FROM TECHNOCRACY TO NET ENERGY ANALYSIS: ENGINEERS, ECONOMISTS AND RECURRING ENERGY THEORIES OF VALUE

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I. Introduction

> "Pragmatically, a way to begin would be to set up a capability in government to budget according to flows of energy rather than money. Energy is the all-pervasive underlying currency of our society."[1]
>
> - U.S. Senator Mark Hatfield

In 1974 the Congress of the United States passed Public Law 93.577, the Federal Nonnuclear Energy Research and Development Act, in which it was stipulated that all prospective energy supply technologies considered for commercial application must be assessed and evaluated in terms of their "potential for production of net energy"[2] -- energy output minus the energy costs of producing that output. This is a rather interesting piece of legislation, for in effect it states that engineering-based net energy analysis should provide the criterion for evaluation of prospective commercial energy supply technologies, rather than conventional economic cost-benefit analysis, even when the latter is adjusted for externalities and market imperfections.

In response to the mandates of this legislation, net energy yields of geothermal,[3] gasohol,[4] and a variety of renewable and nonrenewable energy supply technologies have been undertaken and published.[5] Controversy amongst net energy analysts has arisen regarding whether net energy for nuclear power is positive or negative.[6] Net energy analysis has also enjoyed considerable publicity from the business press.[7]

One of the leading proponents of this legislation, Senator Mark Hatfield of Oregon, interpreted it as one step toward energy replacing money as a standard of value. Hatfield argued that "Energy is the currency around which we should be basing our economic forecasts, not money supply..."[8]. Hatfield's statement followed the much-publicized proposal in 1973 by the engineer Bruce M. Hannon, who called for the adoption of an energy standard of value:

> "The adoption of a national -- and consequently a personal -- energy budget appears to be necessary. The annual budget would represent a portion -- dictated by our value of the future -- of the proven energy reserves. Individual allocations could be similar to that of our present economies, which reflect personal values, except that we would have to strive for the right to consume energy; the accrued currency would be regulated by the amount of energy budgeted for a given period. If less energy existed at the end of the period, then currency would have to be reduced proportionately during the next period; of course, an increase of currency flow would follow an abundance of energy. Recognition of the value of energy is equivalent to setting energy as the basis or standard of value. In doing so, society readmits itself into the natural system in which acknowledgement of energy's importance has never been lost."[9]

This recent call for the adoption of an energy standard of value is not, however, the first time such a proposal has been aired in the U.S. About fifty years ago in the midst of the Great Depression, Harpers Magazine published an article "Technology Smashes the Price System" by the industrial engineer Howard Scott, who stated that:

> "It is the fact that all forms of energy, of whatever sort, may be measured in units of ergs, joules or calories that is of the utmost importance. The solution of the social problems of our time depends upon the recognition of this fact. A dollar may be worth -- in buying power -- so much today and more or less tomorrow, but a unit of work or heat is the same in 1900, 1929, 1933 or the year 2000."[10]

Scott and the fascinating Technocracy movement he founded proposed that dollars and money be replaced by energy certificates denominated in units such as ergs or joules, equivalent in total amount to the appropriate national net energy budget, which could then be divided equally among all members of the North American Continental Technate. The Technocrats argued that apolitical, rational engineers should be vested with authority to guide the nation's economic machine into a thermodynamically balanced load of production and consumption, thereby doing away with unemployment, debt and social injustice.

The proposal to replace money with an energy standard of value is therefore a recurring phenomenon, and at least recently has enjoyed some political success. Professional economists, however, have been notably cool to the notion of an energy theory of value and to the idea that dollars should be replaced by ergs. Most economists believe that the allocation of scarce resources such as energy is the very issue that economic analysis deals with best of all. Although some economists might view net energy analysis as engineering-based encroachment on the territorial domain of time-honored economic analysis, most economists tend not to take it seriously at all. After all, such energy analysis is essentially an energy theory of value, and why should one take seriously any movement which simply replaces Marx and the discredited labor theory of value with Carnot and thermodynamics? Energy is but one of many scarce inputs, and the beauty of the market price system is that it provides incentives for the combined wise use of all scarce inputs, not just energy.

