corporate Capitalism and Corporate Power (Morristown, N.J.: General Learning Press, 1974) and John Kenneth Galbraith, Economics and the Public Purpose (New York: New American Library, Inc., 1973), pp. 77-204.

Another compromise which must occasionally be made for purposes of analytical clarity is the "artificial" separation of theoretical constructs that in reality are inseparable (at least in the context of our problem area). Concepts such as scarcity, renewability, economic quality, user costs, elasticity of supply and substitution are distinct theoretically, but in the context of interfuel competition, these distinctions become somewhat blurred and to a great degree they overlap.

Previous economic studies have confronted the problem of interfuel competition indirectly via uncoordinated analyses of scarcity, renewability, market structure and elasticity of supply and substitution. What I would like to provide at this point is a unified analytical view of the problem of interfuel competition.

Scarcity is a prime factor--operating not only to encourage subsitutions (via relative scarcities) but also to stimulate technological advance (to forestall so-called absolute scarcities). There are two aspects of scarcity--quality and quantity--and these distinctions are often overlooked by both the layman and the economist. These distinctions are crucial.

Over quantities of an energy resource are important of course. But it must be remembered that "quantity," in the modern dynamic sense, is defined economically; i.e., the amount that it is economically feasible to obtain at a given time, at a given price and with a given technology. Resources can only be defined in terms of a known technology and the command over energy is the key to resource availability. Thus we can begin to see that the choices we make regarding which energy source to use affects not only general resource availability but also the availability of other energy resources. A critical series of choices lie ahead!

The distinction between quality and quantity is similarly not sharply defined. A common economic assumption is that society possesses the knowledge and will to use resources in the order of declining economic quality--resulting from increasing cost per unit of output.[9] The quantity of a certain quality energy resource is, however, dependent upon accessibility. The most accessible resources are not necessarily the best quality in all cases. Accessibility itself is multidimensional. Resource availability can be expanded either by geological extensions of supply or through technological advances (extensions).

The importance of technology will be fully discussed in the following chapter on market structure but it is pertinent to note a few facts now in relation to scarcity and substitution. Technical extensions of supply are far more important than periodic geological extensions because a new technology for lower quality resources can open up deposits around the world (as opposed to discrete local discoveries).

The production function of a given energy technology delineates the constraints imposed by the existing level of technology on the activities of energy producers. Technical progress suggests much more than a change in the ratios of technical substitution of factors. It suggests that the production function itself has changed over time.[10]

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[9]Harold J. Barnett and Chandler Morse, Scarcity and Growth: The Economics of Natural Resource Availability (Baltimore: Johns Hopkins Press, 1963) provides an excellent discussion of scarcity under a wide variety of socio-technical assumptions.

[10]For an excellent technical discussion of this distinction, see Edwin Mansfield, The Economics of Technological Change (New York: W. W. Norton and Company, 1968), especially pp. 13-26 and 40-42.

The importance of technology transcends mere theoretical fascination. With less advanced technology, the conversion of natural resources into industrial goods has proceeded further than it would have with advanced technology.[11] For example, it is plainly true that we could use coal much more efficiently today than the coal we have burned in the past. Conversely, however, we might consider whether we would have mastered present efficient techniques if we had not consumed resources so inefficiently in an earlier period (thus the relationship between scarcity and technological advance).

Producers have a good idea what its costs to use up a machine (the price of another) but for energy resources (especially oil and gas) there is considerably more uncertainty and risk about finding replacements. Continued availability depends in part upon new discoveries, cost-reducing output, increasing development and price increases.

Price expectations and user costs are of course crucial variables. Of all the forces which determine the use of privately owned resources, entrepreneurial expectations of future markets and future costs are perhaps most important when taken in conjunction with the current rate of interest. Interest rates can be perceived as "prices" relating purchases between various time periods. They indicate the terms at which the market allows consumption items in different periods to be exchanged.

Price expectations are a function not only of the trend of past prices but represent also an index of balance between the quantity of

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[11] J. V. Krutilla, "Conservation Reconsidered," The American Economic Review (September 1967), p. 784.

remaining stocks and the future demand for those stocks. If past prices have been unstable, investors and owners will be unwilling to commit themselves to <u>any</u> expectation of future prices.

However, there are some indications that a change in prices leads planning agents to expect further changes in the same direction in the future. This can be expressed via a concept known as the elasticity of price expectations. The elasticity of price expectations is equivalent to the proportional change in <u>future</u> prices divided by the proportional change in current prices (i.e., Elasticity of price expectations = $\frac{\%\Delta \text{Future prices}}{\%\Delta \text{Current prices}}$). If the elasticity of price expectations is greater than one, then a current change in prices will cause planning agents to expect further changes in the same direction in the future.[12]

The relationship of the above to user cost analyses is apparent. Economic theory provides a scenario utilizing user costs in the absence of futures markets. Because of the lack of adequate forward (futures) markets operators will have to base their decisions on their own expectations of future prices rather than on definite information. Rumors of future shortages cause prices to rise. The price increase, if it is expected to continue, will cause sellers to hold stocks off the market or will cause buyers to economize on their use of the commodity and begin searching for substitutes.

These two moves will reduce future demand and raise future supply, thus preventing the development of the anticipated shortages. The fact that buyers economize on their use of the commodity and develop

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[12] S. V. Ciriacy-Wantrup, <u>Resource Conservation: Economics and Policies</u> (University of California Division of Agricultural Sciences, Agricultural Experiment Station, Third Edition, 1968), p. 13.

substitutes will also serve to insure a reasonably smooth transition from the resource to whatever is the best substitute when stocks run out.[13]

Essentially what we are discussing is a dynamic resource externality--the effect current use has on future interfuel substitution possibilities. If present energy resources have a price, it is ordinarily not because of present scarcity, but because of some expected differential scarcity within the present time horizon.[14]

Price increases will begin to take place before physical shortages occur. Owners, anticipating increasing costs of output, will restrict output anticipating future profits from the expected shortage. Thus, theoretically, it would pay to retard production until the last marginal unit produced earns the same net revenue regardless of the period in which it is to be produced (assuming a discounted net future return). A producer would then equalize not just marginal cost and marginal revenue but marginal net revenue and marginal user cost in his decision about output. The user cost of the marginal unit would determine the rate of use.

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[13]The reader is advised to utilize such an "ideal" scenario with extreme caution. There are a number of significant problems. For a compact analysis of these problems, see Geoffrey Heal, "Economic Aspects of Natural Resource Depletion" in The Economics of Natural Resource Depletion, ed. D. W. Pearce (New York: John Wiley and Sons, Inc., 1975), pp. 118-20.

[14]Relations may be defined as competitive in costs through time if an increase in one rate increases the marginal cost of another (an increase of use in one planning interval increases the marginal cost in other intervals).

An interesting possibility, however, is that a small increase in the rate of output in the future would precipitate a terrific fall in price, so that the desired increase in that future output of "so many dollars worth" would require a much larger increase than had been contemplated.

Ultimately the quantity of any energy resource is defined (theoretically) by the position of the long-run supply curve for the resource. But the substitution questions involved in interfuel competition hinge primarily on the short and intermediate run. In the very short run, of course, price serves only to ration demand since supply response to price changes is totally inelastic. In the intermediate run, the quality of the collection of known reserves is very important in determining the elasticity of supply. A high quality resource allows a high elasticity of supply; low quality resources, a more inelastic response.[15]

Three main factors will operate to distort the theoretical simplicity of the preceding discussion--ignorance, risk and monopoly. The latter shall be dealt with in the chapter on market structure. Ignorance is reflected in the absence of futures markets. Risk is a critical variable in the process of interfuel substitution--especially where the development of new alternate technologies are involved.

Risk is a function of the level of prices in the short-run and the market for a particular resource in the long-run. The greater the

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[15]The relative inelasticity of low quality resources is due in large part to the marginal diminishing effectiveness of technology to offset declining economic quality--regardless of higher price levels. This is related to the declining productivity of capital in energy intensive industries (that will be discussed later in this study).

risk the more inelastic the long-run supply curve for the resource.

The absence of viable futures markets for energy resources and the consequent uncertainty and risk have a number of important effects on the processes of interfuel substitution. Most generally, it can be asserted that the absence of futures markets leads to inefficiency in the rate of resource depletion (since decisions are based on expectations and not on hard data). Usually risk aversion produces a bias towards present depletion. But we must be careful to ask: "depletion of what level quality resource" and remember that user cost perceptions may produce an opposite effect upon depletion rates. The rate of depletion is a function both of the amount of pollution that will be tolerated and the existing form of market structure. As depletion increases--especially in the fossil fuels--the amount of residuals per unit of energy obtained increases dramatically (the amount of energy required to obtain "new" energy also increases).

The market structure question is a complex one and will not be discussed at length here. What we should consider, however, is what kind of market imperfections exist and what these "imperfections" imply for the actual rate of depletion compared to the "optimal" rate.[16] Incidentally, even the term "depletion" is not value free. Physical resource depletion can be compared to "man-made" depletion which refers to the dramatic shift in political bargaining power and economic rent to the resource producing countries.

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[16]Despite continued efforts, no completely satisfactory model of "optimal" resource depletion over time has been developed (although many have been constructed utilizing stringent but highly unrealistic assumptions).

Much of the preceding discussion has centered on the concepts of scarcity and economic quality and their relationship to interfuel substitution possibilities. A central tenet, because of the role of technology, is that static inventories do not display dynamic scarcity (in the modern economic sense). Although I do not desire to deviate too long from the theoretical nature of this chapter, I believe we cannot avoid considering how the actual order of fuel use (wood, manure, peat, coal, oil, gas, etc.) correlates with the suggestions derived from the economic principles of scarcity and substitution. Does the preceding progression of use suggest that supplies of fuel have been progressively met by utilizing fuels of higher economic quality first and then moving to those of lower economic quality?

Obviously we need an index of declining absolute quality. An excellent technical discussion is provided by Barnett and Morse.[17] The basic point of their analysis that is most useful in our study is the notion that additional amounts of labor and capital are required as we use successively lower qualities of resources. This of course is very similar to net energy analyses that will be discussed in a later chapter.

First, however, we need a definition of deterioration in the economic quality of resources. Barnett and Morse state

> Resources (Ru) are of lower economic quality than resources (R), if, with no changes in any sociotechnical parameters (and for any criterion of optimality that may be selected), total output and the average and marginal productivities of labor-capital (L + C) are lower for every optimal combination of L + C with Ru

[17]Barnett and Morse, pp. 101-25.

in the social production function than for the corresponding optimal combinations of identical amounts of L + C with R.[18]

Declining absolute quality is expressed by increasing "resource conversion cost"--a term indicating that additional amounts of labor and capital (and energy) are needed in inferior quality resources to produce output comparable to that obtained from higher quality resources. Technically, it is formally embodied in a resource conversion function: R = F(Ru + Lr + Cr). This is a special kind of production function showing the combinations of labor and capital and inferior quality resources (Ru) that can substitute for that quantity of superior quality resource (R) in the standard production function.

A resource conversion path indicates the minimum labor-capital cost of "creating" each amount of standard (superior) resources.[19] The fact that Lr + Cr grows at an increasing rate as R (and therefore Ru) increases is both a reflection and a measure of the decline in the quality of successive increments of Ru.

A key question that remains to be answered is whether the marginal diminishing returns due to declining resource quality (as technically defined above) can be overriden by increasing returns to scale in the social production function. The social production function, in a broad macro sense, can be defined as: O = F(R, L, C). Total social output is, broadly speaking, a function of the interaction of resources,

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[18] *Ibid.*, p. 109.

[19] This transformation function will be constructed and compared to another function (relating production costs, the rate of production and increasing entropy) in the chapter on thermodynamics. This latter function provides an alternate conceptualization of increasing scarcity.

labor and capital. Obviously the role of technology is paramount--hence a separate chapter on market structure and technology will be provided.

Regarding the use of technology, however, this note of caution should be added. As successively lower qualities of resources are brought into use, it is unlikely that the initially optimal structure of capital will be optimal later, after depletion has changed the character and quality of the resource. As resource quality declines, the labor-capital costs sharply increase and the nature of the tasks labor and capital are to perform changes as well.[20]

At this juncture it might be useful to reassess the validity of the preceding economic analysis of interfuel substitution. To this point, we have discussed primarily the scarcity, quality, and availability dimensions of the problem and have ignored the formal substitution dynamics. My rationale was simply that the preceding analyses were necessary for a better understanding of the analyses of elasticity of supply and substitution which follow.

Energy supply and growth are broadly constrained by dimensions of general availability of energy resources (just discussed) and the ease of substitution of factors (both energy and non-energy). It is the latter which now shall be discussed. The decisions are crucial. How certain must we be of the existence of viable substitutes to judge it safe to consume irreplaceable materials? Indeed, the preceding may well be the key to long-range energy planning.

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[20]For an excellent, somewhat "revisionist" analysis of production economics related to this problem, see Solo, pp. 53-90.

Elastic<u>ity of Supply Analysis</u>

For the last 200 years, energy seems to have had a higher elasticity of supply than anything else but transport. Indeed, the accelerating elasticity of supply of these two factors is what the industrial revolution was all about.[21]

A product generally has a high elasticity of supply:

(1) if it can be produced in many different ways

(2) if technology seems on the brink of bringing in more effective methods

(3) if the distribution system for it can be greatly improved

(4) if economies in the products use seem fairly likely.

Energy appears to fulfill each of these conditions in profusion.[22]

A crucial but simple theoretical relationship exists between the elasticity of supply for a factor and the economic rent it earns. The more elastic the supply curve for a factor, the less economic rent that factor earns. The economic rent is of course defined to be that total portion of total payments to the factor which is in excess of what is needed to keep the factor in its current occupation. If a supply curve were infinitely elastic (a horizontal line at the prevailing price), there would in fact be no economic rent. At the other extreme, all of the return to a factor which is in fixed supply is in the nature of an

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[21] An example of the importance of elasticity of supply can be demonstrated by the following example: A product has an elasticity of supply of 4 within 5 years if a 10% price rise (above the average of other price rises) is likely within 5 years to expand its production 40% above the rise that otherwise would have been expected.

[22] Be advised, however, that the preceding factors were used to support an argument that a "glut" of oil will soon engulf the world. See Skeptic--The Forum for Contemporary History, pp. 9-12.

economic rent.[23]

The relevance of the preceding to problems of interfuel competition is that the royalties garnered by the OPEC producers are affected by the presence of monopoly elements as well as by basic scarcity. In other words, monopoly power enhances the profitability of natural scarcity. When supply is very elastic, the royalty share will be low; when supply is relatively inelastic, higher prices will not increase output and the royalty share will be high.

Theoretically, under competitive conditions, an inelastic supply curve should indicate a scarcity of the resource. However, scarcity may be imposed by output restrictions of a cartel such as OPEC. The implications for developing alternate energy sources are clear. Since so much of the price of OPEC oil is composed of economic rent (royalties) and not production costs, it would be very easy for them to drastically reduce their price and undercut any "infant" synthetic industries America may try to develop. This would hold true even if we vigorously strive to produce substitutes at less than the cartel price. The "cartel price," having low production costs[24] and high royalty shares can easily be lowered and maintained and the effects on the strategy for creating an elastic demand for OPEC oil (as outlined in Chapter I) must be seriously considered.[25]

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[23]See Nicholson, pp. 332-36 or Raleigh Barlowe, Land Economics: The Economics of Real Property (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1972), pp. 156-85 for a full theoretical discussion of rent.

[24]For a comprehensive discussion of current OPEC production costs see John M. Blair, The Control of Oil (New York: Pantheon Books, 1976), especially pp. 47-49.

[25]The strategy of creating an elastic demand for OPEC oil is of course just one dimension of the overall energy problem. The final

Elasticity of Substitution Analysis

The elasticity of substitution is another key conceptual variable in the analysis of interfuel competition. In simple physical form, it attempts to indicate how easy it will be to substitute factor x for factor y, i.e., it can be defined as equation 2a:

$$\sigma = \frac{\text{percent change } {}^{x}/y}{\text{percent change RTS (x for y)}}$$

("RTS" referring of course to the rate of technical substitution).

In the vast majority of the economic literature the "factors" studied have been capital and labor. The focus has been on finding ways of substituting capital for labor to increase efficiency in production. We should be aware, however, that the substitution of capital goods for labor implies a substitution of inanimate energy for the labor of man and beasts. In other words, capital goods require energy inputs (heat or power) to operate.[26]

What I would like to emphasize is the theoretical and practical importance of shifting the focus of attention from labor saving substitutions to energy saving substitutions. This will be discussed again in the next chapter.

The preceding physical definition of elasticity of substitution does not consider the dynamics of pricing. Equation 2a above indicates

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chapter of this study--concerned with policy implications of the technical analyses--will continue this discussion.

[26] Capital may be defined as the sum total of man-made, non-labor resources (such as machines) which are in existence at some point in time. They are assets representing some part of an economy's output in the past which was not consumed (set aside for production in the future). Technical change may be categorized as neutral, labor-saving, capital-saving (or in our case, "energy-saving"). For an excellent technical discussion of the effects of these changes on (energy) production functions and the elasticity of substitution, see Mansfield, pp. 19-26.

that the quantities of each factor that will be utilized will be determined by 1) the purely technical properties of a given technology relating quantities of these inputs, and 2) their respective marginal physical products. This parameter gives us some information about the shape of the production functions isoquant map. The production function shows, for a given level of technology, the maximum output rate which can be obtained from given amounts of inputs. Information about this shape will indicate how "easy" it will be to substitute one factor for another (in our case, for example, the consequences of increasing the ratio of capital goods to energy resources).[27]

Assuming the firm obeys the conditions of the marginal productivity theory of factor demand, the RTS of capital for energy resources should be equal to the rate at which these factors trade in the market.[28] The elasticity of substitution can then be re-written as equation 2b:

$$\sigma = \frac{\text{percent change capital/energy resources}}{\text{percent change } Pc/Pr}$$

where Pc = price of required capital goods and Pr = price of the required energy resources.

Implications and Limitations of the Preceding Analysis

If $\sigma = 1$, then equation 2b says that the ratio of capital to energy resources will change exactly in the same proportion as Pc/Pr does. Any increase in the capital-energy resource ratio over time

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[27]Capital substitution in this case refers to resource-saving uses of capital. For example, in thermal electric generation, as fuel rises in price, it pays to introduce more capital intensive methods in order to achieve higher initial and lower terminal temperatures.

[28]The marginal theory of factor demand is by no means universally accepted or adaptable to all situations. There are a number of specific theoretical objections. Nicholson, pp. 386-88 briefly describes these objections.

should be exactly counterbalanced by an increase in the MP capital/MP energy resources (=RTS) and this will be manifested by an identical increase in Pc/Pr. If $\sigma < 1$, the percentage increase in the capital/energy resources ratio will decline because substitution will be relatively difficult. Capital's share will tend to decline in this case because the relative price of capital is rising in response to an increasing amount of capital per unit of energy resource input.[29]

The preceding analysis has indicated the technical ways in which capital may be substituted for fuel. Perhaps the best procedure for accomplishing this is by designing machines with a greater heat efficiency. However, as the analysis indicates, marginal diminishing returns to capital will eventually accrue if $\sigma < 1$ (that is, the marginal productivity of capital may decline because substitution will be relatively difficult because more capital is needed to produce a given level of energy output from a given level of energy resource input).

The marginal decreasing productivity of capital in regards to energy production has a number of facets. On one side we must recognize that utility plants, for example, are extremely costly with furnaces typically designed to burn one type of fuel. To change fuels requires extensive capital modifications.

Another aspect of the problem involves the nature of the fuel that is utilized. Residual fuel oil--the product of a selected number

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[29] In the chapter on thermodynamics, the empirical dimensions of this relationship will be discussed (there is evidence of a dramatic decrease in the productivity of capital in the energy industries). This of course has important implications regarding the elasticity of substitution between capital and energy, i.e., the effectiveness of increasingly capital intensive technologies.

of refining steps--can be produced by a variety of refiners and still meet the same specifications.[30] This is not the case with coal, however. Each area of coal reserves has its own physical characteristics (this is why long-term coal contracts to a specific [type of] energy plant are usually employed, rather than frequent open market bargaining).

The choice of the elasticity of substitution allows considerable latitude on the extent to which capital may be substituted for energy resources. With an extremely high elasticity of substitution, the "problem" of resource depletion would become negligible. If the elasticity of substitution between capital and resources is less than one, then the C.E.S. production function assumption implies that resources are essential in the sense that production without net resource use is impossible.[31]

We could come very near to the "Limits to Growth" model conclusions by assuming very low possibilities of substitution and slight incentives to resource economy (such as rising resource prices). Whether _in fact_ the assumptions of these "doomsday theorists" are correct is by no means clear. It is the opinion of this author that there is time for an adjustment process to work--the key question is what should be the nature of this system. This will be discussed in the concluding chapter.

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[30]Recall our previous discussion about the "initially optimal" nature of capital changing as the character of the (fuel) resource changes. Therefore fuel of similar "specifications" has a great effect upon the technology employed.