But if the economic arguments against an energy theory of value are so compelling, why do such proposals appear again and again? While the answer to that question is not yet clear, in this paper I attempt to provide a better understanding of net energy analysis, Technocracy, and the reasoning underlying energy theories of value. I do this because I believe it well worth our while to understand paths rejected by economic analysis, and not just to comprehend those paths accepted and well-trodden. Moreover, it is useful to place current debates over net energy analysis within an historical perspective.

The plan of this paper is as follows. In Section II I provide an overview of net energy analysis and other recent variants on the energy theory of value. In Section III I present a brief history of the fascinating Technocracy movement, a review which by necessity will be considerably less than complete. In Section IV I compare, contrast and assess the Technocracy and net energy analysis movements. Finally, in Section V I comment on the reasoning underlying recurring energy theories of value.

II. Recent Variants on the Energy Theory of Value

"...energy cannot be treated as just another input."[1]

Although recent advocates of the energy theory of value are a heterogeneous group, almost all believe that energy is unique, all-pervasive and critical. Energy is the most important input, certainly more important than labor. Not only has human labor been replaced by energy-driven machines, but man himself can be viewed simply as a machine transforming the calories of food into work, albeit in an inefficient manner.

The pervasiveness of energy has recently been emphasized by Jeremy Rifkin:

> "Because everything is energy, and because energy is irrevocably moving along a one-way path from usable to non-usable forms, the Entropy Law provides the framework for all human activity."[2]

The pervasiveness of energy, along with its uniqueness, makes energy the ideal commodity for a standard and measure of value. Writing in a 1975 issue of Science, Martha Gilliland argued

> "Since energy is the one commodity present in all processes and since there is no substitute for it, using energy as the physical measure of environmental and social impacts, of material, capital, and manpower requirements, and of reserve quantities reduces the need to compare or add 'apples and oranges.'"[3]

Moreover, the energy unit is potentially much more stable than the dollar, for the energy involved in work is an unambiguous and unchanging measure of what has been accomplished. According to ecologists Howard T. and Elizabeth C. Odum, money as a measure of value is rejected because externalities are not properly incorporated by the market pricing mechanism:

> "Money is inadequate as a measure of value, since much of the valuable work upon which the biosphere depends is done by ecological systems, atmospheric systems, and geological systems that do not involve money."[4]

Modern adherents of energy theories of value tend to view all goods and commodities as embodied or sequestered energy. Embodiment of energy, however, occurs in two different senses. First, much like Marx's labor theory of value in which all commodities represent congealed labor, in the accounting sense commodities can be measured by the direct energy input into their production plus the indirect energy input embodied in capital, material and other inputs.[5]

The second sense in which energy tends to be viewed as embodied or sequestered in materials is as thermodynamic potential. From the basic principles of physics and chemistry, it is known that materials have thermodynamic potential which changes as the materials pass through various states in productive processes, encountering heat energy and/or work.[6]

In principle, the sequestered energy of commodities could be measured using process analysis techniques, a procedure by which material and energy balances are described in great detail during each step of a specific physical transformation process. Process analysis is a classic tool of the industrial process engineer, particularly in the chemical process industries such as petrochemicals, aluminum, metallurgy and iron and steel.[7] In the context of energy flows, three features of process analysis models are of particular interest:

(i) All the numbers necessary to develop a complete energy flow-balance of the process are available to the process engineer, or else can be estimated accurately from the principles of physics and chemistry. Indeed, maximum possible energy efficiency for the process can be calculated using the laws of thermodynamics.

(ii) The process engineer is myopic in the sense that he is not interested in what went on before his process inputs reached him, nor is he interested in what happens after his products and wastes leave his plant. The system boundaries of the process analysis model typically coincide with the particular industrial plant. Impacts on upstream or downstream energy flows that might be caused by changes made within the plant are not captured in the process analysis model.

(iii) The process analyst is typically not privy to how his energy balance compares to those of processes at other locations, which implies that he does not have complete knowledge of the whole industry. As a consequence, an accurate process analysis description for the industry as a whole is not in general attainable. In order for the detailed data and analyses of specific plant processes to be useful for broader industry-wide energy calculations, the specific process data of each plant would have to be made available to some central entity. David E. Gushee reports that as of March 1976,

> "...only one industry - iron and steel - has been able to develop such a central capability, at Arthur D. Little, Inc., in Cambridge, Mass. The data and mathematical model are held in tight secrecy to protect the proprietary individual company data, and not all the process units in the industry are represented, although the majority (130 out of 139 plants of members of American Iron and Steel Institute, representing 99% of total AISI production) are."[8]

In summary, while process analysis models could be useful in assessing detailed changes in embodied or sequestered energy on a plant-by-plant basis, the inherent problems of narrow system boundaries and competitive isolation render them less accurate for broader issues such as calculating changes in embodied energy on an industry-wide basis. Hence their potential usefulness for implementing embodied energy pricing is limited. Moreover, not all processes are amenable to easy modelling and detailed physical description. Although manufacturing processes are most easily modelled, manufacturing processes in 1974 accounted for only about 25% of the U.S. gross national product, and about one-third of the nation's energy consumption.[9] For non-manufacturing processes such as agriculture, great difficulties are encountered when attempting to measure energy degradation accurately:

> "Where the system is extremely complex, as in the growth of plants, or in human nutrition, we simply do not know enough to estimate the entropic contribution to free energy to better than one order of magnitude, even when we can measure the energy [heat] contribution fairly accurately."[10]

Undoubtedly, modelling and accurate measurement of energy degredation in sectors such as wholesale and retail trade, finance, insurance and real estate, services, government and government enterprises, would be even more difficult; in 1974, these sectors together accounted for approximately 60% of U.S. gross national product.

Since data requirements at the industry-wide level are immense and since the activities within a large number of industries are not easily amenable to detailed physical-chemical process analysis, it has been suggested that an alternative albeit less accurate procedure to model and account for energy flows would be to employ economic statistics found in input-output tables.[11] I/O tables do not measure energy transfers, although figures on the dollar costs of fuel and electricity inputs are published. Nor do I/O tables indicate the functional end-use of energy inputs, such as feedstocks, process heat, space heat, or electric lighting. Hence with I/O data it is virtually impossible to model accurately changes in the quality of energy, or the extent of its degredation; the necessary process and functional end-use information is simply not available.

However, the important advantage of the I/O energy accounting framework over the process analysis models is that with I/O tables the system boundary is much larger. Not only can I/O analysis describe, for example, direct energy consumption in the automobile manufacturing sector, but it also includes "first round" indirect energy consumption in the iron and steel industry, plus "second round" indirect energy consumption in the mining of ores, and so forth. Indeed, indirect energy equals the limit of an infinite sum of such indirect items. The total direct plus indirect energy requirements for production of a commodity corresponds to a notion of the embodied or sequestered energy of a commodity; analysts often call this its gross energy requirement.

It should be noted clearly at this point that calculations of gross energy requirements using such I/O techniques are quite different from the embodied energy notions of thermodynamics. Instead of measuring energy degradation (depletion of free or available energy), for practical reasons of data availability and at times the sheer lack of scientific knowledge, practitioners of I/O gross energy analysis measure only the heat (enthalpy) attributes of energy.[12]

Considerable empirical work has been published which estimates gross energy requirements of certain commodities, based on the I/O tables. Bruce Hannon's pioneering study of container recycling is noteworthy in that it also attempts to assess income redistribution effects of rising energy prices by examining direct plus indirect energy expenditures.[13] Additional examples of I/O studies include those of Robert Herendeen, Eric Hirst and Herendeen, and Clark W. Bullard III and Herendeen.[14]