[31]The reader should be careful to analyze the assumptions regarding the nature of the production function. Most investigators of real-world production functions have centered on the constant returns to scale, constant elasticity of substitution type. For a detailed discussion, see Nicholson, pp. 206-18.

If we were now to try to develop a computer model of energy economics over the next (say) ten years, we would have to combine the thousands of possible ways of producing energy and possible ways of changing distribution systems and consumption patterns for it, together with estimates of time lags for each as well as today's prices for each. We would also need the estimated elasticities of supply and substitution for each, forming an equation with a multi-billion factor.[32] Obviously, we cannot yet make energy policy by such a process.

The point of all the preceding analytics should be to answer practical questions. Chief among them would be "What changes more rapidly, relative prices of fuels or the relative quantities of fuels?" Unfortunately, the preceding type of analysis is by itself inadequate. Considerations of market structure and its effect on energy technology and the role of thermodynamics must be considered. The following chapters will proceed with these analyses.

To conclude this chapter, however, (and to provide a smooth conceptual transition to the following ones), we should consider a number of cogent points. As mentioned earlier, economic analyses of substitution invariably require evaluation of the effects of scarcity, renewability and economic quality. The substitution decisions, predicated by relative availability and price levels, take into account perceptions of differential scarcities. The stock of resources is not constant and differential scarcities lead to changes in relative prices producing desired substitutions. This theoretical process is not so simple in reality, however. There are a number of serious problems.

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[32] Skeptic, p. 10.

The first is that regulated (low) prices for natural gas distorted the market for other fuels and cut investment in them at just the wrong moment. Remember that fuels are substitutes if a cross-elasticity of demand exists--if an increase in the price of one causes the demand for the other to increase.

Markets are defined in terms of the degree of substituitability (by the degree of cross-elasticity of demand) among various products. Economic theory, however, cannot indicate how substituitable products have to be in order to be considered as trading in the same market. Whether "reasonable interchangeability of use" or "cross-elasticity of demand" in the anti-trust sense will develop can only be dealt with today by speculation because many alternate energy forms are usable only if commercially feasible technology can be developed. Thus much of the preceding analyses of scarcity and substitution is far from being a deterministic indicator of the exact path interfuel substitution dynamics will ultimately follow.

The next chapter will focus primarily upon market structure effects on the production of new (energy) technologies. In the short-run the demand for energy in particular forms is very inelastic; machines are usually designed to use a certain type of fuel and, in the short run, the possibilities of using less of that fuel are very limited. In the long-run adaption is of course possible. Since the demand for energy resource inputs is largely a derived demand, it is clear that the elasticity of demand for energy resources depends on the elasticity of substitution between energy resources and other inputs and the prices of all other inputs.

Recalling that a primary policy goal was to induce a price elastic demand for OPEC oil and remembering also the problems involved with the dynamics of substitution, I would like to now focus the analysis on market structure and technology--factors which affect both the elasticity of substitution and the prices of inputs (upon which the elasticity of demand depends).

CHAPTER III

MARKET STRUCTURE, TECHNOLOGICAL CHANGE AND FUEL SUBSTITUTION DYNAMICS

Introduction

This chapter will continue the economic analysis of interfuel competition, focusing upon the relationship between market structure, technological change and interfuel substitution dynamics. Crucial policy questions such as "Who should develop new (alternate) energy sources?" and "What alternate sources are economically feasible?" depend largely upon the relationships examined in this chapter.

The analytical procedure will be to first examine the general elements of market power and market structure, later considering theoretical dichotomies such as "dynamic versus static performance" and "optimum versus natural" market structure. Next, the relationship between market structure and technological change will be examined. Following this, the implications of the preceding analysis for multi-fuel and interfuel conversions and substitutions will be considered.

Perhaps the single most important development within the energy market over the last decade has been the growth of the horizontally and vertically integrated energy company. Unfortunately for energy planners, both theoretical and empirical evidence is inconclusive about the extent and effects of market power in the energy industries. To be sure there are numerous assertions, charges and counter-charges, theories and counter-theories. But the fact remains that the evidence is inconclusive and indeterminate.[1]

There may be a distinction to economists between "monopoly profits" and a situation where the industry is competitive in structure but is selling a product so much in demand that it can earn "monopoly sized" profits. The relevance of such a distinction may not be perceived or appreciated by the average consumer--hence conspiratorial theories about big business have always been popular among the lay public.

Elements of Market Structure and Market Power

Economic theory provides guidelines for evaluating the extent of market power: concentration ratios, entry barriers, degree of assym metry, relative size, and diversification. Similarly, theory provides rough indications of the determinants of market structure: public policy influences, economies of scale, pecuniary (input) advantages and information concerning the industry life cycle. But examination of the literature reveals nothing determinate in all of this.[2] Much of the theory is useful, however, in attempting to evaluate the status quo,

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[1]This is vividly demonstrated by the vast divergence of opinion in the Interfuel Competition Hearings; Thomas Duchesneau's Competition in the U.S. Energy Industry also indicates the many empirical uncertainties in energy analysis. William G. Shepherd, Market Power and Economic Welfare (New York: Random House, Inc., 1970) and the Thompson study of Corporate Capitalism indicate the theoretical dilemmas concerning the nature and effects of market power.

[2]For detailed analyses of indeterminancy in imperfectly competitive market structures, see Shepherd, pp. 3-48 or Solo, pp. 189-238 and 268-273.

and this I shall attempt to do at this point.

The Structure-Conduct-Performance Model is well known--especially to economists specializing in industrial organization theory. It is one model of evaluating performance in the corporate sector. Alternate models will be discussed later in this chapter. "Structure," in the context of creating alternate energy systems, is relevant because of the importance of entry barriers. Entry barriers determine to a large extent who will develop new energy resources.

Scale economies may make it necessary for an entrant to come in on a large scale. The capital required for such entry may be difficult or impossible to acquire, especially if the industry is very large or capital intensive (such as the current energy industry). Another factor in evaluating market structure is that low concentration ratios need not imply lack of market power. The degree of "corporate interlock" may be of more importance (i.e., interlocking directorates).

Conduct and performance are multidimensional concepts; they cannot legitimately be defined without reference to other social goals. Common conceptions of conduct inquire whether pricing and output decisions are "independent or collusive" (themselves value-loaded terms). Similarly, performance categories are subject to what is important to the analyst--common concerns include efficiency in production at a given point in time, the extent of technological progress and reasonableness of price.

Perhaps the most important point to remember is that restructuring the petroleum industry without carefully considering all implications, risks reverting to a pre-industrial form of business organization. The more technical the product, the more unlikely the market can supply either the components, materials or labor that are required. Energy production is a highly technical process.

There is a danger that higher prices may not be able to accommodate supply requirements fast enough. Highly specialized engineering talent is not always available on short notice in response to higher wages (nor are esoteric materials or components). To counter this inelastic response to specialized talent and materials, firms in the corporate sector attempt to control prices and customer and supplier responses because technical developments tend to make demand increasingly inelastic and markets increasingly erratic. This same technology permits increasing productivity and decreasing costs--to a certain point at least.

The emphasis in the corporate sector (symbolic of the large energy conglomerates) is on intermediate and long-range planning. The goal is to create an overall favorable market environment. There are of course a number of ways of controlling the economic and social environment.

The two primary methods utilized in the energy industries are vertical and horizontal integration and the extensive use of contracts. A fully integrated operation brings both cost and supply factors under control of the firm. Likewise, the extensive use of contracts (in lieu of continued market uncertainties) goes far to solve the problems of vertical coordination in the planning system.[3]

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[3]These strategies are discussed extensively by Galbraith and Thompson in their studies of modern corporate capitalism. In energy analyses, coal provides the best example of the use of long-term contracts (to obtain the "correct" type of coal for a particular boiler technology).

As mentioned in Chapter I, however, there remains the serious problem of coordination between end products (i.e., the production of air-conditioners versus the quantity of electricity available to power them). Professor Galbraith's assertion that blackouts and energy crises stem from the failure to match performance in various sectors of the economy is certainly a partially correct description of the entire energy problem. In sum, a failure in inter-industry coordination indicates that some producers can no longer supply what others require.

What then are the basic elements of "corporate capitalism"--the model of organization that best describes the current energy industry? Certainly market power is prevalent in varying degrees, depending upon the fuel, market environment and other circumstances. Only if unit costs at small output rates are comparable to unit costs at large output rates can firms of lesser size hope to enter the market successfully.

There are large financial (capital) barriers to entry. The nature of competition may more closely resemble a contest for consumer patronage and loyalty than it does an impersonal struggle of nameless firms against omnipotent market forces. But above all is the importance of technological advance, technical and cost imperatives and the need for efficient coordination.

What should be of immediate concern to us is the effect of existing or potentially existent market structures upon the emergence of new energy sources (keeping mind the constraint of other performance goals). Do joint ventures promote competition by lowering entry barriers for smaller companies or do they foster collusive pricing and stifle competition? Is the reduction in output fostered by monopolistic control of markets ("conservation") more than offset by the weakening of the economic structure at other points--i.e., in terms of other performance categories?

Dynamic and Static Performance Criteria

Economic theory posits that when marginal revenue is less than price there is a divergence between price ratios and technical trade-off rates. Marginal revenue is relevant to the firm's decisions; price, to the individual consumer's decisions. Under imperfect competition these will differ. Thus the "efficiency" of the price system will fail.[4]

But is static (price) efficiency as important as other dynamic performance variables? There are two fairly distinct approaches to anti-trust policy: one approach is concerned primarily with market performance; another emphasizes the importance of an industry's market structure. However, one need not and should not necessarily choose between these two views of "competition" and "progress."

Static efficiency criteria, relying upon market structure analyses, uses the perfectly competitive model as a standard for comparison. It asks, "How close is price to marginal cost? Do markets provide a socially desirable allocation?" However, an analysis of competition cannot rest solely on market structure. Wide variations in conduct are possible with a given structural setting--not to mention the question of "which conduct" is desirable.

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[4]It is assumed that prices relate tastes and productive technology via market transactions in a low cost manner (the "equivalence theorem"). For an extended discussion of the limitations of the equivalence theorem, see Nicholson, pp. 451-56.

Dynamic performance is more hazily defined. Its proponents feel that the benefits of technical progress far out-weigh any problems of marginal misallocations caused by market power. Thus, it is felt over the long run that dynamic performance is more important.

Advocates of dynamic performance assert that it is principally from technological change and innovation that society realizes more efficient utilization of resource inputs, gains in the quantity and quality of output and gains in the level of capital income. Thus, over the long run, whether the firm is technically progressive is much more crucial to society than whether it achieves the lowest possible unit costs at some particular moment of time.

There is, however, a divergence of opinion of whether very large firms are needed to produce the technical achievements upon which economic progress depends. This will be discussed in greater detail later in this chapter when the relationship between market structure and technical change is examined.

Large firms were not essential for technical progress in the view of Joseph Schumpeter. In his opinion, the key factor was the "correct" amount of market power and its "fruits" which drew the process onward. Giant firms were not always necessary because small markets can be dominated by small firms. What was important, according to Schumpeter, was a process of "innovative disequilibria" (a sequence of innovation, monopoly and disequilibrium).[5]

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[5]Schumpeter's view has been disputed by a large number of economists who maintain that the ill effects of market power out-weigh its benefits. For a full discussion of the process of "innovative disequilibria," see Schumpeter's book, Capitalism, Socialism and Democracy.

Schumpeter held that a view of competition framed entirely within the neoclassical allocation framework may omit some of the most important elements of performance. Professor Galbraith later extended Schumpeter's view to argue that oligopoly offered perhaps the ideal setting for technical progress. The goal again was to judge markets by their performance, not by their structure.[6]

But what are the "fruits" of the correct amount of market power (alluded to above)? Innovations have been carried out primarily by large firms or those with considerable market power because:

(1) The costs of innovating are so great that only large firms can become involved.

(2) Projects must be carried out on a large enough scale so that successes and failures can in some sense balance out.

(3) For the invention to be worthwhile, a firm must have sufficient control over the market to reap the rewards.[7]

Unfortunately there have been no definite empirical studies to settle the debate.

As is so often the case, we are faced with a series of tradeoffs: minimum average cost today versus future supplies, technologies and market structures. If the market were genuinely restored (in the perfectly competitive sense) in the energy industry, technical competency and innovation would be lowered to the level of the market system (policy unrelated to reality ends in absurdity).[8] On the other hand, one

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[6]Shepherd, pp. 16-23.

[7]Mansfield, p. 108.

[8]The necessity of government sponsored (induced) technological advance in the agricultural sector--which closely approximates the perfectly competitive ideal--illustrates vividly the reduced technical competency that results when economic scale is reduced to a level where the

of the most important shortcomings of corporate capitalism is the excessive accumulation of power (in many forms) by large corporations. Are we to ignore the societal implications of such concentrated power to maximize technical achievement in developing alternate energy systems?

Keeping in mind the importance of interfuel competition and the development of alternate energy sources as national goals--especially considering our dependence upon foreign energy sources--how do we reconcile the above tradeoffs with other national goals? Somehow we need to define a balanced mix of performance goals.

Such a mix of performance goals would, in the American setting, include efficiency, technical progress and competition. Tradeoffs must again be considered. One market structure may foster efficiency, another technical progress, another fairness. But it is difficult to determine where and when the social disadvantages of corporate power begin to outweigh the advantages of large size and market power discussed earlier.

It would be highly desirable if we could formulate a precise, accurate and determinate theory of "optimum dynamic performance." Unfortunately, no such theory exists. There are, however, a variety of models for social control of corporate power that do exist that I would like to briefly mention.

One is the model of "social responsibility" where the corporation feels that it is "good business"--given its size and power--to actively assume a socially responsive posture. The limitations to this approach are obvious and I shall not discuss them further. Other options (or

individual operator cannot afford either the necessary R & D expenditures or the risk of innovation.

models) include government regulation or ownership. A discussion of these would of course far exceed the limits of this study. The model of "workable competition" appears to be the paradigm in greatest favor with economists.[9]

Arthur Thompson provides a good summary listing of criteria useful for evaluating corporate power. Keep in mind that what follows is laden with generalizations and is neither totally accepted nor thoroughly tested economic doctrine.

The criteria are:

(1) The production decisions of large corporations should be in accord with consumer tastes and demands.

(2) Production should be undertaken according to the most efficient and low cost methods consistent with meeting consumer demand.

(3) The operations of corporations should be technologically progressive.

(4) Competitive forces should impose severe enough restraints upon the exercise of market power to preclude the earning of profits in excess of what is actually required to induce firms to supply the amounts of output that consumers desire.

(5) The activities of large corporations should be in harmony with the achievement of such national economic goals as price stability, full employment, economic growth, rising

[9]Thompson, p. 55, outlines the criteria for "workable competition." The essence of the approach is that competitive forces should be judged workable and effective if and when no clearly indicated public policy measure could be implemented to produce superior competitive performance.

living standards, an increasing quality of life, economic freedom, equal opportunity, economic security and an equitable distribution of income.[10]

"Optimum" and "Natural" Market Structure

At this point it would be interesting and analytically useful to examine the distinction between what economic theory might consider as an "optimum" market structure in comparison with that market structure that "naturally" seems to manifest itself in the American corporate economy.[11] Optimum market structure depends upon tradeoffs among many elements of which minimum cost is only one. If the economies or diseconomies are steep, they may be controlling.

According to William Shepherd, optimum market structure

> ...is as close to loose oligopoly as scale economies permit (in terms of gradients), leading firms are always approximately symmetrical, entry barriers are low, cooperation is held to a minimum and other external elements (size relative to total distribution of firms, diversification and vertical integration) are weak except when they are needed to neutralize or supplant scale economies.[12]

Ideally, the socially optimum form of market structure would combine the short term results of competition among large numbers of small firms with the long term performance of competition among giant corporations. However, the optimum number of firms in an industry differs, depending upon technological considerations, the importance of research innovation,

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[10]Ibid., p. 39.

[11]The definition of "natural" market structure was derived by careful empirical examination of the existing structural elements of typical large scale industries (apart from the utilities). For a detailed analysis, see Shepherd, pp. 152-64.

[12]Ibid., p. 17.

the size of the relevant market, the strength of competition from foreign firms and other factors.

Assymmetric "natural" structure has two specific features. It is inferior to symmetry (optimum structure) in terms of both efficiency and the innovation it yields. This structure will usually involve more market power than the optimum structure would prescribe.

Shepherd describes "natural" market structure as a situation when

> ...At least one firm will usually go beyond the "efficient" size into the range of increasing costs. This firm will accept and be able to sustain this relative inefficiency to the degree that its extra size confers added input price and market power advantages. The leading firm (or firms) may then adopt a relatively passive imitator's role in technical change, partly because its larger market share reaps it a larger reward for any improvement it may preempt, buy out or imitate. The net total of innovations will, however, be less than it would if all were at the optimum size.[13]

A broad generalization we might make from the preceding analysis is that, in the corporate sector as a whole (including the energy industries) the existing (natural) market form is inferior to a potentially "better" form. This type of analysis is a veritable "Pandora's Box"--the complexities, dead-ends, uncertainties and lack of definite data suggest extreme caution. It is a topic itself for a major study. The main purpose for including this analysis in this study of interfuel competition was to emphasize strongly the importance of distinguishing whether market power arises and is maintained for genuine technical reasons or whether it exists merely as a function of pecuniary advantage.

Much market power arises not from any technical imperative but

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[13] Ibid., p. 19.

from the ability to acquire inputs at low prices and to secure various types of government sponsorship. Vigorous efforts must be made to distinguish the pecuniary advantages of large-scale operations from the truly technical advantages.

The distinction between pecuniary (input-price) advantages of scale from those resulting from technical efficiency is extremely crucial. It relates directly to the question of who should develop alternate energy systems. What will be the optimum size firm or optimum market structure to produce a particular type of energy technology? Technical economies represent a genuine improvement in social efficiencies; pecuniary economies reflect only bargain prices paid for inputs rather than greater efficiency of turning inputs into outputs.

This topic will be discussed again in the final chapter on policy implications. But I feel I should stress at this point that this is one theoretical issue that has immediate and vital social significance. If radically new energy technologies, requiring inputs and capital investments vastly different from those of existing energy production are preempted by existing (oil) companies solely on the basis of pecuniary advantage, is this efficient or equitable? I would think not. Solar power is an excellent example to consider.

Thomas Duchesneau's comprehensive study of competition in the U.S. energy industry indicates that energy company development has not substantially altered the structure of the energy market and that the current structure is compatible with "effective" competition.[14] This,

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[14]Duchesneau, p. 188.

however, does not by itself indicate that effective competition does exist either in the energy market or in the market for individual fuels. Institutional features are major determinants of competition in energy production.

To reiterate, an analysis of competition cannot rest solely on a study of market structure. Wide variations in conduct are consistent with a given structural setting. The market structure dimensions analyzed by Duchesneau were: 1) the degree of interdependency among sellers and buyers, 2) conditions of entry, 3) degree of product differentiation, and 4) demand elasticity.[15]

The structural characteristics of a market, especially the level of seller concentration and entry conditions, do provide a partial guide for evaluating the state of competition in a market. However, defining the relevant market is not easy. For example, in energy market analyses, substantial variations in the degree of interfuel substituitability exist among the various end uses of electricity.

The statistical technique employed to measure substituitability among products (cross-elasticity coefficients) is of limited value in defining market boundaries. There is no a priori way to identify the critical level of the cross-elasticity coefficient which, if exceeded, warrants the conclusion that the products trade in the same economic market. As a result there is a strong subjective element in any interpretation of cross-elasticity coefficients.

Duchesneau concludes that

> ...no one has directly addressed himself to the question of whether cross-elasticity coefficients can be used to establish

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[15] Ibid., p. 13.

> market boundaries and more specifically to the question of whether the fuels trade in a single market or a different market.[16]

The question of whether or not fuels trade in a single market is of course crucial for determining the degree of interfuel competition. As always, the problem is a complex one. There is a broad concensus that a "relevant" energy market exists for the utilities. There are a number of economically feasible fuels that can be used to produce electricity--hence a strong cross-elasticity of demand exists. However, in many other end uses, direct substitution is significantly less, but <u>indirect</u> substitution in the form of increased use of electricity is possible.

Given the preceding theoretical discussion, we may now legitimately inquire about the general structure of the energy industry. Duchesneau's study, being recent and widely cited in many other sources, is again a good reference. Keep in mind that any analysis of market structure (given the indeterminate nature of theory in this area) is at best a rough index. Structural data and statistical analyses can be conformed to the beliefs of the analyst. Duchesneau's ultimate conclusions make him as vulnerable to suspicion as any other analyst in this regard.

He concludes that the structure of the energy industry and the individual fuels is not monopolistic. He states:

> The structure is not perfectly competitive, but it appears to be sufficiently competitive to yield competitive performance. The long run preservation of competition requires that entry barriers be low.[17]

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[16] *Ibid.*, p. 21.