An additional development in energy accounting emerged from the simple observation that it takes energy to get energy. Concern over whether new energy technologies would produce less energy than they consume (directly plus indirectly) has led to the practice of net energy analysis:

> "Net energy analysis of an energy supply system involves identification and computation or measurement of the energy flows in a society that are needed to deliver energy in a particular form to a given point of use. These flows are then compared to the energy converted or conserved by the particular system under consideration."[15]

Martha Gilliland has proposed that the net energy ratio -- energy output over direct plus indirect energy output -- should be used to define an upper bound for fossil fuel reserve measurements. As Senator Hatfield and many others have stressed, current reserve estimates tend to be "gross" rather than "net".[16]

Net energy analysis received wide public attention in the mid-1970's when a debate took place concerning whether the net energy ratio for nuclear power was greater or less than unity.[17] More recently, in response to the mandates of federal legislation in the U.S., net energy analysis has expanded to consider the net energy yields of other non-nuclear energy supply systems; see, for example, Gilliland for a study of geothermal, and Hannon for a comparison of a number of renewable and non-renewable resources.[18] Net energy analyses of gasohol have reached widely divergent conclusions due, apparently, to different assumptions regarding systems boundaries and computational techniques.[19]

For purposes of calculating embodied energy and implementing energy theories of value, it is clear that gross energy requirement calculations would be more useful than the net energy analyses of energy supply systems. Suppose, however, that a nation determined it would maximize its net energy -- the amount of energy remaining after the energy costs of finding, producing, upgrading and delivering the energy have been paid. As has been shown succinctly by David A. Huettner,[20] the traditional competitive price mechanism would yield such a maximum net energy situation if and only if all products were priced solely on the basis of their gross (embodied) energy, i.e. only if a complete energy theory of value were implemented.

This result highlights the important fact that notions of gross (embodied) energy requirements, net energy analysis and an energy theory of value are very closely related. Indeed, it can be argued that net energy analysis makes no contribution at all unless it is motivated by an energy theory of value. Despite this logical problem, it should be pointed out that not all net energy analysts seek to identify themselves with an energy theory of value. Clark W. Bullard III, for example, states:

> "While some practitioners of net energy analysis may subscribe to an energy theory of value, there is nothing about the quantitative methods proposed here that demand it."[21]

At the IFIAS Workshop on Energy Analysis and Economics, sensitivity regarding the association between net energy analysis and energy theory of value notions led workshop participants to conclude that

> "The principal goal of energy analysis is the development of a portion of the precise physical description of the operation of real-world processes. This description does not supplant that of economic analysis, but supports and complements it and may provide new perspectives."[22]

Specifically, participants in that workshop speculated that energy analysis might furnish signals of impending critical situations more quickly than the market, might require less time than economic analysis, would provide a more understandable specification of technological constraints than economic analysis, and would yield conclusions less sensitive to variations in prices. Participants also noted that the presence of externalities and market imperfections might render the market and economic analyses less useful and valuable for policy analysis. Some energy analysts compared net energy analyses of energy supply systems to environmental impact statements, since both introduce "considerations that are not easily translated into economic terms."[23]

Critics of energy analysis, particularly economists, have of course pointed to the critical logical relationship between net energy analysis and energy theories of value. Moreover, after noting that energy analysis offers no assistance with the difficult problems of intertemporally allocating resources in finite supply, and that energy analysis faces aggregation problems similar to those encountered in economic analysis, Michael Webb and David Pearce state,

> "Thus we must conclude that EA [energy analysis] as now formulated and practised does not have any use beyond that which is currently served by some other analytical technique."[24]

In summary, recent advocates of the energy theory of value have cited the unique, pervasive and critical features of energy, and have attempted to measure sequestered or embodied energy using the techniques of process analysis and net energy analysis. Hence embodied energy pricing would in principle be possible through use of such energy accounting procedures. However, it is a well-known analytical result in economic analysis that a competitive price mechanism will maximize net energy if and only if all products are priced solely on the basis of their relative gross embodied energy, i.e. if and only if a complete energy theory of value were implemented. This has created a serious problem for net energy analysis, for in effect it means that the notions of maximizing net energy and an energy theory of value are logically equivalent.[25]