[17] *Ibid.*, p. 182.

Thus any monopoly power by existing firms will attract new firms and lead to competition.

As emphasized earlier, institutional features are a major determinant of competition in energy production. Duchesneau is concerned that many government imposed restrictions on free markets are responsible for many of the energy problems facing the U.S. (i.e., administrative decision-making as a substitute for market prices--natural gas pricing, for example).[18] Consequently, firms have faced a different set of incentives than would have existed without government intervention.

Present energy market structures thus do not appear to be monopolistic <u>in structure</u> (with the exception of uranium). But there does appear to be a strong element of <u>government intervention which should be scrutinized just as carefully as individual corporate strategies</u>. Whether one is an advocate of Laissez-faire economics or strict government regulation, we should be aware of the possible over-use of either strategy in terms of detrimental overall economic performance.

Duchesneau is concerned that the oil companies' concept of "free markets" (extensive government intervention) will be transferred to the coal industry. Others feel that still more government control is necessary. The answer cannot be answered unequivocably. The evidence, generally available, does appear to indicate that concentration levels tend to be low but that a strong upward trend is present. The evidence is

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[18]Other examples would include attempts to influence the pattern of resource allocation by various subsidy programs (market demand prorationing and use of import quotas in oil).

less clear on the extent to which oil companies have entered the coal industry.[19]

Relationship Between Market Structure and Technological Change

The preceding analysis has focused upon the central elements of industrial organization theory and related these theoretical constructs, where possible, to recent empirical studies of the energy industry. At this point, I would like to focus the analysis upon the relationship between market structure and technological change.

Multi-fuel and interfuel substitution dynamics are critically related to the process of technological advance. At the outset, a number of important conceptual distinctions should be emphasized. One involves the distinction between economies of scale and technical progress; the other, the difference between marginal or minor changes in technique as opposed to major (often non-marginal) changes in technology itself.[20] Both distinctions are vital in understanding fuel substitution dynamics.

Economies of scale (moving along a given cost function) shall be recognized as a clearly different process than technical progress (represented in part by a shift downward of the cost curve). This first distinction cannot be considered apart from the second difference--that between a change in technique and a major technological advance.

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[19]See for example, Interfuel Competition Hearings or Duchesneau, pp. 13-119.

[20]Remember that "non-marginal" change distorts the analyst's ability to assess the economic impact and feasibility of a new technology. It may alter the level of all prices due to the magnitude of its impact on the economy. Thus factor prices of existing (competitive) technologies may be affected.

A technological change is an advance in knowledge; a change in technique is an alteration of the character of existing equipment, products and organization. A change in technique can be represented by marginal technical improvements in the efficiency of a steam-powered railroad locomotive. Technological advance can be represented by replacement of steam locomotives with diesel-electric units. Traditional economic theory (especially production economics) has a great deal to offer regarding changes of the first type (technique) but offers little in regard to the role of the economic system as regards technological advance.[21]

Obviously all of these categories are not mutually distinct or exclusive--theoretically or in practice. There are many subtle permutations that are possible. Movement along a given cost function (trying to find the point where economies of scale are maximized) is strongly influenced by the development of an altogether new process (in our case, a new energy source or technology). The new technology may drastically alter not only the demand for the old technique (or its product) but will also strongly influence the shape of the supply curve of the old technique by its influence on factor inputs.[22]

A technological breakthrough, providing an environmentally clean, but higher priced fuel, will have mixed dynamic effects on existing energy technologies. Much of the price of "old" energy technologies

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[21]The next chapter will discuss in detail the limitations of existing theory as an energy problem solver.

[22]The amount of available capital will especially affect the future shape of the cost curve. The chapter on thermodynamics will discuss in detail the relationship between energy and capital.

now represents "add-on" techniques to make them environmentally acceptable. Most of the cost of entirely new energy sources comes from the expense of R & D expenditures and lack of any economies of scale in production (such as exist in established technologies with pecuniary [input-price] and government sponsorship advantages).[23]

The intent is not to confuse the reader but rather to demonstrate that much of the "simple" substitution processes are not simple at all. They are complex, subtle and like the whole energy problem--insidious in nature.

Technological change will result in a change in the production function <u>or</u> in the availability of new products (energy sources). The production function shows for a <u>given</u> level of technology the maximum output rate which can be obtained from a given amount of inputs. Changes in <u>techniques</u> are due primarily to changes in factor prices but are also affected by changes in the production function due to technological change (as discussed above).

In evaluating the efficiency of existing energy technologies, a useful tool would be a simple <u>productivity index</u> relating the ratio of energy output to resource input. (For example: productivity index = $\frac{\text{changes in energy output}}{\text{changes in capital and resource inputs}}$). A theoretical complication arises, however, because the index assumes that the marginal (value) products of the inputs are altered <u>only by</u> technological change and their ratios remain constant and independent of the quantities of inputs.

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[23]Obviously, if you find alternate technologies that are cheaper than existing sources <u>and</u> environmentally cleaner, the analysis would be greatly simplified. Such a scenario does not appear to be likely--at least in the foreseeable future.

To reiterate, it is assumed that the ratio of the marginal (value) productivities of input remains constant and independent of the ratio of quantities of input. $\left(\frac{\text{MP Factor } x}{\text{MP Factor } y} = K \approx \frac{\text{Quantity of Factor } x}{\text{Quantity of Factor } y}\right)$

Recognizing the stringent limitations of the preceding assumption, we may perceive the productivity index as reflecting the prevailing configuration of product and input prices as well as purely technical factors. For energy analysis, the primary implications of the preceding relate to issue of energy saving (as opposed to labor or capital saving) technologies. How does technical change affect the productivity of capital relative to the productivity of energy resource inputs? This question was partially addressed in the previous chapter (in the elasticity of substitution analysis) and will be discussed at length in the chapter on thermodynamics.

Assuming technological change is a desirable strategy for resolving interfuel substitution problems, we may now inquire what factors influence the rate of technical change? In simple terms, technical change depends upon factors which influence the rewards from particular types of technical change and on factors which influence their costs. A key problem is that sunk costs may severely limit adoption of new technologies--regardless of their advantages.

New technologies are sought for three primary reasons:

(1) To further lower costs

(2) Increasing output per unit of input

(3) Producing new and superior products.[24]

It is important to recognize, in the context of the above objectives,

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[24] Thompson, p. 43.

a distinction in economic theory between (constant, increasing and decreasing) returns to scale and costs. The first is a purely physical-technological function; costs on the other hand, may reflect economies and diseconomies unrelated to the technical efficiencies of the productive process.

The main determinants of technical progress may lie in each industry's scientific character and opportunities rather than in its market structure (that is, heed the old adage, "Beware of mistaking correlation for cause and effect). At the very most, technical change may have tended to be slightly faster in industries with some market power though there is no proof at all that the latter has caused the former in any real sense.[25]

What is important to remember is the ability of giant corporations to absorb the losses from research that proves unfruitful, their superior access to capital for financing innovation and their greater organizational capacity that serves to rank them ahead of lesser social enterprises as potential pacesetters in pushing back the barriers to technical progress. When this capacity for innovation is combined with a strong incentive for achieving technical superiority because of vigorous competitive forces--the result (logically and theoretically) should be a superior organizational vehicle for advancing technical progress.

For each potential technical advance there may be an optimum configuration of market structure and profitability rewards, yielding the best performance in creating, installing and diffusing a new technology. In some cases there may be a range of equally effective market

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[25]Shepherd, p. 207.

structures for any given technical change. In sum, whether or not the largest firms do, in fact, more than their share of innovating, seems to depend on the average size of investment required to innovate, the minimum size of firm required to use the innovation and the size distribution of firms in the industry.[26]

An alternate means of viewing the problem of technical progress in the energy industry is provided by Edwin Mansfield. He hypothesizes that the probability that a firm will introduce a new technology is an <u>increasing</u> function of the proportion of the firms already using it and the profitability of doing so, but a <u>decreasing</u> function of the size of the investment required.[27]

As is readily apparent, evidence in this area is inconclusive and sketchy. There appears to be some support for the notion that oligopoly provides a superior market structure for technical progress because the innovator realizes at least a major share of the total benefits to the industry and moreover, will be strongly induced to innovate both as a means of non-price competition and as a defense.[28]

Mansfield concludes, however, that contrary to the allegations of Galbraith, Schumpeter and others there is little evidence that industrial giants are needed in all or even most industries to insure rapid technological advance and rapid utilization of new techniques. There is no strict statistical relationship between the extent of

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[26]Mansfield, p. 132, discusses these factors in detail.

[27]For a detailed description of the model employed, its assumptions and validity, see Mansfield, pp. 119-33.

[28]Shepherd, p. 57.

concentration in an industry and the industry's rate of technological advance.[29]

With the exception of the Galbraith-Schumpeter school of thought, the majority of the literature appears to support the notion that market power is greater than technical efficiency would require in most industries. It appears to follow the neoclassical belief that whatever its origins, market power in itself makes possible a restriction of output, raising of prices, retardation of technical progress and further inequality of distribution.

In regards to alternate energy technologies and the possibilities for increasing substitution possibilities, it should be emphasized that it is the rate of technological progress and not the efficiency with which a firm operates at any particular moment of time that ultimately determines the quality and quantity of output available at various prices. The precise relationship between market structure and economic performance, however, has yet to be defined.

Effects of Market Structure and Technological Change on Fuel Conversion and Substitution Dynamics

What are the implications of the preceding analysis for interfuel substitution dynamics? The most important consideration is that the full exploitation of the social benefits from new energy technologies and substitution possibilities requires that the process be as smooth as possible to avoid catastrophic transitional inequities.

Sudden abandonment of existing technologies may place severe strains on the economy in the form of dislocations and unemployment.

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[29]Mansfield, p. 217.

The problem is particularly severe when there are immobile resources that cannot easily be shifted to the "better" forms of production. The depressed areas of Appalachia and Michigan's Upper Peninsula are excellent examples of a resource-dependent economy being severely depressed when immobile resources (coal or low-grade ore) were no longer demanded by the current "new technology."

Conversely, too rapid conversion to new technologies may place a severe strain on the economy because we must link these new technologies to <u>existing</u> systems and simultaneously consider the elasticity of the supply curve for new materials and skilled personnel (the problem of inter-industry/inter-sector coordination). The new processes have to be integrated gradually to insure such coordination.

This chapter has indicated the link between economic market structure and the type and rate of technological advance. Technological advance may affect interfuel competition in a number of ways. New techniques to improve existing energy systems may be devised or technological advance may permit a conversion to an entirely new procedure or energy source.

Interfuel substitutions and conversions are also strongly linked to technology (and the existing economic structure). Technology plays a crucial role in converting "primary" energy sources (coal, oil, natural gas, etc.) into "secondary" sources such as electricity. This conversion process often physically wastes up to two-thirds of the energy input. Low technical production efficiencies and losses through the electrical distribution network are primary causes.[30]

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[30]The next chapter will discuss these inefficiencies in detail.

Logically, the electric utility sector provides a fertile opportunity for evaluating questions of interfuel competition and fuel substitution dynamics. Increased use of electricity tends to increase the extent of interfuel competition. Since all of the primary fuels can be used to generate electricity, the range of possible substitutions is greatly increased. To reiterate, the extent to which energy is consumed as electricity is an important determinant of interfuel competition.

To the extent that electricity can be substituted for other forms of energy in any use, substitution among all primary fuels is at once possible in that use. Even when direct use of some fuels would not meet special requirements, all of the primary fuel sources through conversion to electricity are alternative substitutes.

But the dynamics of interfuel substitution are not quite as simple as the above suggests. There are several distinct end uses of energy with differing degrees of interfuel substituitability. A more important complication is that in certain end uses, electricity, produced by converting primary fuels into electricity, <u>competes</u> with those same primary fuels.

There are a number of factors affecting interchangeability of energy sources. One is that natural gas has been over-substituted because of artificially low regulated prices and because coal (a logical substitute) is at a basic disadvantage due to air pollution restrictions. Another consideration is that consumption decisions in many non-utility uses are generally not very responsive to relative price movements because of the large capital costs involved with any change in fuel use. For example, a heating system in a home--once installed--is a powerful economic deterrent to switching to an alternate source of heat energy that does not utilize the existing "sunk" investment.

Interfuel substitution analyses are also complicated by the fact (discussed earlier in this chapter) that cross-elasticity coefficients--used to measure substituitability among fuels--are of limited value. Another analytical weakness is that consumption patterns may change for reasons other than changes in relative prices. Tastes and institutional factors (such as pollution standards) have a significant effect on fuel use patterns.[31]

To this point, the analysis has focused on how existing economic theoretical constructs can be used to confront the problems of interfuel competition (and the broader problem of dependence upon OPEC). The following two chapters will delineate the limits of existing theory as an energy problem solver. The next chapter will address general limitations and the following chapter, the confrontation between the "laws" of thermodynamics and economics. They will indicate that no matter what form of economic analysis is employed (mine is only one possible procedure for addressing this problem), there are inherent deficiencies in existing theory that must be corrected if economics is to realistically confront energy problems.

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[31] Duchesneau, pp. 16-22.

CHAPTER IV

A CRITIQUE OF EXISTING ECONOMIC THEORY AS AN ENERGY PROBLEM SOLVER

Introduction

The analysis to this point has demonstrated the many subtle complexities of interfuel competition. The intricate nature of the problem requires a multi-disciplinary approach for realistic solutions, even though the skills of one discipline may be emphasized more than those of another. Certainly an engineer or a systems analyst would perceive the same "problem" differently, define it differently and use a different methodological approach than would an economist.

The key point is that there is much more to solving problems of energy than applying the maximizing principles of economics. This is not to say that in certain well defined cases, maximization strategies are not extremely relevant or useful. But in many other cases (including the focal point of _this_ study--interfuel competition), problems involving energy grow out of _changes_ in institutions, cultural values and technology. This is in marked contrast to the ceteris paribus assumptions of traditional Neoclassical theory.

In the "real world" there is a growing credibility gap between economists and public and private decision-makers. Much of this is due to public realization of the necessity of seeking non-market changes (in technology, institutions and cultural values) to deal with problems traditional economic theory seems incapable of or unwilling to handle.[1] Neoclassical marginalist theory retains its orientation toward perfectly competitive markets while new developments in the economy indicate a growing trend toward more and more monopoly power.

The Neoclassical system is not a description of current reality--rather it more accurately describes a society which once existed. It lends itself to endless theoretical refinement. With increased complexity goes an impression of increasing precision and accuracy. Meanwhile the orthodox economist can conveniently overlook the social consequences of his esoteric body of theory.

Economists must transcend the role of Neoclassical theory to begin to grasp the conceptual framework needed to comprehend group behavior and collective choice. The existing paradigm limits not only what we can do but what we can see as well. We must ask as Nicholas Georgescu-Roegen does ". . .why a science interested in economic means, ends and distribution should dogmatically refuse to study also the process by which new economic means, new economic ends and new economic relations are created."[2]

The point is that we should be receptive to new definitions as to what constitutes "economics." The pressures of social and technological change really leave us little choice unless we intend to be blacksmiths in an age of micro-circuits and space travel. Shall we

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[1] Glenn L. Johnson, "The Role of the Economist in Studying Problems Involving Energy and Food," (East Lansing, Michigan, Michigan State University Mimeograph, 1974), p. 13.

[2] Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process (Cambridge, Mass.: Harvard University Press, 1971), p. 320.

guard the old dogma for its relevancy or for its aura of precision?

This study is entitled "An Economic Analysis of Interfuel Competition" because I believe that economics, realistically defined, provides an excellent (although incomplete) procedure for examining this complicated problem. In energy analysis there are a number of significant limitations of existing theory that require examination.

First, some general statements about existing theory and energy analysis will be provided. Next, problems with the market as a feedback system will be discussed. Then, conventional Neoclassical production economics will be compared to alternate modes of conceptualizing production processes. The next topic will be the important distinction between qualitative and quantitative economics, and the importance of this distinction to energy analyses. Finally, net energy analysis will be compared to economics as a method of resolving energy problems.

The first distinction we should recognize is an obvious one, but it has far reaching implications. Simply stated, it is the distinction between physical efficiency (more output for the same input) and economic efficiency (more dollar profit for the same capital investment). Theoretically, under perfectly competitive conditions, these two indexes are identical and maximized.[3]

As discussed earlier, where there are market imperfections and cases of market failure ($P \neq MC$, externalities, indivisibilities, irreversibilities, etc.), the theoretical distinction becomes a real world one. In the case of energy for example, the pricing system may not

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[3]An excellent technical discussion of general equilibrium analysis is provided by Nicholson, pp. 399-462.

adequately take account of thermodynamic factors or consider the consequences of net energy analyses. This breakdown in congruity between the "laws" of economics and thermodynamics is the key element in the failure of economic theory to deal, by itself, with energy problems.

Production is normative--what we call "waste" and "product" involves value judgements. As the next chapter will demonstrate thermodynamics and economic processes interrelate concepts of normative and positive variables in a pragmatic way. It will show that "efficiency" is the derived result of the choice of the context of the input and output categories.

Even when energy problems are divided into subcomponents--depletion studies for example--there are theoretical complications. For example, there is no such thing as "the economic approach" to natural resource depletion. There are widely divergent viewpoints about the optimal rates of depletion centering on the extent to which the standard Neoclassical approach, based on the maximization of present value of future flows of income, adequately allows for future generations' well being.[4] In fact a number of economists have concluded that economic theory alone cannot determine whether resources are being overdepleted; i.e., they feel that continual empirical investigation is necessary.[5]

The basic shortcoming of Marshallian supply and demand analyses is that they are static plus they are primarily concerned with output

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[4]Pearce, p. 9.

[5]Ibid., p. 177.

and not with the rate of using up the fixed factors of production nor with the switch from one kind of fixed factor to another (the latter two factors are of course crucial elements in analyzing interfuel competition).[6] We should be uneasy about the above, especially when we consider another strongly held economic belief that the price mechanism can offset any shortage, i.e., resources are properly measured in economic not physical terms.

This latter belief rests strongly on the notion that resources are "created" (by relative price changes and technology). U Thant once said,

> The central stupendous truth about developed economies today is that they can have (in anything but the shortest run) the kind of scale of resources they desire to have. . . .It is no longer resources that limit decision. It is the decision that makes the resource. This is a fundamental revolutionary change, perhaps the most revolutionary man has ever know.[7]

As we shall see, however, this type of reasoning ignores the limitations of material and energy reserves and overlooks the thermodynamic and ecological constraints that limit accessibility of resources.

What we clearly see is a conflict between the Neoclassical analytical assumption that resources are limited in extent and that they must be explicitly allocated over time and the view that resources are created via technology (i.e., Reserves = F [relative price levels and technological change]). Economic theory, as a coherent body of knowledge has not satisfactorily reconciled this conflict and, until it does, its energy problem solving capabilities must certainly be

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[6]Anthony Scott, The Economics of Conservation (Toronto: McClelland and Stewart Limited, 1973), p. 6.

[7]Koenig and Edens, Resource Management, p. 5.

questioned.

It is not "net social benefits" (however defined) that guide the allocation of resources; it is internalized gains. Externalities increase with the degree of decentralization--hence the atomized and decentralized markets of perfect competition increase this distortion. If the rigid assumptions of perfectly competitive theory are met, however, net social benefits and personal profit are both maximized. When, however, there are imperfections--as there usually are--we must look elsewhere for solutions.

Market decisions are based on the marginal differences between existing rates of profit and hoped for larger ones. Most experts now agree that from a long term resource management point of view and in light of the problems of shifting to alternate sources, the prices of petroleum and natural gas have been considerably underpriced for several decades. This should lead us to inquire about the viability of the market as a feedback system.

The Market as a Feedback System

The market system is essentially a feedback process in which correction signals, in the form of price changes, are generated after the fact. The critical question is, quite literally, how much longer can we afford this? There are a number of serious problems to consider.

The market "solution" encompasses only those goods and services which command tangible prices and can be directly or indirectly regulated through the market structure. Conventional market processes are fundamentally incapable of dealing with irreversibilities; only when the initial allocations are reversible can normal market mechanisms properly reallocate resources. The market will send correction signals, in the form of price changes, after the fact.

There are three major problems of the market system as it relates to natural resource problems: 1) externalities, 2) non-marginal change and 3) time and irreversibility. Economic theory recognizes these as problems and, depending upon the context of the analysis, has a variety of means of integrating these "causes" of market failure into the body of theory as a whole.[8]

As technology progresses and society becomes more dependent upon that technology for survival, we must carefully examine the feedback process of the market system, both in terms of how accurately its correction signals (prices) reflect real world parameters, and also the speed of communication of these messages.

This study has focused on the supply-substitution dynamics of energy, considering environmental pollution resulting from these processes as a constraint. This constraint has not been operationalized (in the sense of incorporating it into the formal analysis) because the question of economics and pollution is itself the topic for a major study. This analysis has focused on pricing considerations affecting supply and substitution with pollution remaining a ceteris paribus constraint--i.e., a constraint that is recognized but the analysis proceeds as if it were a constant). As such this represents an important limitation of this analysis.

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[8]For an excellent extended discussion of institutional alternatives to deal with these problems, see A. Allan Schmid, The Economics of Property, Power and Public Choice (East Lansing: Michigan State University Publication, 1974), esp. pp. 187-260.

Market interactions have not, by themselves, been able to determine the relative prices for environmental quality. Considerable literature has developed regarding procedures for modifying the price system to reflect environmental realities.[9] This of course is a highly complex and diversified field, beyond the scope of this study.

When considering the limitations of existing theory as an energy problem solver, we should be aware of the option (with a somewhat ominous sounding title) of administered pricing. This procedure attempts to modify the operation of markets to alter outcomes so that they more accurately reflect not only environmental limitations, but scarcity and thermodynamic constraints as well. For example, environmental pricing schedules would introduce environmental diseconomies of size to counter technical economies of size thereby internalizing environmental, net energy or thermodynamic costs not previously included.

The resulting cost schedule (technical production costs + environmental costs + thermodynamic costs + net energy costs, etc.) would thus have a stabilizing effect on the "optimal" economic size of the firm. Costs of production would reflect costs other than those postulated by traditional U-shaped cost curves. As figures 1a and 1b indicate, production costs would no longer be decreasing monotonically--rather there may be plateaus or variations in the slope of the cost curve depending upon the number of extra constraints that are considered.

Figure 1a demonstrates the long-run average cost of energy production as postulated by Neoclassical production economics. It

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[9]An excellent overview is provided by Robert Dorfman and Nancy S. Dorfman, Economics of the Environment (New York: W. W. Norton and Company, 1972).

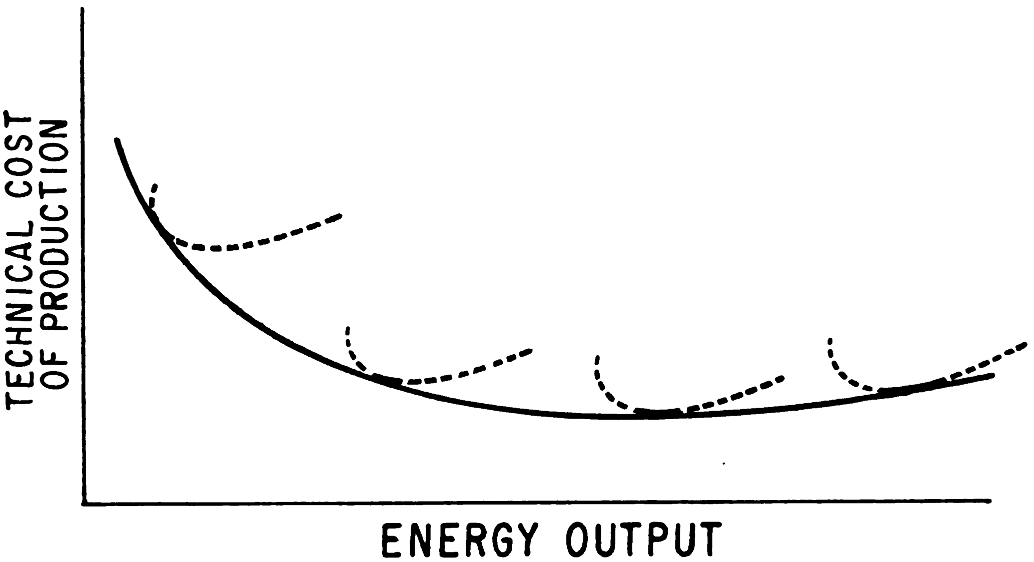

Figure 1a.--Neoclassical Approach to Energy Production

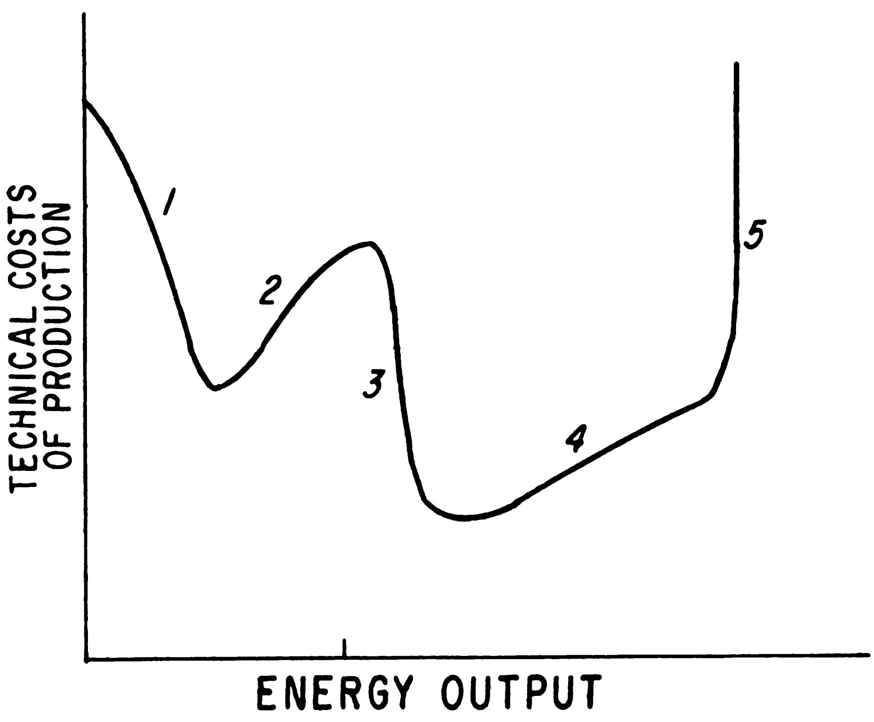

Figure 1b.--Scenario Incorporating Ecological and Thermodynamic Constraints

represents the hypothetical technical cost of producing energy as a function of scale of operations and temporal advances in technology. The determinants of the shape of this LRAC function are economies and diseconomies of scale. The broken curves represent short-term economies for a given technology. These short-run average cost functions turn upward because decreases in average fixed costs are eventually more than counter-balanced by increases in average variable costs due to decreases in the average product of the variable input.

Figure 1b demonstrates the effect of internalizing environmental, net energy and thermodynamic constraints. Stage 1 represents the beginning of technical economies of scale. Stage 2 represents the effect of internalizing pollution costs via taxation or administered pricing. Stage 3 represents the effects of a major technological advance in energy production (low cost production-low pollution). Stage 4 indicates what happens as the economic realities of net energy costs are begun to be felt. Stage 5 indicates the ultimate thermodynamic limits on energy production that cannot be overcome by technological advance.

It is crucial to note the difference in shape between these two postulated cost functions. The shape of the LRAC function is of great significance from the viewpoint of public policy. If the LRAC decreases markedly up to a level of output that corresponds to all, or practically all, that the market demands of the commodity, it makes little sense to force competition in the industry since costs would be higher if divided among a number of firms than if it were produced by only one firm (i.e., a natural monopoly would exist).

The preceding considerations are important in determining the optimal design and scale of our future energy industries. As discussed earlier, large scale should represent "true" economies--not mere pecuniary input advantages. Similarly, scale economies--via LRAC functions--must represent ecological and thermodynamic realities.

The central point of concern is that the rates of change induced by potentially precipitous increases in recovery costs (Stage 5, Figure 1b) may lead to serious economic and social discontinuities. The structure of the economy, which has evolved over decades of changing technologies, land-use patterns, cultural values and life styles, has become wastefully and overly dependent on the low cost non-renewable resources during the first half of the recovery cycle. As stated earlier, in view of the problems of shifting to alternative sources the prices of petroleum and natural gas have been considerably underpriced for several decades.

Koenig and Edens suggest a number of options for dealing with this discrepancy between theory and reality. One possibility is controlling annual production of non-renewable resources directly through a production quota system. Annual production may also be controlled by establishing new price schedules in the form of severance taxes added to the technical (and other) costs of production.

The key factor is establishing a planning horizon for energy resources (and the estimated quality and quantity of reserves that are required) and annual availability rates. Koenig and Edens suggest that, in principle, annual quotas, determined by national or regional authority could be sold on the open market as extraction rights to competing firms. It would be entirely analogous to the sale of discharge rights to polluters to control pollution (except, here, we control depletion).[10]

From the standpoint of the economist, the virtue of the preceding is that it incorporates the inherent dynamic advantages of the pricing system (instead of central government planning as in certain communist-bloc nations) and still includes the additional information that energy analysts require. As to the precise elements of such a procedure, little can be said now except that a great deal of further work needs to be done regarding feasibility, design and implementation. Such a procedure does not have the rigid limitations of central government planning without markets and that is a considerable "plus" to remember.

Another major problem with the market as a feedback system involves the role of relative prices in fuel supply-substitution dynamics. Theory dictates--and logic substantiates--the proposition that scarcer and higher priced fuels will be used less and in more highly specialized processes than will plentiful lower cost fuels.

The problem is that there is a limit on the influence of relative prices on energy use patterns. In other words, fuels do not compete solely on a cost basis. Electricity, with a price of $7.50 per million BTU's, is used far more than its relative price would indicate (the price of fuel oil for example, is $2.25 per million BTU's; natural gas--$1.25 per million BTU's).[11] Factors such as cleanliness, convenience,

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[10] Koenig and Edens, Energy, Ecology and Economics: Elements of a Thermodynamically Based Economy (DMRE-75-1, Michigan State University, December 1975), pp. 38-42 and Koenig and Edens, Resource Management, p. 43 provide more detailed analyses of these "market adjustment" strategies.

[11] Freeman, p. 143.

cost of heating systems and shortage of alternative sources also affect the choice.

What is necessary, if we wish to retain the market system as a viable mechanism for energy allocation, is to make pricing more "realistic." Whether this is accomplished by taxes, subsidies, administered pricing or another strategy is not as important as the recognition that the definition of "cost" must somehow be expanded to include other factors besides technical costs of procurement, production and distribution. To a great degree that is what the next chapter is all about.

A final problem of the market as a feedback system involves the lack of futures markets and what we are to do about this inadequacy. At least in their current form the energy industries have a strong technical imperative for planning. The market may not produce information on future demand and prices sufficient to support the large fixed investments necessary for modern productivity. Such problems of cost discontinuities and investment coordination are critical. They create costs not incurred when the demand curve can be discovered by offering marginal quantities at marginally different prices (the essence of Neoclassical "marginalist" theory).

A discussion of strategies and policy implications will be provided in the final chapter. At this stage, it would be useful to briefly mention some options. There is a striking similarity between option demands involving natural resources (where there is no demand now but there might be in the future) and the problem of fixed assets as demand declines or technology changes. Many so-called depressed regions exhibit this latter characteristic. What can we do about the lack of futures markets?

In Western Europe, "participatory" or "indicative" planning is often used to reduce some of these uncertainties. Indicative planning gives participants in the market and independent experts and government officials an opportunity to compare expectations and intentions. Out of the process may come some correction of mutually inconsistent expectations that may guide decision-makers. Participatory planning attempts to provide a coherent statement of economic intent of all relevant parties. This is useful to the firm in formulating its own expansion plans. In theory, at least, "groping" is replaced by "planning."[12]

Production Economics and Energy Analysis

Interfuel competition and the development of alternate energy sources are strongly related to the dynamics of production. This section will examine the efficacy of Neoclassical production economics in solving energy problems and consider some possible options.

The true nature of the dynamics of production in the energy industries is obscured in part by the lack of a generally accepted theory of oligopoly pricing. For example, the kinked demand curve model (Figure 2) is better at explaining why a price persists at a particular level than how it reached that level or under what circumstances it might change.[13]

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[12]Professor Robert A. Solo of Michigan State University has compiled a considerable body of literature on participatory and indicative planning. Reading lists for his political economy courses provide a fertile ground for investigating these strategies further.

[13]An excellent critique of the kinked-demand curve model is provided by Thompson, pp. 20-23.

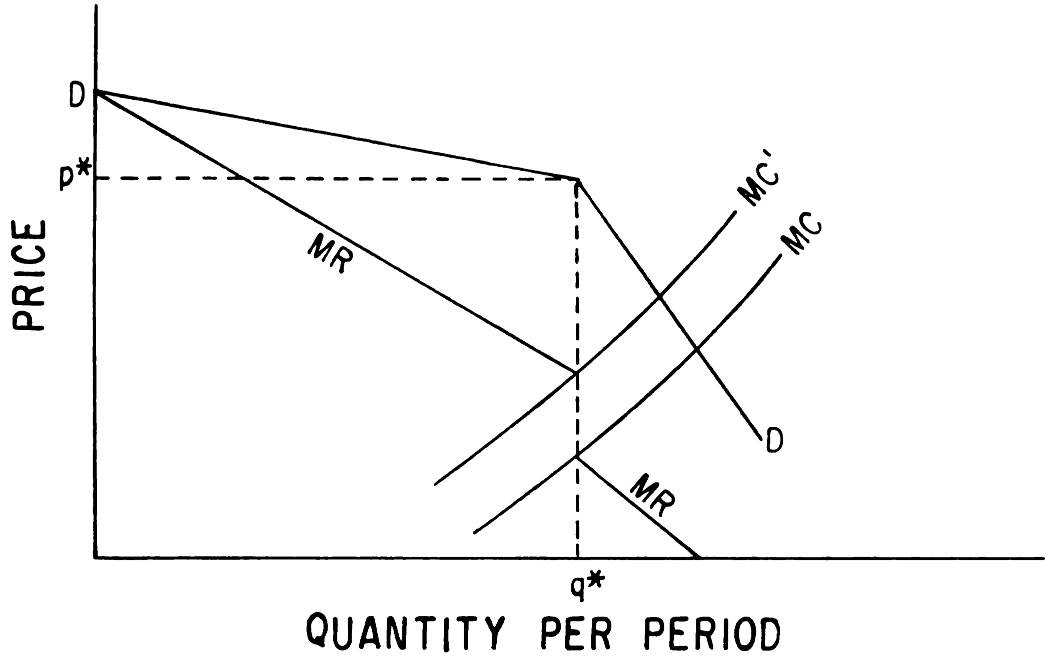

Figure 2. The Kinked Demand Curve Model

Source: Nicholson, pp. 314-15.

A firm in an oligopoly industry may believe it is faced with a demand curve (D) with a kink at the prevailing price (P*). If the firm considers raising its price, others would not follow and demand would appear to be very elastic since customers would shift to its competitors. Conversely, the firm may believe that if it lowered price, all of its competitors would do the same. Demand would be relatively inelastic below P*. The kink at P* means that the MR curve will be discontinuous at this point.

If a firm believes it is faced by a kinked demand curve it may not react to small changes in costs. The MR curve is discontinuous at q* reflecting the kinked nature of the assumed demand curve. Suppose that marginal cost were initially MC and that cost increases have shifted this curve to MC.

With this new marginal cost curve there will be no incentive to change either price or quantity because marginal revenue is still "equal to" marginal costs and profits are being maximized. Prices will tend to remain fixed until some kind of unifying event can get all firms to raise prices together. Since firms do not "properly" respond to shifts in their MC curves, production dynamics are affected.

In addition to the uncertainty of oligopoly pricing strategies there is also uncertainty regarding the goal of the energy producer. In Neoclassical theory it is presumed that profit maximization alone is the goal. However, as Galbraith indicates, above a certain profit threshold the members of the technostructure[14] are better rewarded by growth itself.

Thus he emphasizes that the most basic tendency of modern economic society has been for firms to become vast and keep on growing.[15] The separation of ownership from control involves a sharp challenge to the Neoclassical assumption of profit maximization--the managers are not beholden to the owners. We must certainly ask, "Is Neoclassical theory ignoring corporate reality by assuming profit maximization as the only goal?"

Also affecting production decisions are possible goal inconsistencies within an energy firm. For example, the need to show an improvement in earnings may conflict with the goal of growth or technical development may be in conflict with the security of earnings. Compared with the simple development in perfectly competitive markets, technology in the energy industries is complex and associated with highly specialized capital equipment. Much longer planning periods are employed.

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[14]The "technostructure" as used by Galbraith consists of a complex of engineers, scientists, technicians, sales, advertising, marketing, public relations experts, lobbyists, lawyers, coordinators, managers and executives who control the corporation--instead of the stockholders. That is, he posits that authority has passed from the owners of capital (of the means of production) to the technostructure.

[15]Galbraith, pp. 77-85.

The increasing overhead costs of the "technostructure" mandate that prices and costs should be under control and so to the extent possible should be consumer and government demand.[16]

Given the power to influence or control in the corporate sector, a strategy directed towards survival, growth or profits will not be expressed as a series of instantaneous marginal adjustments. Rather it is more likely to take the form of a plan, taking into account probable responses of competitors, customers, and suppliers.

Compare for example the Neoclassical approach to production (choosing lowest cost inputs) with the long term contract procedures used by utilities to secure appropriate and acceptable kinds of coal to avoid costly and expensive equipment modifications. Energy companies desire certainty in all sectors and depend heavily on their ability to anticipate, plan and influence (as much as possible) the activities of other sectors.

Current modes of energy production often involve economies of scale and cost discontinuities. Both of these involve the necessity of investment planning. Where one firm used inputs produced by another, investment coordination can reduce both unit costs and avoid unused capacity while the other firm reacts to price reduction. The policy problem we face is how to achieve this coordination. It can be achieved by increasing the scale of the firm or by contracts. The problem is that if it were done by vertical integration, undue monopoly power may result. If it were performed by the government, there is a risk that different groups will "unfairly" shape the benefits of government coordination.

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[16] Ibid., pp. 106-17.

How does existing production economics relate to the preceding "realities"? The marginalist backbone of Neoclassical production theory requires that choice be managerial; that production decisions be made within the framework of an established and operating technology. The energy choices facing us today require not only marginal adjustments in existing technologies--they require a rational choice between different competing technologies. Choice between processes (each requiring a different but fixed set of resource inputs per unit of output) renders the marginalist conception irrelevant as an explanation of producer choice.

Neoclassical theory assumes that the long-run average cost curve always has the same shape (the "envelope curve"). We, however, are facing a path of expansion where a firm faces a multiplicity of energy technologies, each quite appropriate to a particular output level. Keeping in mind the consequences of a pricing scenario incorporating thermodynamic and ecological constraints, the key question becomes: Whether to continue to produce at rising average cost (as defined by figure 1b) with installed technology or whether and when to install and produce incremental output with a smaller scale (alternate) technology.

The practical implications involve the use of multi-fuel and shared power applications. If production theory is to take account of these possibilities, LRAC must be reconstructed. Robert A. Solo suggests an LRAC curve that would actually be a set of functions taking into account both the costs of production and costs of procurement.

Figure 3 represents LRAC when we encounter a path of expansion where the firm faces a multitude of technologies, each most appropriate to a specific output level. We assume that output OM using technology

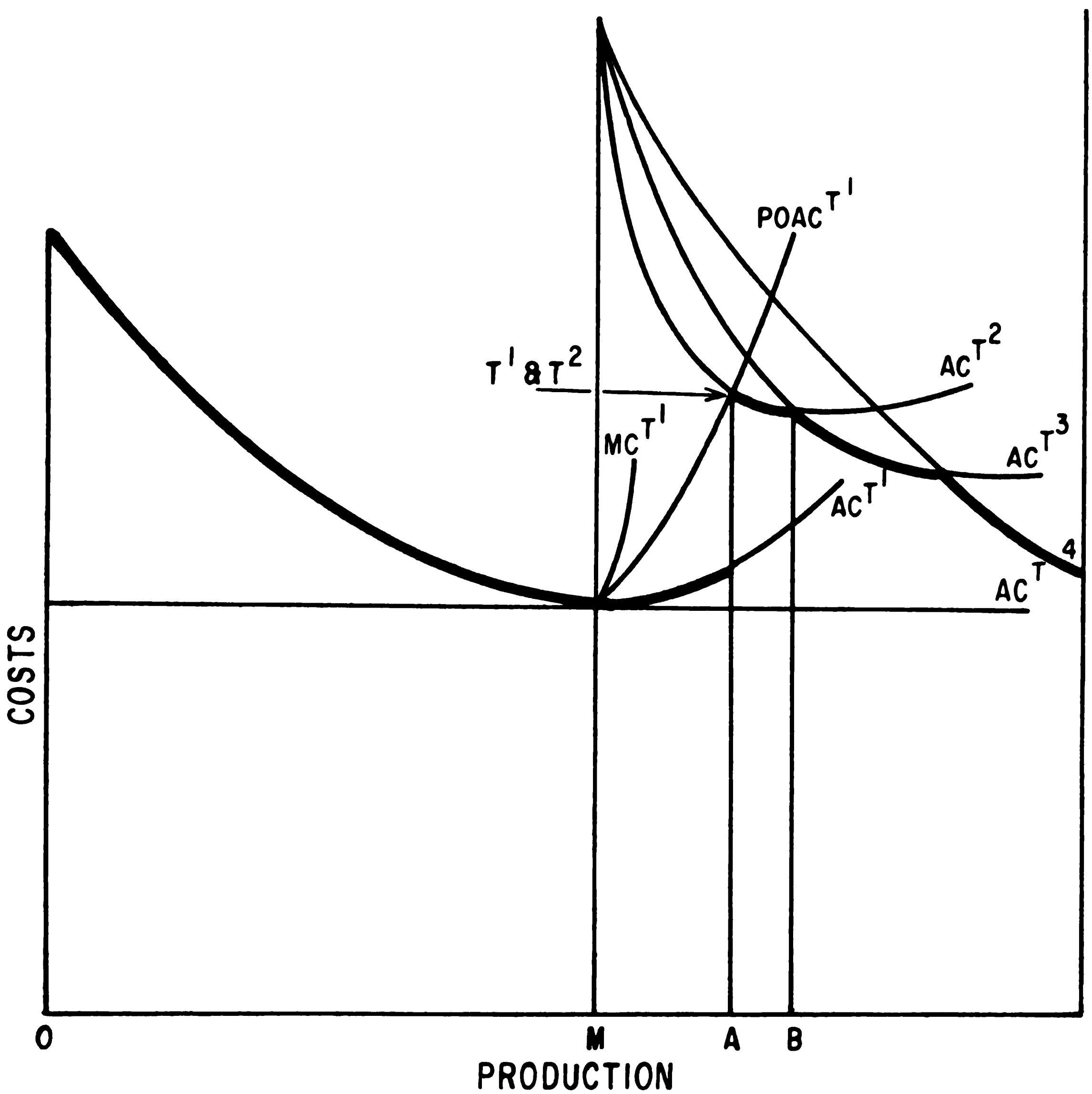

Figure 3.--LRAC Reconstructed to Consider Multifuel Energy Systems

SOURCE: Solo, p. 82.