III. Technocracy: A Brief Historical Background[1]

Having briefly reviewed recent literature on measuring gross and net energy in order to implement energy theories of value, I now discuss earlier experiences with energy theories of value. Many of the themes underlying recent net energy analysis and energy theories of value were enunciated already half a century earlier by the Technocrats. Moreover, as we shall see, the gross energy requirement calculations undertaken by modern net energy analysts represent to some extent the fulfillment of dreams in the minds of these earlier advocates of an energy theory of value. To understand better the Technocratic movement in the U.S. and Canada, it is useful to begin by reviewing the political, economic, and intellectual environment of the early 20th century.

Much of the optimism of progressive intellectuals in the first two decades of the twentieth century was grounded in the view that increasing industrialization and growth of the corporate form of organization could be directed rationally to bring about important social change in which injustice and class conflict would be abolished. Although progressives were a heterogeneous lot, one stream of progressive thought pointed clearly toward centralized, expert planning and administration. Disagreement arose as to whether government or the corporation was the appropriate institution for organizing the new society, but substantial consensus emerged that centralized planning would necessarily be guided by experts.

During this same period of time, a new generation of formally educated engineers began to appear, some of whome paralleled and interacted with the larger progressive movement. For example, Frederick W. Taylor and his scientific management disciples argued that the shift in factory and society from arbitrary power to apolitical, scientific administration would bring about the long-sought realization of social harmony.[2] The central figures in such revolutionary change would of course be the professional technicians -- industrial engineers who bypassed traditional authority and operated out of planning departments, free from business and political interference, and who organized human affairs in harmony with natural laws.

Mobilization during World War I provided further evidence to progressives and like-minded engineers in support of national planning, political nonpartisanship, the separation of administration from business pressures and politics, and reliance on experts. As William Akin has noted,

> "Mobilization directed by the wartime planning boards, staffed by nonpartisan experts, apparently balanced efficiency and the nation's well-being, planning and democracy. Was there any reason why such policies, if beneficial in war, should not be equally valuable during peacetime?"[3]

One important theme of the progressive-engineering movement was that engineers and technicians, not bankers and businessmen, were to be regarded as the sources of necessary expertise. Although initially unconnected with the progressive engineers, Thorstein Veblen effectively echoed these sentiments, particularly in The Engineers and the Price System.[4] Like the engineers, Veblen honored machine technology and mechanical rationality. To Veblen, engineers embodied ideal traits for the new social order: rationality, efficiency, scientific analysis and workmanlike qualities. Business, however, was much different than industry. While industry was concerned with the common good, maximum production, peace, workmanship, efficiency and matter-of-fact rationality, business was inextricable focussed on pecuniary gain, the maximization of profits, waste, idle capacity, and coercion. According to Veblen, although businessmen were incapable of understanding the logic of technological progress, the engineer-technicial fully understood and appreciated its rationality. Hence to Veblen, control of industry must be transferred from businessmen to engineers.

Veblen began to explore the practical possibilities of organizing engineers for the revolution when he arrived at the New School for Social Research in New York in the fall of 1919. The only engineer prominent in an informal discussion group centered at the New School was Howard Scott, a radical young man who sought, among many other plans, to form an organization of technicians, a "technical alliance", to conduct an industrial survey of North America. Veblen became convinced that such a data gathering project was the necessary first step toward engineers' gathering control. This, he hoped, would "bring the population to a reasonable understanding of what it is all about",[5] and would provide engineers with data concerning energy resources, materials, manpower and production -- information which would enable them to determine objectively the most efficient and rational means of running industry.