T^1 is installed and that choices are between uninstalled technologies T^2, T^3 and T^4 for further expansion.

To produce an output greater than OM but less than, say, OB, the firm must determine whether to continue to produce at rising average costs with the installed technology T^1, or whether and when to install and to produce the incremental output with smaller scale technology T^2. To deal with this problem, Solo introduces a concept known as post-optimal average costs (POAC).

POAC is the average cost of operating beyond the low cost point with already installed plant where the question of installing additional plants first becomes meaningful (in our case the average costs of producing outputs with installed plant T^1 beyond the point of lowest average costs OM) shown as $POAC^{t1}$ in Figure 3. It would be logical for the firm to continue production on installed technology T^1 until $POAC^{T1}$ is greater than the average costs of producing outputs additional to OM with technology T^2.[17]

It becomes advantageous to operate T^2 only when the average costs of producing a given quantum of output with T^2 is less than the average costs of adding that same quantum of output to OM with installation T^1. This add-on point--where it becomes advantageous to operate T^2 in addition to T^1-- is shown by the intersection of $POAC^{t1}$ and AC^{t2} in Figure 3.

Solo's analysis indicates that when multiplant technology is already installed, it would be the <u>marginal costs of increasing output</u> in the various operations that should rationally determine the point of switch-over or switch back from one technology to another, and the

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[17]POAC is calculated by dividing the sum of marginal costs accumulated beyond the point of optimal operation by the number of units produced beyond that point. POAC can be perceived as a type of specialized <u>average</u> marginal cost function between two specified output levels.

allocation of production as between one installation and another. Beyond OM, cost follows the average cost curve T^1 until OA. From then on output additional to OM would be produced on technology T^2 with the average costs of the output additional to OM shown on the curve AC^{t2}.

As output continues to increase beyond OB, it would become advantageous to operate medium scale technology T^3 only when the average costs of additional outputs would be less than with continued operation on T^2. In this case, and subsequently when the shift is from T^3 to T^4, no POAC function is relevant since the average cost function of the smaller scale technology (in Figure 3) intersects with the average cost function of the larger scale technology before the optimal cost point on the former is reached. LRAC reconstructed to consider multifuel energy systems would be represented by the heavy line in Figure 3.

Solo at this point indicates that the preceding analysis explains only when it would be advantageous to operate with additional plants. A vital concern in the planning of multi-technology energy systems is that the preceding analysis does not explain when it would be advantageous to build additional plants and install new operations, since it leaves out of account the costs of building new plants and installing new operations or of transforming existing operations.

Transformation costs are one of the keys to the timing of expansion and the choice of an expansion path. There are problems of recovering some of the capital investment made in the technology that one is contemplating abandoning. This recovery process delays the installation of new plant, novel and innovative technology and inhibits the process of technological advance. Excellent real world examples are the capital intensive industries of Germany and Japan--destroyed in

World War II. They are now much more technologically advanced than their counterpart industries in the U.S. which came out of the war undamaged.

Another factor affecting transformation costs is the rate of interest. Higher rates of interest inhibit plant expansion and hold down increases in production, inhibit transformation and the pace of technological advance. High interest rates are also likely to force a series of small scale investments. This is explained by the fact that a firm often chooses a margin of excess capacity (utilities are a good example). That is, they may choose to employ a large scale technology anticipating increasing future demand and requisite production increases.

High interest rates shorten the time horizon of viable investment opportunities favoring small scale, higher operating cost technologies (T^2) as against large scale technologies (T^1) that could only be brought into full production in the future.

A problem manifests itself when we consider that an energy firm serving a particular market can and will be constituted of different technological combinations, parts of which will necessarily be suboptimal. Choice is not usually of a single technology but a series of related technologies (nor a single output, but a series of related outputs) each of which has an optimal scale.

There exists the option of purchase on the market rather than production which is illustrated in Figure 4. In Figure 4, MP is the market price at which an intermediate product (for example, utilities buying power from other producers in times of peak demand) can be purchased rather than produced. Beyond OM, T^1 would continue to be the preferred technology until OA.

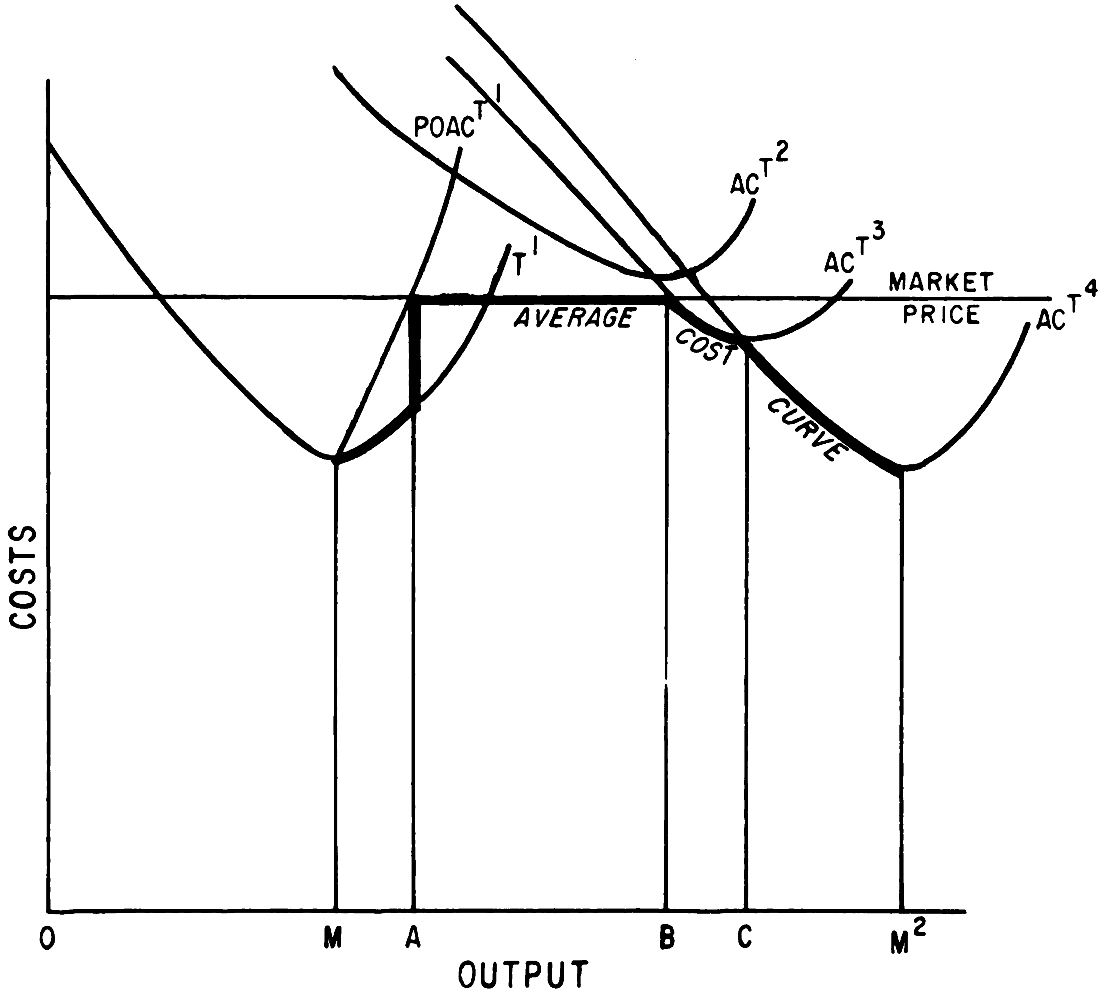

Figure 4.--LRAC Reconstructed to Consider Market Purchase of Energy

SOURCE: Solo, p. 89.

When demand exceeds OA it would be preferable to purchase the additional power until OB. Beyond OB, it would be appropriate to install and use T^3. When energy output demands exceed OC, it would be appropriate to use T^4. Average cost for various levels of output or procurement beyond OM are indicated by the heavy shaded line.

Thus, as stated earlier, Solo's reconstructed LRAC would be a set of functions taking into account both the costs of production and procurement.[18] Before leaving this critique of existing production economics as an energy problem solver, one final factor should be mentioned. The transformation of technology is an entirely different matter than the accumulation of capital. Capital has meaning only in relation to the installation and operation of a particular and specific technology. This is directly related to the issue of the effectiveness of technology (and its current form of expression--capital intensive energy technologies) to deal with the realities of resource scarcity and the ecological and thermodynamic constraints presently ignored by existing theory. The next chapter will examine in depth the limitations of capital intensive technologies.

So far, the Malthusian hypothesis has not been confirmed by history. In part, it has failed because micro-economic theory takes no account of the causes and consequences of technological advance. The law of diminishing returns (output diminishing per unit of variable input) assumes that technology is given (constant). Marginalism reflects the primacy given by Neoclassical theory to efficiency in the use of resources. Technological advance is quite outside the scope of

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[18]A more detailed analysis is provided by Solo, pp. 75-90.

marginal analysis. As the previous chapter indicated, efficiency in the modern economy is a secondary consideration to technological transformation and productivity changes.

Qualitative Versus Quantitative Economics

The preceding analysis has briefly examined the major shortcomings of existing theory as a tool for energy analysis, leaving the discussion of the conflict between economics and thermodynamic principles for the next chapter. There are decisively qualitative aspects of the relationship between entropy and economics for which the mechanical analogue of modern economics has no capacity to consider. The statement that the fundamental principles of economics are universally valid may be true only as their form is concerned; their content, however, is determined by the institutional setting.

As A. Allan Schmid has emphasized again and again, "efficiency" is the derived result of the choice of the context of the input and output categories. Thus cost minimization can follow from any set of property rights but produce quite different performance in terms of relative product prices, kind and amount of output. In other words, rights determine efficiency, not the other way around.[19]

A major problem of an economist (especially one specializing in energy) is that he is studying a process which is evolving faster than he can complete his professional training. It is a perfectly logical desire for him to desire the objectivity of classical physics and mathematical determinancy. As Nicholas Georgescu-Roegen says, "The difficulty of the subject of economics does not lie in the mathematics it

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[19]Schmid, pp. 36-39.

needs, but in the fact that the subject itself is much too involved to be fully accessible to mathematics."[20] What makes this subject not fully amenable to mathematics is the role that cultural propensities play in the economic process.

We must be careful, however, not to de-emphasize too much the role of determinate analyses. Edgeworth once said, "To treat variables as constants is the characteristic vice of the non-mathematical economist."[21] But an economist who relies entirely upon mathematical models is burdened with an even greater vice, that of ignoring altogether the qualitative factors that make for endogenous variability.

Roegen indicates two important values of mathematical models that are important for energy analysts to recognize. Perhaps the most obvious merit of a mathematical model is its value in bringing to light important errors in the work of "literary" economists who reason dialectically, i.e., economic theory shows what is wrong rather than what is right. The second role of a mathematical model is to illustrate certain points of a dialectical argument to make them more understandable.[22] These two roles of the mathematical model comprise the raison d'etre of what currently passes for economic theory--which is to supply dialectical reasoning with a "firm backbone." We must, however, be sure to remind ourselves that a mathematical model has little value unless there is dialectical reasoning to be tested.

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[20]Roegen, The Entropy Law and the Economic Process, p. 341.

[21]Ibid., p. 327.

[22]Ibid., p. 337.

Economic Theory and Net Energy Analysis

This section will explore the relationship between economic theory and a suggested alternate analytical model--net energy analysis. In net energy analysis kilocalories (or BTU's) replace dollars as the index of consumer and producer value. This approach of course has not been the only attempt to restructure the theory of value. To the physiocrats, land was the primary factor; to Marx it was labor. How valid is this approach considering the complexity of current energy problems? Is it a viable substitute for economic theory?

Net energy is the amount of energy that remains after the energy costs of finding, producing, upgrading and delivering the energy have been paid. While gross energy production may increase rapidly, net energy will certainly increase less rapidly and may even begin to decline. For example, the energy output required to find and utilize a low quality energy resource may equal or exceed the energy output obtained from the resource. Exclusive emphasis on energy as the index of value rests on the assumption that energy is the ultimate limiting factor since substitutes for other inputs can always be synthesized from it.

Economic analysis and net energy analysis would yield identical results if inputs were priced according to their energy content alone, i.e., the relative prices of all goods would be determined solely by the nature of their energy content. But as long as there are lags in supply and demand, existing inventories, capital equipment and current output will have a temporary scarcity value completely unrelated to energy content or the past or future price of energy.

Net energy calculations therefore are market determined in the sense that they depend on the technology, the structure of the industry and the prices existing at the time they are made. Changes in prices will therefore alter the manner in which inputs are produced and will undoubtedly alter their energy content.[23]

Thus it appears that net energy analysis <u>by itself</u> is not a viable substitute for the market mechanism (with all of its imperfections). As has been repeatedly stressed, a synthesis of existing models will be required to effectively deal with energy. The significant fact for the economist is that thermodynamics began as a physics of economic value and basically can still be regarded as such.[24] As the next chapter will indicate, the entropy law itself emerges as the most economic in nature of all natural laws.

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[23]David A. Huettner, "Net Energy Analysis: An Economic Assessment," <u>Science</u>, Vol. 192 (April 9, 1976), pp. 101-04.

[24]An example is the concept of <u>energy quality</u>. This is calculated by evaluating the energy used in converting from one form of energy to another (from coal to electricity for example).

CHAPTER V

THERMODYNAMICS, ECONOMIC THEORY AND ENERGY POLICY

Introduction to Thermodynamic Analysis

This chapter will indicate that thermodynamic analyses of energy must be incorporated into existing economic models and pricing practices if the problems of energy are to be adequately confronted and resolved. As the last section of Chapter IV indicated, alternate models (such as net energy analysis) are by themselves likewise inadequate and depend upon the operation of the economic system--hence some type of synthesis will be required.

The method of analysis will be to first provide a solid description of the fundamentals of thermodynamic analysis. Next the economic implications of thermodynamic constraints will be discussed. Given the preceding theoretical base, the relative competitive positions of alternate energy sources will be examined. The chapter will conclude with a brief discussion of the social and institutional implications of the technical analyses.

It will be useful at the outset to describe what thermodynamics is all about. The field of thermodynamics--narrowly defined--is a discipline for analyzing, designing and controlling heat engines (devices or systems used to convert heat [thermal energy] into mechanical energy). The key conceptual elements are the first and second laws of thermodynamics.

The first law states that the energy of a system (the universe) is constant. It focuses on the stores of available energy--i.e., the energy content of a fuel--and computes how much of it fails to get where it is supposed to go. A first law index of efficiency provides a computational tool for conserving energy with no preference as to its form.[1] Economic pricing principles as we shall later see have relied exclusively upon the tenets of the first law.

The second law of thermodynamics asserts that while the total amount of available energy in a system remains constant, the ability of that energy to perform useful work is constantly decreasing. Entropy can thus be viewed as an index of the amount of unavailable energy in a system. This is why the second law is often referred to as the "entropy law."

The second law--the entropy law--is the key to integrating thermodynamic and economic analyses. The second law approach focuses on the task to be performed and determines how much work is required to get it done. It then seeks out whatever method of performing a task that comes closest to doing it with the least amount of work. This approach makes the best use of the quality of an energy source that gives it most of its economic value--the work we can obtain from it.[2] This is the quality which, unlike energy itself, is always consumed.

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[1]The important point that will be emphasized later is the extent to which pricing distinguishes between heat and work. A detailed analysis is provided by Roegen, The Entropy Law and the Economic Process.

[2]Work is defined as force exerted through distance and the flow of energy is the agency that produces work.

A second law index of efficiency is consequently a tool for matching the quality of energy and associated technology to the task to be performed. It is a computational device for measuring the active component of our energy resources. It is an index of the loss of ability to perform work. Second law efficiency is equal to the ratio of the least available work that could have done the job to the actual available work used to do the job.

To reiterate, entropy is a measure of the unavailability of energy for work. When the entropy of a system increases, its energy is less able to perform work (and produce economic value). For example, fossil fuels, having a high energy density, have low entropy (high economic value) before combustion and high entropy (and low economic value) after combustion.[3] The key point to remember is that whole systems lose the ability to perform work--not energy itself.

The scarcity of low entropy that man can use does not suffice by itself to explain the peculiar balance and the general direction of economic development. The origin is in the asymmetry of the sources of low entropy: the sun's radiation and the earth's own deposits. Up to this point, technical progress has meant a shift from the more abundant sources of low entropy (solar radiation) to the less abundant ones--the earth's mineral resources. We should, however, recognize that without

[3]Following combustion (after conversion of fossil fuels to mechanical work) the remaining residual heat energy cannot be converted to mechanical form. "Waste heat," however, does have some economic value. The problem is to design systems that utilize this form of energy to heat buildings, water, etc., instead of letting it escape in the form of "thermal pollution." The problem of pollution is intimately connected with the way mankind is going to make use of the low entropy within its reach.

technical progress some of the resources would not have come to have any economic value.[4]

Nearly all of the energy produced in the U.S. is derived from fossil fuels. These are limited non-renewable sources of energy and our nearly total dependence upon them is a blatant violation of the essential principle that the production system--if it is to survive--must be self-sustained, regenerating the resources it uses.

Every barrel of oil taken makes the next barrel more costly to obtain; the law of diminishing marginal returns is at work--consequently the marginal productivity of capital fuels. If coal is to replace the massive use of petroleum in transportation, it must be coverted into liquid or gaseous fuels (drastically increasing the capital costs). Therefore the productivity of invested capital is likely to fall as well.

Nuclear power represents an extravagant case of "thermodynamic overkill" (heat many thousands of degrees above that needed for steam). As we shall later see, both fossil fuels and nuclear power--representing non-renewable resources and complex technologies--will ultimately lead to decreasing effectiveness of capital and higher prices.[5]

What can we conclude at this point? The second law tells us that the spontaneous processes occuring in the real world always lead to states that are <u>less ordered</u> than the states in which they began. Decay

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[4]The relationship between scarcity, entropy and technological advance is a crucial variable in the development and implementation of new energy sources. An excellent discussion of entropy and development is provided by Roegen, <u>The Entropy Law and the Economic Process</u>, pp. 292-305.

[5]These assertions will be discussed in detail in section III of this chapter which examines the relative competitive positions of various energy sources.

leads to disorder in natural substances. The second law also tells us that such natural processes can be reversed by the application of energy but this can be accomplished only at the expense of further decay in the overall world.[6]

The long term economic problem is best analyzed in terms of adjusting the rate of conversion of low entropy to high entropy. The entropy law places the role of technology in proper perspective; that is, it indicates that technology for the most part does not expand the size of "spaceship earth" along the dimensions most significant for human existence.

Thermodynamics, via the entropy law, focuses attention on flow resources as a means of increasing the value of output per unit of entropic degradation. That is, it suggests that we can increase entropic efficiency by using flow resources.

The economic implications are clear. If techniques could be made available--entropy budgeting should be incorporated into economic analyses. This would be potentially useful in providing early warning of coming changes in scarcity and price relationships.[7] Then perhaps policies aimed at simply substituting somewhat scarce fossil fuels for very scarce ones will appear as they really are--myopic and inadequate.

Net energy analysis was introduced in the preceding chapter as an alternate analytical technique for dealing with energy problems.

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[6]Commoner, pp. 21-24, discusses in great detail the relationship between order, disorder, probability and the second law of thermodynamics.

[7]This suggestion was made by Allan Randall, "Growth, Resources and Environment: Some Conceptual Issues," American Journal of Agricultural Economics, Vol. 57 (December 1975), p. 806.

It is fundamentally linked to the basic thermodynamic concepts just discussed. Production represents a deficit in entropy terms. It uses up an irrevocably greater amount of low entropy than the difference between the entropy of the finished product and that of the inputs.

This is a crucial consideration for those who advocate "production" of synthetic fuels. There will be thermodynamic and economic (declining marginal productivity of capital) constraints. The useable energy derived from a conversion process may be less than the energy required to build the capital facilities and carry out the extraction, processing and transportation operations. Consequently, net energy will decline even more rapidly than stocks of energy resources.

The thermodynamic waste of converting coal to liquids for example, can be conceptualized via net energy ratios which indicate the return on investment in energy terms. Net energy ratios for alternate energy conversion systems illustrate vividly that there are immutable technical constraints on the rate at which transition to alternative sources can be carried out.

The concept of net energy ratios is applicable to the development of solid fossil fuels, solar technology and all other alternatives to our proven petroleum and natural gas systems. The energy ratio for alternative energy conversion systems is defined: a) as the ratio of energy delivered to final consumption by the energy system over its lifetime to b) the energy required to construct, maintain and operate the facility, i.e., the return on investment in energy terms.

This type of analysis has many important implications. As Koenig and Edens indicate, a perfectly "acceptable" nuclear reactor (with an energy ratio of 5, i.e., $E_r=5$) can become a net consumer of energy. Recent reports suggest that fusion electrical power, if it develops, will also be plagued by very high capital costs and relatively low energy ratios.[8]

Ideally net energy calculations should take into account the qualitative distinctions between energy sources (their entropy index--the ability to perform useful work). This will be discussed in some detail on the following pages in this chapter on thermodynamic efficiency and thermodynamic matching. The realities of the second law will ultimately force a recognition of these qualitative distinctions--the question is will the economic system be able to react in time? We can continue just so long the vicious circle of burning coal for industrial processes and then having to use more coal to produce the energy to control the pollution.

As noted many times before "efficiency" must be defined in terms of the context of the input and output categories. In this section we will deal with the distinction between efficiency in terms of energy and economics. We must consider the thermodynamic efficiencies of alternate economic systems in carrying out transformations of heat into mechanical energy (and vice-versa) and the relative compatibilities with the natural environment plus temporal stability. Remember from the analysis in Chapter II that depletion itself limits the technical

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[8] Koenig and Edens, Resource Management, pp. 24-25 utilize net energy curves to demonstrate the relationship between energy ratios and building schedules. The key point is that energy ratios must be placed in context with other variables (such as the planning horizon) to be truly meaningful. "For example, a reactor with an Er=5 can become a net consumer of energy if an attempt is made to develop the facilities too rapidly as a replacement for fossil fuel."

substitution possibilities of one energetic factor for another.

We should first make a distinction between thermal efficiency and thermodynamic efficiency. Thermal efficiency is the efficiency with which heat is converted to mechanical work (a diesel is more efficient in this sense than is a gasoline powered engine). It is of primary importance in the optimal operation of existing energy systems.

Thermodynamic efficiency involves matching the quality of the energy source to the quality demanded by the task. This index is a function of the quantity of available energy and the preservation of the quality of energy resources (i.e., it is concerned with decreasing the rate of entropy increase over time). Under this criteria the characteristics of tasks should determine the thermodynamic quality of the energy used to perform them. The goal is to avoid "thermodynamic mismatches" leading to low efficiency readings.

For example, there are two kinds of energy produced by a power plant: 1) electricity and 2) waste heat. The conversion of heat energy to work through heat engines requires relatively high temperatures (over 1,000°F for efficient steam based electrical power generation). However, the choice of the proper thermodynamic efficiency index is critical. As the next section will indicate, energy pricing practices are implicitly based upon first law efficiency assertions and ignore second law assertions.

First law thermodynamic efficiency is defined as the ratio of the useful energy output to the total energy input regardless of form. It effectively ignores the fact that the input energy is in the form of heat whereas the output energy is in the form of work (in most cases).

Second law efficiencies are indices of how effectively the active (work) component of energy is being utilized (i.e., 2nd law efficiency = $\frac{\text{minimum active energy needed for the task}}{\text{actual active energy used by the task}}$). The important point of the preceding distinction in efficiency indexes is that the high losses (50% or more) associated with the conversion of heat energy to work energy is indicative of a basic physical law that cannot be overcome by technological innovation. As the next section indicates, this has striking economic implications (especially regarding capital requirements) for expanding energy production.

A practical example will illustrate the importance of the second law index of efficiency. The second law efficiency index for electrical water heating is 1%. This compares to a second law efficiency of nearly 100% when residual heat is used and about 50% when natural gas is used for this task.[9] The preceding efficiency ratings do not correlate well with actual use patterns or relative price levels; in fact the availability of waste heat for non-commercial heating is almost non-existent.

Regarding the general overall topic of this study--interfuel competition--we can observe that thermodynamic matching of sources to tasks is actually a "conservation" measure regarding the choice, development and use of specific fuels for specific tasks. As is true with any of the analytical methods discussed, thermodynamic efficiency by itself is not a valid criteria for selecting one option over another. The problem of achieving the "desired" thermodynamic linkages between energy sources and energy-requiring tasks is complex and mult-dimensional.

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[9]*Ibid.*, p. 26.

For example, economic efficiency implies energetic efficiency but the converse is certainly not true. The use of natural gas is thermodynamically more efficient for many tasks than the use of electricity but electricity is often cheaper. Likewise, while it is possible to make gas from coal, it is currently cheaper to extract gas from natural products. Should the natural resources of gas become exhausted before those of coal, we will certainly then have to consider resorting to the method that is now economically inefficient. This, of course, is only a hypothetical case, but it does serve to illustrate the real world problems of achieving desired thermodynamic linkages.

It is hoped that the preceding brief introduction to thermodynamic analysis will provide the framework upon which we can examine the economic implications of thermodynamic constraints--i.e., the "price" of moving (or not moving) from existing practices to more rational thermodynamic pricing and fuel use practices. Obviously there is a great deal more to the science of thermodynamics than I have presented in this very brief overview.[10] Hopefully the reader will feel adequately prepared to appreciate what I primarily want to emphasize--the close relationship and apparent conflict between the "laws" of economics and those of thermodynamics.

Economic Implications of Thermodynamic Constraints

This section will analyze the extent to which the economic system, in its current form reflects thermodynamic realities and examine the

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[10]In fact, thermodynamics is a branch of physics that many physicists feel uncomfortable explaining. Roegen, The Entropy Law and the Economic Process provides a somewhat complex but detailed look at this "sub-discipline" and its many philosophical and economic implications.

implications of any incongruities between economic theory and the principles of thermodynamics. Does the economic system reflect the first and second law realities?

There are a number of key questions that must be addressed. One that we must ultimately answer is "What economic considerations (which, after all, govern how the instruments of production are designed and used) have so uniformly imposed upon those instruments of production features that drastically curtail their thermodynamic efficiency? Remember that in the real world, energy is perceived <u>not</u> in BTU's but in dollars--the cost of energy required to do some needed work.

To date, market systems have developed largely outside of the influence of absolute resource shortages or residuals. Likewise, the monetary costs assigned to material and energy extracted are often heavily weighted in favor of short term opportunities rather than long term thermodynamic and ecological considerations. Additionally, economic policies have given undue emphasis to labor productivity without careful consideration of thermodynamic efficiency (recall the discussion in Chapter II on the desirability of switching from labor-saving [capital intensive] substitutions to resource-saving substitutions).

<u>Can we use thermodynamics to ask the right questions regarding the operation of our economic system?</u> After all, it is thermodynamics, through the entropy law, that recognizes the qualitative distinction which economists should have made from the outset--that between the inputs of variable resources (low entropy) and the final outputs of "valueless" waste (high entropy). I have tried to indicate how the second law efficiencies are the more relevant figures upon which we should base our economic calculus. Yet all of the present measures

of "efficiency" and "conservation" are based on the first law.

The point is we do have a choice! The economic process consists of a continuous transformation of low entropy into high entropy. This process is more efficient than nature's automatic "shuffling" in producing higher entropy (i.e., waste). But economic choice is related to the types of energy we use in another more fundamental way. Roegen states, "The economic process is entropic in each of its fibers but the paths along which it is woven are traced by the category of utility to man."[11]

Thus, while we cannot deny the laws of thermodynamics, we can alter the "production path" we take to satisfy our needs. Our values and many of the elements of Neoclassical theory may have to change drastically, however. Economics has reacted to the first law of thermodynamics but has failed to react to the second law--the entropy law--the most economic of all physical laws.

The quality of energy resources is a major determinant of the structure of our productive economy. The energy required to produce a given economic substance is a function not only of the thermodynamic characteristics of energy resources but also of the technical structure of the economy--the technologies of production, market power considerations, scale of operations, etc. These were examined in earlier chapters.

We must recognize that the rate at which we consume our non-renewable energy resources "buys time" at the expense of a rapid increase in the entropy of remaining stocks. Technically we may have remaining reserves--in the physical sense--but the cost of providing

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[11] Ibid., p. 282.

these in usable forms will eventually be prohibitively high. Increases in entropy will eventually lead to technical costs that cannot be countered by increased scale of operations and technological innovation. Technical production costs will increase rather precipitously at a later date because the entropy of the resource increases while simultaneously production rates decrease.

This can be illustrated by Figures 5a and 5b. Figure 5a--a resource conversion path--was introduced in Chapter II as one way of defining deterioration in the economic quality of resources. The resource conversion path indicates the minimum labor-capital cost of "creating" each amount of superior resources from inferior resources. Note that Lr + Cr grows at an increasing rate as R (the superior "standard" resource) increases. This is both a reflection and a measure of the decline in the quality of successive increments of Ru (representing decreasing quality stocks, i.e., "inferior" resources).

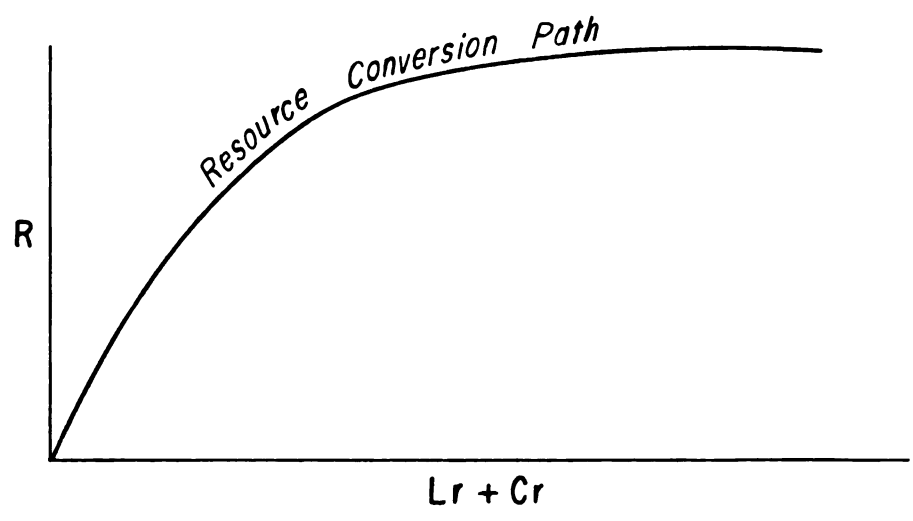

Figure 5a.--Resource Conversion Path

Source: Barnett and Morse, p. 276.

Figure 5b incorporates the thermodynamic elements discussed in this chapter. It postulates that the technical cost of recovery is a function of the production rate and the changing entropy of a resource. This is one of the most important economic implications of increasing entropy.

Figure 5b illustrates the relationship between production costs, the rate of production and increasing entropy. As the entropy of the resource increases (AD and BC) the average cost of extraction tends also to increase for each rate of production. Over time plant size is increased in an attempt to cope with higher entropy levels of the materials. As extraction proves to be more difficult technically, the cost of capital equipment required in the process increases. The long term average cost curve AB eventually shifts to new levels (EF and DC in Figure 5b) reflecting the progressively higher technical costs of extracting higher entropy resources. Note that as the entropy of the resource increases, would-be entrants into the extraction industry are faced with higher initial costs.

This is true at both the domestic and international levels and implies that increased entropy itself will lead eventually to greater firm size and market power. As noted before, progressive increases in entropy also eventually lead to price increases that cannot be countered by increased scale of operation and technological innovation.[12]

Figure 5b suggests that as non-renewable resources such as petroleum are phased out, the price of the resource increases precipitously. Koenig and Edens cite three primary reasons for this sharply

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[12]Koenig and Edens, Energy, Ecology and Economics, p. 37.

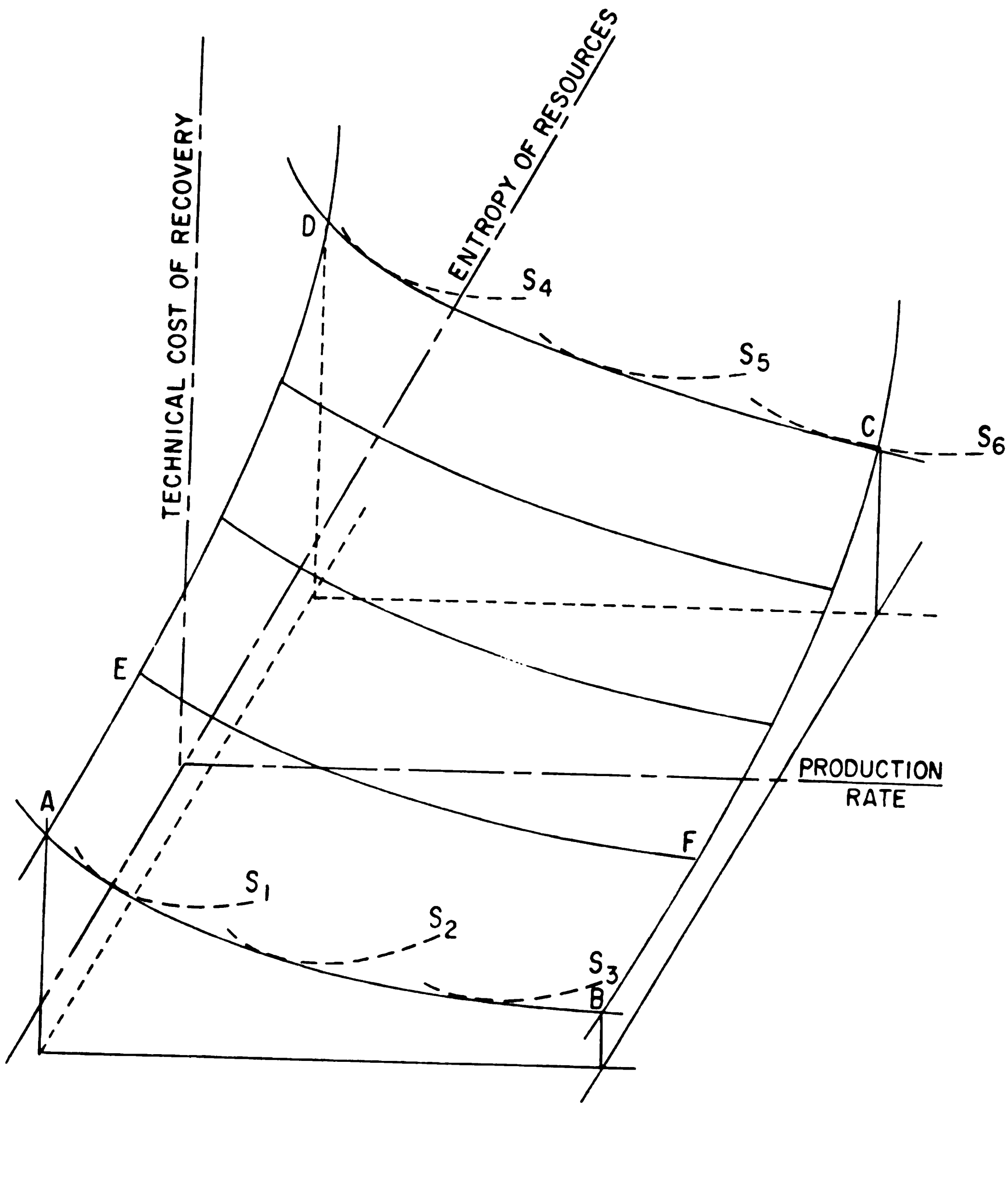

Figure 5b.--Technical Cost of Recovery as a Function of Production Rate and Changing Entropy of Resource

Source: Koenig and Edens, Energy, Ecology and Economics, p. 36.

increasing price:

1) The increasing entropy of the remaining resources

2) Reduced cost advantages imposed by monotonic decreases in production rates

3) Increasing imputed administered prices that are reflective of the future value to the economy of a vanishing resource[13]

As mentioned earlier we can infer from the preceding analysis that the cost of production can no longer be decreased monotonically either by technical innovation or expanded scale of operation.

Koenig and Edens' analysis greatly enhances the previous economic analyses presented in Chapters II and III. In Chapter II existing theoretical constructs were utilized to address the problems of scarcity, supply and substitution of energy resources. Chapter III examined the relationship between market structure, technological change and fuel substitution dynamics. The elements of this chapter add a new dimension (thermodynamics) to these preceding analyses.

Two crucial policy questions that are emphasized in this study are "What types of energy sources should be developed for the future?" and "Who should develop them?" The analyses in Chapters II and III indicate that considerations of scarcity, market structure, technology and substitution dynamics are crucial in making these determinations.

The larger policy problem of freeing ourselves from dependence upon OPEC depends to a great extent upon inducing a price elastic demand for their oil. The preceding analyses have indicated the many problems of producing substitutes at less than the cartel price

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[13] Ibid., p. 39.

(especially if pricing is to reflect long-run thermodynamic and ecological realities).

Increasing scarcity (increasing entropy to be more specific) entails higher recovery costs. Consequently only large firms can afford to enter energy areas where recovery costs increase with depletion. Solar energy is of course another matter.

Chapter III indicated that the relationship between firm size and the rate of technological innovation is far from being well understood. This chapter (Chapter V) has indicated that increasing entropy leads to increasing concentration of capital and technical competency in large energy firms. Barry Commoner goes on to suggest that there is a built-in conflict between the biology of the ecosystem and the thermodynamic characteristics of present energy sources.[14]

Consequently increasing efforts to control pollution or obtain increasingly scarcer resources leads to increasing capital costs and marginal diminishing effectiveness of capital (and technology). This ignores the effect of incorporating in the price of energy the thermodynamic impacts just discussed. Koenig and Edens describe "administered pricing" as the economic costs of flexibility--of keeping the options for the future open.[15] Such a system would incorporate a series of economic weights or signals to the decision-maker providing "early warning signals."

The key role for economics in the future should be to devise pricing practices that more effectively match energy sources to tasks.

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[14]Commoner, p. 215.

[15]Koenig and Edens, Energy, Ecology and Economics, p. 47.

This would be an excellent topic for a separate intensive study. In the interim, what can we do?

As previously indicated, the development of multi-source energy systems is both economically feasible and thermodynamically rational. For example, utilities could establish a special rate for customers who install solar or windmill operated power systems that feed back into the utility system any excess electricity that was generated. The utility in effect could "buy back" the electricity (measured by an extra meter) that flows back into the system.[16]

This procedure would not only be economically possible in the short run but would have the desirable effect of decentralizing power production and offset somewhat the problem of marginal declining productivity of capital that will be discussed later. Additionally since flow resources are utilized, it is thermodynamically efficient in the sense that the quantity of energy required can be obtained via the design of the solar collectors or windmills, i.e., no "thermodynamic overkill."

Another economic implication of thermodynamic constraints is expressed in the thermodynamic meaning of decreasing accessibility. The decreasing accessibility of energy supplies is formally embodied in the second law of thermodynamics. The entropy law is the essense of economic scarcity. If net energy is zero, then in reality, new energy sources are not accessible. In the very long run, it is only efficiency in terms of energy that counts in establishing accessibility.

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[16]This idea has already been approved for use by the New York State Public Service Commission. For details, see the Lansing State Journal, May 15, 1977, p. 12.

If the entropic process were not irrevocable (i.e., if the energy of a piece of uranium or coal could be used over and over again), scarcity would hardly exist. To be available energy must be distributed unevenly; energy that is completely dissipated is no longer available.

If costs for recovering reserves are measured in energy terms, the lead times for remedial action will be drastically shortened. As the preceding analyses have indicated the cost of production can no longer be decreased monotonically through technical innovation and expanded scale of operations.

There are many important policy implications in the subtle relationships between entropy, firm size (market structure) and technological advance. Increasing entropy leads to increasingly centralized production facilities with large expenditures of capital and energy. Centralized technologies produce high labor productivity but also, because of the specialization of labor, isolate the individual from the thermodynamic consequences of his or her actions.