Although little was known about Howard Scott's early life, he claimed to have been educated in Europe and to have had considerable experience as an industrial engineer. Flamboyant, lean and six-foot-five inches tall, Scott lived in Greenwich Village and established himself "as a kind of bohemian engineer."[6] In 1920, as an outgrowth of his discussions with Veblen at the New School, Scott and some of his friends established a formal organization called the Technical Alliance, opened an office and published an eight page prospectus. The important research tasks of the Technical Alliance were to be accomplished by an extensive industrial survey of "three-thousand leading commodities" which would chart changes over the past century in industry employment, productivity per employee, horsepower capacity, and horsepower used in production. A unique feature of the survey would be its attempt to measure production and waste in terms of horsepower or kilowatt hours, rather than in the more conventional measures of labor expended or monetary costs.

The Technical Alliance lasted only about a year, breaking up in the spring of 1921 due to financial difficulties and internal dissension. Members went their own ways, and only Scott remained, "expounding his theories to anyone who would listen."[7] In the meantime and into the early 1930's, Scott ran a floorwax business and preached to all who would listen that the price system would collapse imminently, that it must be replaced with a distribution system based on energy accounting, and that only technicians could provide the necessary technical expertise to manage such a system.[8]

In 1931 or early 1932, a young geophysicist named M. King Hubbert came from Chicago to be an instructor at Columbia University. Hubbert met Scott in New York, was most impressed by his ideas and sought to give them a more firm scientific basis. According to Elsner, Hubbert "paid Scott's back rent, moved in with him, and set about reestablishing something like the old Technical Alliance -- an attempt that culminated in the Energy Survey of 1932."[9]

Apparently it is not clear yet precisely how Scott first met Walter Rautenstrauch, chairman of Columbia University's prestigious Department of Industrial Engineering. Rautenstrauch was an early advocate of the scientific management ideas developed by Frederick W. Taylor, identified himself with the progressives' sense of social concern, and believed deeply that engineers should not only be responsible to their employers, but also to all of society. Although he was trained as a mechanical engineer with special interests in machine design and became a distinguished academic, Rautenstrauch felt that the university curriculum should be devoted more to specific problems of industrial research and industrial engineering, issues which in his view were not adequately dealt with at Columbia's School of Mines, Engineering and Chemistry. In 1916, Rautenstrauch persuaded Nicholas Butler, then president of Columbia University, to establish a Department of Industrial Engineering, the first such university department in the United States.[10]

The depression convinced Rautenstrauch that the time had finally arrived when engineers must accept their social responsibilities and develop plans for solving the nation's crisis. To him, the malfunction of the socio-economic mechanism was an engineering problem whose solution required technical expertise. Like most other such engineering problems, the first step was to assemble data to facilitate evaluation and to determine the feasibility of proposed solutions. Rautenstrauch quickly realized that he required a far more exhaustive industrial survey than could be accomplished by his students.[11]

Initial contacts between Howard Scott and Walter Rautenstrauch proved to be mutually beneficial. In Scott, Rautenstrauch found an industrial engineer who shared a similar interest in an industrial survey, and who had in fact been at work on such a survey off and on for a decade. For Scott, contact with the distinguished Rautenstrauch provided renewed enthusiasm for the industrial survey. In summer of 1932, Rautenstrauch obtained permission to conduct a survey under the auspices of the Department of Industrial Engineering, called it the Energy Survey of North America, and appointed Scott as Director. A Committee on Technocracy -- a research organization to conduct an empirical analysis of production and employment measured in terms of energy expended -- was formed to supervise the project.[12] This committee included, among others, Rautenstrauch and M. King Hubbert. Funding was obtained on the dole from the Architects' Emergency Relief Committee of New York. Clearly, to Howard Scott, association with Columbia's prestigious Department of

Industrial Engineering provided a much more credible public forum than the coffee-houses of Greenwich Village.