With increasing size and a heavy demand for capital, costs can be borne only by large companies. (Remember the implications of market power and performance examined in Chapter III.) My conviction is that the best short- to intermediate-run solution lies in multi-fuel energy systems. This is demonstrated by the decentralizing effects of solar energy. Here the capital needed to provide domestic heat and power is broadly held rather than concentrated in large power companies.

I am obviously <u>not</u> going to suggest the elimination of large public utilities, but given the increasing inability of technology and increasing scale of operations to surmount scarcity and ecological problems, we must consider some broadly based options. Regional environmental differences (wind and sunlight) and rapidly changing demand patterns will certainly require the use of centralized power production--and the use of regional power grids or pools--for many years to come. The time for transition is now.

One of the most important implications of the thermodynamic constraints we have been discussing is the "capital crisis" in the energy industries--the marginal declining productivity of capital being the most disturbing feature. The supply and productivity of capital are crucial elements not only in maintaining current energy production levels but also in the design and installation of alternate energy production technologies. They strongly affect the lead times for these alternate technologies.

The capital problem involves much more than just the future of the energy industry. With the apparent necessity of large and complex energy firms (required by the declining quality--increasing entropy of non-renewable energy resources) has come a heavy demand for capital. Large firms of course have their own means of generating capital (reinvesting profits) but costs are rising so quickly that the energy companies' demand for "external" capital will significantly reduce the availability of capital for the rest of the economy.

The capability of the production system to regenerate capital at a rate sufficient to sustain itself is achieved by using less labor relative to output (i.e., increased marginal labor productivity). This is done by utilizing more and more capital-intensive technologies and requires constant growth and a reliable supply of abundant energy. Unfortunately, the marginal productivities of all factors (except labor) that contribute to production (capital, energy, raw materials and other resources) have either declined or have remained relatively constant during the post-war technological transformation, especially in those sectors of production which use a great deal of capital and energy.[17]

Capital represents the costs of the machines that are used in the production process. As technology advances, machines tend to become larger, more complex and more costly. This added capital cost is "acceptable" because the new technology is expected to reduce the costs of other inputs, to increase the value of the output (or both) and thereby enhance overall economic returns.

Energy is required to run the machines, so as the latter becomes larger and more complex, the cost of the energy required to operate them typically increases as well. Thus as productive technology is transformed, we can expect the inputs of capital and energy to increase together. Empirical data support this expectation.[18]

At this point, permit me to coalesce and stress the key points of the preceding analysis. The greatly intensified use of capital and energy has lead to both marginal decreases in capital productivity (incremental output per additional dollar of capital) and energy productivity (incremental output per additional unit of energy resource input). But as was noted earlier, the marginal productivity of labor typically increases with the introduction of new technology.

In order to sustain itself, the economic system must set aside from its current output sufficient capital to support projected future production rates. However, if the marginal productivity of capital

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[17] Commoner, p. 244.

[18] *Ibid.*, p. 223.

falls, so that more and more of it must be used to maintain the same ratio of output, this capability is threatened. At the same time, if progressively less labor is required for a given rate of output, the ability of the economic system to regenerate jobs is also threatened.

Commoner concludes

> It is worth noting that none of the reports on the capital shortage makes any serious effort to relate the problem to the effects of the sharp reduction in capital productivity that has accompanied the transformation of productive technologies. They regard it as a purely economic problem and ignore its origin in changes in the production system, which after all is the source of the wealth that takes the form of capital...It seems evident then that the fault which lies at the root of the three interlocked crises [the problems of the ecosystem, production system and economic system] will be found in the realm of economics.[19]

By failing to recognize the relationship between the capital crisis and the change in the character of productive technology, conventional analyses tend to foreclose the option of curing the problem at this basic level.

The capital shortage is most acute in the sector with the most pronounced decrease in marginal capital productivity--the energy industries. The most immediate and intense expression of the capital shortage is the electric power industry. In fact capital requirements may interfere with the growth of its customers.[20]

Especially disturbing, given the past distribution of energy funding, is the rising capital costs of nuclear power plants. In 1966 of the total cost of producing electricity from nuclear power, 34.2% was fuel costs; 49.9%, capital costs and the remainder, operation and

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[19] *Ibid.*, p. 234.

[20] B. Bosworth et al., *Capital Needs in the Seventies* (Washington, D.C.: Brookings Institution, 1975), pp. 27-29.

maintenance costs. By 1975 capital costs represented 77.1% of the total and fuel costs had risen only 18.2%.

This did not occur because the price of nuclear fuel declined (in fact, it rose about 19%). Rather there was a sharp rise in the cost of constructing nuclear reactors--about 244% in that period. That trend continues. There has been a steady increase in the capital costs of nuclear reactors which has now considerably reduced the significance of fuel costs.[21] Capital costs will be discussed more specifically later in this chapter when we examine the relative competitive position of various energy sources.

This analysis has asserted that the scope of economics, indeed the definition of what constitutes economics, must be altered to include additional relevant socio-technical variables. Precise and rigorous analytical definitions of the input and output categories are necessary if "efficiency" is to have any real meaning.

In energy analysis, cost consists in essence of low entropy and currently the pricing system does not adequately reflect this cost. It is fairly easy to accept the assertion that we can increase the value of existing energy sources by "increasing overall thermodynamic efficiency." Understanding the full implications of this assertion requires a more careful examination of the relationship between entropy and economic value.

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[21] See R. E. Scott, Projections of the Cost of Generating Electricity in Nuclear and Coal Fired Power Plants (St. Louis, Center for the Biology of Natural Systems, Washington University, December 1975) and I. C. Bupp et al., "The Economics of Nuclear Power," Technology Review, February 1975, p. 15 for details on the costs of nuclear powered electrical generation.

Economic value is a function of both <u>usefulness</u> and <u>scarcity</u>. In our energy intensive society our whole economic life feeds on low entropy. Low entropy is thus one necessary condition for an item to be useful (a given amount of low entropy can be used by us only once).

We can describe thermodynamics as a physics of economic value because it deals in essence with a typically economic problem. That economic problem is one of determining the conditions under which one could obtain the highest output of mechanical work from a given input of heat.

Low entropy is a <u>necessary</u> <u>but</u> <u>not</u> <u>sufficient</u> condition for an item to have value. Perhaps the easiest way to explain this assertion is to note that the relationship between economic value and low entropy is of the same nature as the relationship between price and economic value. Theoretically there should be no divergence between the price of an item and its economic value.

The key point is that we must <u>discriminate</u> between the economic value of heat produced from coal, gas or wood. The problem is how can we accomplish this procedure? It has been suggested by some that all economic values can be reduced to the common denominator of low entropy. I believe this would encounter difficulties similar to those of net energy analysis, where net energy calculations were to a great extent market determined.[22]

Another approach we might consider is that even though we may not believe there is a direct equivalence between low entropy and economic value, it would be possible to establish a <u>conversion</u> <u>factor</u>

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[22]Recall our previous discussion (pp. 96-97) on the limitations of net energy analysis and its relationship to economic analysis.

of the former into the latter. Thus a certain social organization under similar conditions would render approximately the same amount of selected forms of energy in return for a given sum of money. This, however, is not free from analytical difficulties. Assuming we could establish viable conversion factors (of low entropy into economic value), we would still be faced with a difficult problem. That would be to explain why these coefficients (conversion factors) differ from corresponding price ratios.[23]

Relative Competitive Positions of Alternate Energy Sources

The proper pricing of energy is especially critical when we consider the development and utilization of alternate energy sources. The analysis in Chapter II examined the dynamics of fuel scarcity, supply and substitution, assuming that prices reflected all relevant variables and touched only briefly on the problem of capital shortages. Thus a conceptually "neat" analysis was possible. Each following chapter has added qualifications and extra refinements which complicate the "simple" dynamics of substituting cheaper (less scarce) resources for more expensive (scarce) ones.

The chief problem with energy sources based on fossil fuels is the operation of the law of diminishing returns and its economic implications. As discussed earlier, the price of oil must rise disproportionately more than the increase in production that it is supposed to finance. For each additional dollar spent to meet the oil industry's

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[23]Roegen, The Entropy Law and the Economic Process, pp. 276-83. provides a fascinating look at these possibilities and associated problems.

demand for higher prices, the nation would receive progressively less return in the amount of oil produced.

In the oil industry the average productivity of invested capital (in 1974) was approximately three barrels per dollar. It is estimated that to produce about 80 billion barrels of oil between 1975 and 1988, about 100 billion dollars of capital would be needed representing an average capital productivity of about 0.8 barrels per dollar.[24]

Coal appears to be well suited thermodynamically for the tasks it performs in the American economy (i.e., to generate electricity, provide heat for industrial processes and industrial steam). All of these tasks require relatively high temperatures and therefore a high quality energy source.

Second law efficiencies for these tasks computed on a national average are about 25-30 percent--much higher than the efficiencies for the main uses of petroleum (transportation, space heat and hot water heating).[25] Thus in sharp contrast with petroleum, the use of coal in the United States is fairly well matched thermodynamically to appropriate energy-requiring tasks.

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[24] For details regarding the capital required for petroleum production, see "How Much Oil--How Much Investment," Energy Economics Division, Chase-Manhattan Bank, March 1975, and Commoner, pp. 55-65.

[25] "Efficient Use of Energy," APS Studies on the Technical Aspects of the More Efficient Use of Energy, edited by K. W. Ford et al. (New York: American Institute of Physics, 1975), pp. 4-35. This study appears to be the first effort to delineate in a comprehensive way what thermodynamics tells us about how to compute the efficiency with which energy is used and to apply the procedures to a wide range of typical energy processes.

The economic implications also contrast with those of oil. Because of the relative abundance of coal relative to oil, further extension of coal production likely can be carried out without any significant reduction in the marginal productivity of invested capital (at least in the immediate future). All that is necessary is to extend operations into new areas that have about the same capital requirements as the older ones.

The competitive position of nuclear power is less clear. As noted earlier, the cost of electricity now depends much more on capital costs than on fuel costs. Commoner asserts that the need for the breeder reactor (a far more complex device than conventional reactors) has been removed by a kind of technological irony: Compared with a conventional reactor the breeder would reduce fuel costs but greatly increase capital costs. Thus the reduced cost of fuel which the breeder was supposed to achieve is much less economically significant.[26]

The main justification for constructing nuclear power plants was that they could produce electricity more cheaply than coal. The key question is whether the competitive economic position of nuclear power can be maintained in the future.

A statistical analysis of the costs of 87 nuclear power plants ordered between 1965 and 1970 indicates that capital costs have been increasing at the rate of $13 per year per kilowatt of electric capacity (in real uninflated 1973 dollars).[27]

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[26] Commoner, p. 112.

[27] See reports by Scott and Bupp (cited above) for details of the procedures used. In brief, these analyses represent extrapolations of future expectations from past data.

If the capital costs per kilowatt of power-plant capacity continue to rise at the rates of increase that they have exhibited since 1965, and coal continues to cost about $26 per ton and uranium about $25 per pound (in real uninflated dollars), then Commoner projects that the "break even" point will be reached between 1979 and 1980. Thereafter the cost of uranium-based power will exceed that of coal-based power.

If in order to eliminate the air pollution disadvantages of coal-fired plants we add $100 per kilowatt to the capital costs to pay for sulphur-control devices, then the break even point is delayed until 1983. Thereafter the economic advantage lies progressively with coal. In these computations, it was assumed that the uninflated costs of these fuels would remain constant--that is, their prices would rise along with the general course of inflation.[28]

Synthetic fuels derived from coal also require a careful analysis. The capital advantages of coal (discussed earlier) quickly disappear if synthetic fuel production is included. Recall that the main advantage of coal production over oil and natural gas production in future energy programs would be the fact that, unlike the production of petroleum, coal production can be expanded without a significant reduction in capital productivity.

However, this advantage quickly disappears if coal is to be converted into liquid or gaseous fuel. This conversion process would have technical complexity comparable to an oil refinery. Consequently, the capital costs are very high compared to the costs of producing coal itself.

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[28]Scott and Bupp Reports and Commoner, pp. 114-15.

Thus if coal were liquified, for example, studies indicate that marginal capital productivity would be reduced by 87 percent. Coal gasification likewise involves a 92 percent reduction in marginal capital productivity as compared to direct production of strip-mined coal.[29] If we intend to replace oil and natural gas we would thus face the same problem--escalating capital costs--that makes the expansion of crude oil production so difficult. Estimated costs of synthetic fuels reflect this problem. They indicate that prices of these coal-based synthetic fuels may be as high as $26 per barrel (obviously <u>well above</u> the current price of natural crude oil.)[30]

As discussed in earlier chapters, there are significant risks involved in investing in intrinsically higher priced synthetic fuels. Because such a large share of OPEC's price is composed of royalty shares (economic rent) and not production costs, it would be very easy for them to "undercut" domestic infant synthetic fuel industries by lowering prices. What options do we have? After all, the logical way to induce a price elastic demand for OPEC oil (one of our big policy goals) is to introduce lower cost substitutes.

One option that has been suggested is a 100 billion dollar corporation to provide government guarantees against the resks of investing in synthetic fuel production. Commoner's criticism of the preceding sums up well the choices we may have to face. He states

> This new scheme has a special kind of irony. It proposes to use public funds to guarantee an enterprise that would burden the people of the U.S. with higher fuel prices if it succeeds or with higher taxes if it fails.[31]

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[29]Commoner, p. 78.

[30]Business Week, August 11, 1975, p. 19.

[31]Commoner, p. 81.

This statement may be somewhat simplistic by itself but it illustrates well the dilemna we face.

Solar power is the darling of the "eco-freaks" but it does indeed have many advantages over conventional energy sources. Because it is diffuse, solar energy has certain major thermodynamic advantages. It is intrinsically of very high quality; the thermodynamic quality of radiant energy is determined by the temperature of the source that emits it (the surface of the sun has a temperature of 10,000°F). The low temperature of direct sunlight at the earth's surface (100-120°F) does not mean that the quality of energy has been degraded enroute. Rather it signifies that the energy has spread out enormously.

Thus all we have to do to increase the temperature of solar energy to any desired level (up to the 10,000°F temperature of the solar source) is <u>concentrate</u> it. Solar energy can thereby be precisely matched, thermodynamically, to any given task without pollution or nuclear radiation. This is in marked contrast to conventional fuels which almost always generate energy at temperatures well above those needed for most energy-requiring tasks. Consequently the thermodynamic quality of the energy is wastefully downgraded in the process.

Solar energy is not a panacea. It cannot by itself solve our immediate energy problems. But the economic realities of solar energy are precisely the reverse of conventional energy sources. The chief reason for the increasingly intense demand for capital for the production of conventional sources of energy is that they are heavily affected by the law of diminishing returns. In every conventional energy source, the marginal productivity of capital--the energy produced by each additional dollar of capital--has fallen sharply with increased production.

Every barrel of oil that is produced makes the production of the next barrel more difficult and more costly in terms of invested capital. Every new environmental and safety problem that is uncovered in a nuclear power plant makes the next one more complex and more demanding of capital.

Because the production of each additional unit of solar energy in no way makes it more difficult or costly to procure the next unit (i.e., the marginal cost of each additional unit is zero), solar energy "production" can be continuously expanded (theoretically) with no decrease in marginal capital productivity.

Since a large solar installation is not basically different from a smaller one, there are no significant economic advantages to be gained by size as there are in (for example) nuclear power plants. Thus "economies of scale" are not required for solar energy to be efficient and much of the problem of excessive market power is eliminated. Theoretically, no giant monopoly could control the supply or dictate the use of solar energy for it is ideally suited to local or regional development.

However, we must consider the following. Large energy companies with considerable pecuniary (input price) advantages may be able to provide the relatively simple technology for solar power cheaper than smaller firms--hence the effects of market power may better be described as minimized rather than eliminated (the theoretical ideal). For example, the most difficult task in developing high efficiency solar heat concentrators is keeping the price of manufacturing the mirrors low enough so that the price of the system is within reach of competitive power plants.

When the above analysis assumes that the marginal cost of another unit of solar power is zero it ignores possible economies and diseconomies. These economies and diseconomies of scale are due not to efficiency or operation of the law of diminishing returns but are a function of market power in the factor market--the market for inputs. This distinction should be clearly recognized.

As stated repeatedly, it would seem that the best short run, transitional role of solar power is in multifuel "mixed" solar/conventional installations. Solar can thus be viewed as a supplement--not a replacement--energy source in the near future. Since prices of solar collectors should fall significantly as production is expanded while conventional energy prices are increasing rapidly, these mixed installations should provide the logical means of transition with the minimum social disruption. Thus we can "buy time" while the full development of solar energy gets underway.

The "optimal" interfuel mix will vary as technology and prices change and in the case of solar power, may vary with the regional location of the mixed solar/conventional units. The methods of producing hot water which best satisfy the private concern and the social one are not currently the same. For example, a system that is 46% solar and 54% electric will be best for a householder's pocketbook, but a 100% solar system will save the most fuel. An 85% solar system would maximize the social value of saving fuel at no cost to the householder.[32]

As always a careful definition of "cost" is necessary. The difference between solar heat and electric heat is not as large as it

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[32]*Ibid.*, p. 149.

might appear because the cost of the solar collector should be compared not only to the cost of the electric heater, but to the capital cost of producing the electricity as well.

The individual homeowner's calculus, however, may not take this into account; his concern would be the direct cost to him in the relatively short run. The more subtle indirect effects of the declining marginal productivity of capital in the utilities may not be felt because rates are regulated and the Public Service Commission may keep rates lower than scarcity, ecological and thermodynamic constraints would dictate.

Conclusions and Institutional Considerations

This chapter has attempted to provide a unified analysis of the relationship between thermodynamics, economic theory and energy policy. The link between thermodynamics (especially entropy) and economic value is so strong that it cannot continue to be ignored in energy policies and pricing.

There are, however, a number of serious obstacles to operationalizing these linkages in the real world. Contemporary institutional structures reflect the short-range era of cheap energy within which they evolved. <u>The political will to implement is inextricably related to the question of who bears the cost of adjustment</u>.

The economic and physical facts of depletion urgently require that we begin now to plan for the <u>orderly</u> transition of fuels. Without adequate planning, there will be serious socio-economic dislocations in the transition from the current "unplanned" market system to one that considers thermodynamic and ecological constraints.

What is the best path to take--administered pricing, Socialism, centralized government control of key institutional variables or participatory and indicative planning? The next chapter will examine our options.

At this point what can be said with certainty is that there is an urgent need to re-examine the operation of the whole system which governs the development and use of energy. This includes the operation of government as well since government decisions strongly influence the economic feasibility of alternate energy sources and use patterns.

CHAPTER VI

POLICY IMPLICATIONS, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This study has demonstrated that interfuel competition is a complex issue requiring a wide variety of analytical approaches. What initially appear as relatively simple price-substitution questions are complicated by a myriad of problems--social, economic, ecological and thermodynamic.

This paper has attempted to provide a unified analytical view of interfuel competition. The "economics of interfuel competition" had to be constructed for this analysis as there was no (single) currently available procedure for conceptualizing the problem.

Previous economic studies have confronted the problem indirectly via uncoordinated analyses of scarcity, renewability, market structure and elasticity of supply and substitution (ignoring until very recently pertinent ecological and thermodynamic constraints). In this study, each following chapter has added qualifications and extra refinements which complicate the "simple" dynamics of substituting cheaper (less scarce) resources for more expensive (scarce) ones.

The key word is choice. Will changes in our mechanisms of choice keep pace with the development of the scope of choice? While economics does not provide complete answers to all of our problems, it does

provide--as a science of choice--powerful conceptual tools to make the problem more comprehensible.

As stated in the first chapter, the key question for public policy is how to take advantage of the beneficial aspects of the price system while remaining cognizant of shortcomings (assuming of course we desire some form of a price system). But we must inquire about the nature of this adjustment process. The market system is a feedback system; correction signals (prices) are generated after the fact. We must question strongly the accuracy and speed of response to these signals.

The purpose of this chapter will be to review the policy implications of the preceding technical analyses. Initially some general implications will be discussed. Then we shall examine the long-run versus short-run choices that are available.

The discussion will then narrow to focus on three especially important policy choices:

(1) Who should develop new energy sources?

(2) What should we do about imported energy? That is, how realistic are proposals for inducing a price elastic demand for OPEC oil given the constraints cited in this study?

(3) What policy options are available to remedy the problem?

Finally, overall concluding remarks will be provided.

General Policy Implications

To reiterate, this chapter will emphasize the limitations and potentialities of economics in dealing with energy issues. This section will highlight some general implications; succeeding sections will elaborate further. One question we must ask is how does the actual order of fuel use correlate with economic principles and thermodynamic and ecological realities. Have fuel utilization practices followed "rational" economic and thermodynamic concepts?

The practical manifestation of the above is reflected in the question: Will we be able to develop alternate technologies fast enough to compensate for the decline in quantity of fossil fuels? The problem of technological lag plus the consequences of stringent pollution standards have greatly complicated the problem.

The issue of technological assessment is critical. Energy choices we face today require not only marginal adjustments in existing technologies--they require a rational choice between different competing technologies. The crucial question that must be analyzed further is "How does technical change affect the productivity of capital relative to the productivity of energy resource inputs?" The results of this study indicate that capital is a major problem that must soon be confronted directly, by analyzing the relationship between the character of productive technology and capital productivity.

Capital costs are rising so quickly that energy companies' demand for "external" capital will significantly reduce the availability of capital for the rest of the economy. By failing to recognize the relationship between the capital crisis and the change in character of productive technology (the sharp decrease in the marginal productivity of capital that has accompanied the transformation of productive technology) conventional analyses tend to foreclose the option of curing the problem at this very basic level.

The heart of the problem involves the nature of the "transformation of productive technology." The current expression of this transformation has taken the form of increasingly capital intensive technologies. However, as previously indicated (p. 39), marginal diminishing returns to capital will eventually accrue if the elasticity of substitution between capital and energy is less than one (that is, the marginal productivity of capital will decline because substitution will be relatively difficult because more capital will be needed to produce a given level of energy output from a given level of energy resource input).

As long as the transformation of productive processes takes the form of increasingly capital-intensive technologies, inputs of capital and energy will increase simultaneously. This greatly intensified use of capital and energy has led to both marginal decreases in capital productivity (incremental output per additional dollar of capital) and energy productivity (incremental output per additional unit of energy resource input). Centralized technologies produce high marginal labor productivities but, because of the specialization of labor, isolate the individual from the thermodynamic consequences of his or her actions.

This leads one logically to ask whether we can use thermodynamics to ask the right questions regarding the operation of our economic system. More specifically, "What economic considerations have so uniformly imposed upon the instruments of production features that drastically curtail their thermodynamic efficiency?"[1] Thermodynamic analyses of energy must be incorporated into existing models and pricing practices

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[1]Some assert for example that "nationalism" and regulatory policies favoring capital-intensive technologies have combined to cause premature development of nuclear power. Without these policies (it is suggested), the timing of nuclear power--if based on its economic workability relative to fossil fuels--might have been quite different.

if energy problems are to be realistically confronted. Otherwise, policies aimed at simply substituting somewhat scarce fossil fuels for very scarce ones will not appear as they really are--myopic and inadequate. In short, does the current economic system reflect both first and second law realities?

The distressing manifestation of the preceding set of inquiries is that increases in entropy will eventually lead to technical costs of production that cannot be countered by increased scale of operations and technological innovation. Another manifestation is that increasing entropy leads not only to increasing recovery costs but also, as a consequence, increasingly larger firm sizes. To escape this "entropy trap" the role of economics in the future should be to devise pricing practices that more effectively match energy sources to tasks.

Long Run and Short Run Choices

The preceding general implications lead us to some difficult policy choices for both the immediate and distant future. From an economic perspective, perhaps the most important question is "What changes more rapidly--relative prices of fuels or relative quantities of fuels?" Or we might well ask: What alternate sources are economically feasible under varying conditions?

The key point is that full exploitation of the social benefits from new energy technologies and substitution possibilities requires that the process be as smooth as possible to avoid potentially catastrophic transitional inequities. This involves two factors. First, how certain must we be of the existence of viable substitutes (in the long-run) to judge it safe to consume irreplaceable materials in the short-run?

Secondly, depletion and declining resource quality alters the character of the optimal structure of capital (technology). For example, the residuals problem could become so serious as to set an effective limit to the adoption of new energy technologies. Whether marginal diminishing returns due to declining resource quality (increasing entropy to be more specific) can be overriden by increasing returns to scale in the social production function remains to be seen, but the previous analyses indicate that we are quickly approaching a point where this will no longer be possible.

This study has suggested that it is desirable to shift from labor-saving (capital-intensive) substitutions to resource saving substitutions. As fuel rises in price it pays to introduce more capital-intensive methods in order to achieve higher initial and lower terminal temperatures. Recall that the elasticity of substitution between capital and energy--"capital substitution"--refers to resource-saving uses of capital.

There are, however, serious problems with capital-intensive methods. As discussed many times before the declining marginal productivity of capital implies that the effectiveness of increasingly capital-intensive technologies is in doubt. The implications are both long and short term in nature.

The supply and productivity of capital are crucial elements not only in maintaining current energy production levels, but also in the design and installation of alternate energy production technologies. They strongly affect the lead times for these alternate technologies. Additionally, the more subtle indirect effects of the declining marginal productivity of capital may not be felt immediately because rates are regulated by public service commissions (rates lower than long-run scarcity, ecological and thermodynamic constraints would dictate).

For the long-run we must consider the thermodynamic efficiencies of alternate economic systems in carrying out transformations of heat into mechanical energy. The high losses (50 percent or more) associated with the conversion of heat energy to work energy is indicative of a basic physical law that cannot be overcome by technological innovation.

This has striking economic implications (especially regarding capital requirements) for expanding energy production. As Chapter V indicated (p. 106), second law efficiency ratings of various energy sources do not correlate well with actual use patterns or relative price levels. There is a limit on the influence of relative prices on energy use patterns, i.e., fuels do not compete solely on a cost basis.

Other aspects of capital-intensive technologies are the societal implications of concentrated economic power. We must ask: Is this the only viable way to maximize technical achievement in developing alternate energy systems? But we cannot restrict our analysis to one of "minimum average cost today versus future supplies, technologies and market structures." As discussed in Chapter III, if the market were genuinely restored, technical competency (the key to new energy sources) would be lowered to the level of the market system typified by agricultural markets and the necessity of government-sponsored research and development.

It is difficult to separate long-run and short-run decisions because policies for the near future must start us moving in directions compatible with and contributing to the long-term solution. Crudely stated, we can either alter our technical dependence on natural resources or somehow continue to "augment" our stock of natural resources.

Gerard M. Brannon indicates that the present tax structure provides substantial incentive for using scarce resources and relatively small incentives for using energy from cheap resources. One need not accept the preceding as true to recognize that artificially low prices from price regulation or indirect subsidies through tax advantages (such as percentage depletion and deductibility of intangible drilling expenses) have discouraged development of alternate energy sources. Tax incentives for domestic energy development produce increased supplies and decreasing prices encourage more use by consumers. Opponents suggest that producer incentives through higher prices are more sensible because they increase supplies while (ostensibly) lowering consumption.[2]

Who Should Develop New Energy Sources?

The preceding sections on policy implications provide much needed background for specific analyses of crucial energy problems. The question of who should develop new energy sources--and what these new energy sources should be--cannot be answered unequivocably. But we can address some important policy issues that arose in the course of analyzing interfuel competition.

Primary factors are entry barriers--primarily in the form of scale economies. Chapter III indicated the strong influence market structure has on the emergence of new energy sources. Elusive questions must be answered: Do joint ventures promote competition by lowering entry barriers for smaller companies or do they foster collusive pricing and stifle competition?

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[2]Gerard M. Brannon, Energy Taxes and Subsidies (Cambridge, Mass.: Ballinger Publishing Company, 1974), p. 12.

Naturally the form of energy is a critical determinant of who should develop it and the optimum market configuration. Radically new energy technologies, requiring inputs and capital investments vastly different from those of existing energy production, should not be preempted by existing oil companies solely on the basis of pecuniary (input-price) advantages.

Vigorous efforts must be made to distinguish the pecuniary advantages of large scale operations from the truly technical advantages. The key question becomes: What will be the optimum size firm or optimum market structure to produce a particular type of energy technology? There are numerous factors to consider.

We must weigh the advantages of technical competency, access to capital and organizational skill of the large energy conglomerates against the danger of monopoly power (and its consequent ill effects) and the possibility that large economic entities would hesitate to develop new energy sources that would threaten the value of their existing oil reserves. Anti-trust efforts in the United States (attempting to deal with the above problem) have taken two forms: 1) Efforts to preserve competition and market integrity and 2) Recognition of the necessity of maintaining a functional entity--i.e., not breaking up economically efficient units.

The crucial question is who will develop alternatives if "Big Oil" doesn't? The potential capacity for innovation of large institutions coupled with incentives for achieving technical superiority (vigorous competitive forces) theoretically would suggest that large entities with rigorously enforced competition would be the optimal solution.

Yet for energy sources such as solar, financial barriers appear to be much lower--theoretically much wider participation should be possible. While economies of scale in "production" of solar energy may not be nearly as important as they are in capital-intensive technologies such as coal or nuclear powered electrical generation, there are diseconomies in the factor market for small firms. This will affect how well smaller firms can compete with larger firms with pecuniary (input-price) advantages.

Additionally, while solar power is not subject to diminishing returns due to depletion, there may be diseconomies of scale if extremely large tracts are used for solar power generation. Another consideration is that because of the unique property rights involved, private sector entrepreneurs could expect to capture the patents to technologies they develop but not the ownership rights to the resource whose value is suddenly increased.

We must recognize, however, that perfecting technology for an adequate supply of clean energy conflicts with the energy industries' incentive to live with the current technology and profitable continued scarcity. (Thus the argument: Why should oil companies develop solar or other forms of energy to compete with their own profitable petroleum reserves?) Regardless of personal views, one should be careful to analyze how synthetic fuel prices compare with those of crude oil derived products--that is, how do the production costs of synthetics compare with their selling price and the market price of crude oil.

Feasibility of Inducing a Price Elastic Demand for OPEC Oil

This section will address the problem of what we should do to counter our growing dependence on foreign sources of energy--especially OPEC oil. The focus on interfuel competition and substitution is keyed to the development of low cost substitutes for foreign energy sources. The question is one of whether these low cost substitutes (necessary for creating a price elastic demand) are feasible, given the political, economic and thermodynamic realities discussed in this paper?

Recall that the "ideal" situation would be to cause the ratio of future to present crude oil prices to be lower--the expectation of lower future oil price would be due to a rapid development of alternate low cost energy sources. Theoretically, OPEC's "low price" oil strategy (to keep us from developing substitute energy sources) will work only if (we) their customers will continue to buy more oil. Their monopoly power enhances the profitability of natural scarcity--i.e., scarcity may be imposed by OPEC.

Various proposals "covering" the sunk costs of synthetic fuels (to be discussed later) ignore not only the ease with which OPEC suppliers can undercut these synthetic fuel industries but also the thermodynamic constraints (and consequent economic implications) of synthetic fuel production discussed in Chapter V. Oil import quotas to protect infant domestic synthetic fuel industries are likewise undesirable for a number of reasons--most are concerned with retaliatory measures associated with such actions.

There are a number of serious questions that must be answered about the "synthetic fuel solution" to the import problem. First of all, no one knows with any accuracy what price incentives it may take to spur development of synthetic fuels or whether incentives are needed at all. Additionally, we should ask: Will there be a market for synthetic fuels?[3] Another consideration is how well will these processes "mesh" with existing energy systems. If the products of synthetic fuel production are not capable of being utilized in existing systems their economic value and chances for long-run success will be quite low.

There are five factors affecting synthetic fuel development: 1) supply and demand elasticity, 2) world oil prices, 3) cost of synthetic fuels, 4) the expansion capacity of the construction industry and 5) national security.[4] In addition the shape of the long-run average cost function for various synthetic fuels is of great significance from the viewpoint of public policy.

This function is critical in determining the optimal design and scale of our future energy industries. Specifically, scale economies via long-run average cost (LRAC) functions should represent "true production economies" and not merely pecuniary input advantages and should also include ecological and thermodynamic constraints.

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[3] M.I.T. Energy Laboratory Policy Study Group, Energy Self-Sufficiency: An Economic Evaluation (Washington, D.C.: American Institute for Public Policy Research, 1974) concludes for example that it might require a doubling of current oil prices to provide enough incentive to bring about large scale commercial development of synthetic fuels and that their development is not sufficiently promising of large supplies to justify high prices for all energy. This possibility plus the dangers of "premature" development discussed earlier (OPEC price cutting and non-recognition of thermodynamic/net-energy constraints) suggests extreme caution in the proper timing of synthetic fuel development.

[4] Ibid., pp. 3-6.

Policy Options

Public policy must be concerned with how efficiently the market will respond to price signals and with the extent and distribution of income changes brought about by new prices and supplies. The market economy in its present form pays more attention to short-term benefits than to long-term social and economic costs (despite the arguments of Anthony Scott to the contrary!).

The crucial question for energy policy is: What is the proper division of responsibility between government and industry? Institutional features are a major determinant of competition in energy production. Therefore we should analyze the effects of government intervention just as carefully as individual corporate strategies.

Should we provide tax or other incentives for development of domestic energy reserves? Gerard M. Brannon concludes that percentage depletion and deductibility of intangible drilling expenses have increased the output and lowered the price of petroleum products and natural gas but they have done so by maintaining artificially low prices that discourage development of new fuels from other resources.

The argument is that tax incentives meet the problem of short supplies of domestic oil and gas by increasing the supply. This in turn keeps the price lower than it would have been in lieu of the tax incentives. This is "poor policy" because it encourages consumers to use more oil and gas than they would if the price were higher.

Producer incentives earned in the market place through higher prices are deemed "more sensible" than tax incentives because they lower rather than increase consumption. The tax provisions serve to lower the price on the scarce resource and to increase the royalties of the landowner. Thus the development of substitute sources is retarded.

In sum, it is believed that our present tax structure provides a very substantial incentive for energy produced from oil and gas because these sources are scarce and have a high value in the ground. It provides a very small incentive for energy from cheap resources where the energy is obtained by applying manufacturing processes (which have their own set of net-energy/capital problems) or where energy is derived directly from the sun.[5] The possibilities that oil companies will be denied future access to oil supplies through nationalization or embargo must accelerate the rate of depletion. Natural gas regulation, inasmuch as it has succeeded in its professed aim of holding down rates, also serves to accelerate depletion. Most grotesque of all, for decades quotas were imposed limiting the importation of oil, allegedly for the sake of national security. For the sake of national security, public policy promoted and guaranteed the more rapid exhaustion of domestic oil supplies!

Thus while in theory the state is the guardian of future generations (conserving critical resources for their sake), in fact it appears everything the political authority has done has accelerated depletion. Public policy and private decisions alike have been based on the assumption of the "bottomless well." In sum, there is certainly now no rational policy for the deployment of depletable resources over time.

The question of the proper division of authority between government and industry is thus not easily answered. Such diverse scholars as John Kenneth Galbraith and Barry Commoner advocate socialism as a remedy. Assuming, however, that we desire to retain the market system

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[5]Brannon, pp. 12-22.

as a viable mechanism for energy allocation, we need to make pricing more realistic. Whether this is accomplished by taxes, subsidies, administered pricing, participatory or indicative planning is not as important now as gaining acceptance of the notion that the definition of "cost" must somehow be expanded to include other factors besides technical costs of procurement, production and distribution.

In addition to determining the proper division of authority between government and business, the second critical policy choice we must make is: How can we channel technology to best serve the needs of society? The task of the political authority should be to develop or insure the development of suitable, technologically workable economic alternatives to any threatened element of the economic process.

Given this objective, a rational policy for resource depletion would be either to speed up the development of alternative technologies or slow down the rate of depletion until the new technology can be phased in as the old is phased out. The danger is not one of monopoly or bureaucracy. Rather it stems from the great organizations of the corporate sector and the public regulatory agencies that oversee the operation of selected industries.

These great entities, without effective external surveillance, control or constraint and driven by technological imperatives, may hurtle down pre-determined tracks, dragging society into an unwanted future. What can be done? The capacity of the political system to comprehend, control and give direction to the forces of technological transformation is virtually nil. Yet economic forces by themselves seem to be essentially "rudderless" from a social point of view--like so many ships following courses set by their own technological imperatives.

Somehow a blend of the political system and the market system must be contrived to give a coherent thrust to the solution of energy problems. As indicated in Chapter V, the political will to implement is inextricably related to the question of who bears the cost of adjustment.

There are a number of options we might briefly consider. Socialism and centralized government control will not be discussed since it is assumed that some variant form of market solution is desired. Administered pricing (as advocated by Koenig and Edens in Chapter V, pp. 80-81) and participatory and indicative planning (p. 83) have been discussed in earlier chapters. Both offer the flexibility of market adjustments with added features that incorporate much needed factors such as opportunities for comparing mutual expectations for coordinated investment planning and consideration of long-range ecological and thermodynamic constraints necessary for more realistic pricing practices.

Another option not previously discussed in this study is suggested by S. David Freeman in his book Energy--The New Era. He asserts that the U.S. government should become fuel supplier of last resort to the extent that private companies fall short of delivering fuels or building refining capacity; that is, the U.S. government should develop the capacity to "take up the slack."

The government would not compete with private companies but would only fill the gap where they failed. Freeman believes that such a federal corporation would play a vital role in alleviating the cyclical fear of shortages and their consequent adverse economic consequences.

The "U.S. Fuel Supply Corporation" would be empowered to develop detailed projections of energy demand or to obtain the detailed commitments of the industry concerning its programs for new production and construction. The corporation would then be empowered to take whatever actions were required to assure that the nation's energy supply was adequate with minimum damage to the environment. It could buy energy from abroad, contract for development of fuels on federal lands, build refineries, develop synthetic plants or do whatever else seemed necessary to meet the nation's energy needs.[6]

Conclusions and Recommendations

As this chapter has indicated, we face a bewildering array of policy options. This study will not attempt to provide a definitive statement of the precise policies we should follow to resolve all of the problems analyzed in this study. However, some general observations, conclusions and recommendations for further study are appropriate.

First, energy problems, perhaps more than any topic of inquiry, demonstrate the necessity for multi-disciplinary study. The essential conceptual tools of one discipline may be used to enhance or modify the elements of another discipline to more effectively deal with a problem whose solution is amenable to no one disciplinary approach.

Perhaps most important, however, is the realization that analytical studies such as this seldom lead (by themselves) to actual enactment of needed policies. There are countless cases of learned men with "rational and logical" studies who have been "proven" correct only _after_ the disaster they hoped to avert had already occurred. Remember (again!) the important fact that the political will to implement is inextricably related to _who_ bears the cost of adjustment.

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[6] Freeman, p. 321.

The years of indecision since the Arab oil embargo of 1973 provide evidence that urgency coupled with intensified research will still produce no forceful action unless people want to accept the harsh realities described in this study. In a large economy where individuals are so isolated from the economic and thermodynamic consequences of their actions, it could hardly be otherwise.

Unfortunately, the longer we delay, the less overall freedom we shall all possess. Every BTU of non-renewable energy consumed forecloses (albeit minutely) the options we have for the future. A desirable option would be the implementation of some form of "amended" market adjustment process to deal with the harsh economic and thermodynamic realities before it is literally too late for a dynamic process to function--i.e., when we become so desperate that government must make our decisions, order our lives, allocate our resources and determine the overall quality of our existence.

We should not become melodramatic, metaphysical or non-analytical at this point. This study has been, for the most part, "hard core analytical" in the sense that it skirted the difficult social questions of implementation in order to provide a clear and "neat" conceptual view of the problem of interfuel competition.

The need for "amended market adjustments" indicates that "markets" in their current form are incapable of making proper long-term allocative decisions in the energy area. On the other hand, overall government control of the allocative process would be detrimental. The communist-bloc economies of Eastern Europe and the Soviet Union appear to be very good at producing a few specialized items--i.e., weaponry or space-related technologies--but based on conversations with economists from these areas, it would seem that overall allocative efficiency is very poor.

What steps should be taken? A system of national economic planning--based on the European model of participatory planning--should at least be investigated and tried in selected sectors (such as energy). The administered pricing scheme of Koenig and Edens is also intriguing but the problems of implementation give one considerable concern. The "U.S. Fuel Supply Corporation" proposed by Freeman is another "amended" market process that warrants further investigation. None of the preceding offers the answer to the whole problem, however. As stated at the beginning of this section, this study will not supply the correct answers. Some recommendations for further research may be useful at this point.

One area of vital importance would be more detailed integrative work involving traditional economic theory (especially pricing policies and the redefinition of the term "cost" along more thermodynamically rational lines), thermodynamics and the economics of public choice (the study of the interrelationship between law and economics--i.e., the analysis of collective choice). The latter field is where much of the implementation-oriented work must be done. Another area that requires much more study is the empirical dimension of the relationship between the elasticity of substitution (capital/energy), the direction of technical progress and the declining marginal productivity of capital in capital-intensive productive processes. However, none of these areas of inquiry are by themselves adequate.

It is evident that many authorities in a wide range of disciplines are becoming aware of the subtle interrelationships described in this study. The problem for the future is how do we get people and politicians to accept these harsh realities before it is too late. Energy problems are much like cancer--they are insidious and increase in severity with each moment of delayed action. Unlike a cancer victim, society as a whole is not directly affected--those who bear the burden of adjustment (or their representatives) are the ones who will forestall implementation of the required integrative policies.

The transitional inequities must be dealt with separately from energy policy itself. There will always be those who are adversely affected--and they should be compensated--but this should be done separately and not as an integral part of any energy program.

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