Although Rautenstrauch publicly announced formation of the Committee on Technocracy using cautious academic language, Howard Scott was considerably less restrained. Within weeks, Scott recorded a sensational interview with the New York Times. Scott told reporters that industrial engineers, of whom he was one, had been working for more than a decade on an analysis of the industrial and social system in the United States, measuring activity using energy consumption rather than dollars, since the latter was a "rubber yardstick".[13] Results of research indicated, according to Scott, that because of the substitution of kilowatt hours and machines for manhours, technological developments had been so violent that the whole economic meachnism had been thrown out of gear; even if a 1929 scale of operations were resumed in 1933, only 55% of the workers thrown out of employment by the depression would be re-employed. The problem, according to Scott, was that production and consumption were no longer being balanced. Such a highly technical exercise could not be accomplished using elastic monetary units of measurement, but instead must be done using energy accounting and the technical principles of science.

Insisting that the industrial survey work of the past twelve years had been carried out quietly "without reference to the social, political or sentimental aspects of the problem," Scott defended his decision to make public the research findings in late 1932 because the researchers believed that violent collapse of the industrial system was inevitable and imminent unless engineering principles were applied:

> "The difference between this depression and those of the nineteenth century rests in the degree of speed at which the industrial system was traveling. The system of the past may be likened to a slow-moving oxcart which suffered a little damage in collision with a tree. The present highly mechanized system, however, by comparison resembles a high-speed racing car hurtling down a highway. When the car collides with an obstacle the resulting wreck is in proportion to the mass and velocity of the vehicle. In other words, the larger

> and more highly powered the industrial system, the more rigorously exacting must be its technical control in order to avert a wreck."[14]

According to Scott, while orators might appeal to people and sway public opinion, they were impotent when it came to handling the vast mass of energy unleashed by modern science. Finally, concerning future research by the Committee on Technocracy, Scott indicated that a start had been made toward charting 3,000 industries -- roughly 150 had been completed to date; about 100 men would be employed at Columbia during the 1932-33 winter to finish the project.

So provocative and sensational an interview, backed as it seemed by the authority of the scientific method and the prestige of Columbia University, naturally created a great stir. Instantaneously Scott became a celebrity, entertained by Wall Street barons and the nation's leading industrialists, sought after by the editors of _Time_ and _Fortune_ as well as by numerous other journalists. _Business Week_ carried his portrait. Hordes of the curious descended on Columbia.[15]

Shortly thereafter _The New Outlook_ published an article by Wayne Parrish, "What is Technocracy?" which elaborated on Scott's interviews. According to Parrish, "this civilization on the North American continent must be operated on a thermo-dynamically balanced load," and "all social problems of North America today are technological."[16] Parrish concluded his article by stating "Technology has written 'mene mene tekel upharsin' across the face of the price system."[17]

With such sensational interviews, prophesies of imminent disaster and provocative magazine articles, Technocracy rapidly captured the attention and interest of the nation. The January 23, 1933 issue of _Time_ devoted substantial space to the Technocrats, noting that in the previous week Technocracy had been cartooned (funniest: a technocratic hen laying an "erg"); had been scorned by engineers ("Cleverest pseudo-scientific hoax yet perpetrated" -- American Engineering Council); and economists ("Greenwich Village economics" -- University of Chicago); had made publishing houses scramble for interpretations; and had caused a store in Monrovia, California to place a sign in its window, "Pre-Technocracy Clearance Sale."[18] Cardinal Hayes of New York questioned the wisdom of Technocracy making public its preliminary research results, for "it has introduced a disturbing element in an already sorely distressed world."[19]

National leaders extensively discussed the theories of Scott and the Technocrats in articles and magazines. Liberal economist Paul H. Douglas summarized the Technocrat's energy theory of value as follows:

> "Commodities would be priced according to the amount of energy consumed in producing them. The sum total of prices would therefore be the number of millions of horsepower or kilowatt hours of energy which had been expended...The members of society would then be given energy cards, which would resemble suburban railway tickets, entitling them to purchase commodities with these energy quotations. As the purchase was made, the requisite number of energy units would be punched from or torn off the card. By the time the card was used up, the commodities would have passed into the hands of their final purchasers and the money units would also have disappeared from circulation. Here again, it is argued, consumption would balance production and depressions and unemployment would be avoided."[20]

Douglas' final appraisal of Technocracy was a cautious one:

> "The Technocrats...underemphasize the great practical and theoretical difficulties which would be attendant upon the use of 'energy prices' ...Particularly difficult would be the evaluation of services. How much energy, for example, would be involved in a surgical operation, the extraction of a tooth, the playing of a Beethoven concerto, the delivery of a lecture?...Technocracy is, therefore, as utopian as the theories of Owen and Fourier...it is necessary to combine the engineers with the labor movement before any real and fundamental change can be made."[21]

Similar but even more sympathetic criticisms were voiced by Stuart Chase, a widely read economist and earlier disciple of Veblen:

> "Whenever a critic desires to refute any body of doctrice in this republic, he says, first, that it is inspired from Moscow; second, that it is against human nature. Technocracy, it appears, is both and immediately is endeared to me. At the same time I should like to know where the service trades fit in, and how a painting is to be measured in ergs. I can readily comprehend an energy system

confining itself to physical things, like a water system confining itself to supplying the people of a given system with water. But as Technocracy's analysis stands, it accounts for only about half, or to be generous, two-thirds, of the present economic total...I cannot, therefore, take my energy economics straight."[22]

Dr. Karl T. Compton, president of the Massachusetts Institute of Technology, criticized Technocracy for neglecting human factors in industrial management and for having given a misleading picture of the replacement of men by machinery. Compton believed instead that "adequate sponges" could be found to "sop up" any technological unemployment due to increasing mechanization. The automobile and the radio were such new industries in the recent past, and "new ideas of home building and air conditioning" might be similar new industries in the near future.[23]

Leaders of alternative radical movements in the early 1930's were notably less enthusiastic in their reactions. For example, Paul Blanshard pointed out that:

"The amusing thing in the whole technocratic epidemic is that Socialists have been saying ninety-five percent of what the technocrats say for a decade, and saying it better, but the American public has gone on believing that socialism has something to do with free love, anarchy, and the dividing up of all the world's wealth equally among workers and loafers...Socialists must go on using the new stimulus to thought in technocracy and pointing out how socialism has a program and a movement for economic reconstruction, whereas technocracy has only a few significant footnotes."[24]

Norman Thomas, the 1932 Socialist Candidate for President of the United States, described the technocratic arguments as "inadequate, though very illuminating."[25] A Marxist reviewer pointed out that "What has popularized Technocracy is not the simple content, but the esoteric quality of science in which it is wrapped," then complained that "the indebtedness of the Technocrats to Marx is everywhere patent and nowhere acknowledged," and finally concluded "The Technocrats tinkle on a xylophone, while Marx played on a mighty organ."[26,27]

A particularly slashing attack on Technocracy was authored by Virgil Jordan, an economic and social writer who called the Technocrats "slide rule Mussolinis."

Jordan rationalized the sudden popularity of Technocracy as follows:

> "While there is no justification in any facts that technocracy has assembled or in any of its speculations for any forecast of the future course of events in this or any other country, we are obviously eager to believe them at their face value because our faith in ourselves has been shaken. We just want to believe in Santa Claus, even though he is only a technocratic Kris Kringle."[28]

He then added that

> "The technocratic trinity is the erg, the electron, and entropy. Energy is its jealous Jehovah. There is no God but the kilogram calorie and the engineer is his prophet. Its gospel is the second law of thermodynamics; the technocratic testament is written in statistical tables and charts and its catechism in differential equations. If Mr. Scott is not precisely the Technocratic Christ, at least he is the engineering John the Baptist who has been living in the economic wilderness for forty years feeding on logarithmic locusts and wild-honey."[29]

On a more serious vein, Jordan objected to technocratic suggestions that their industrial survey was based on an hitherto unanalyzed micro-economic data base, and noted instead that "they are based largely on familiar census data, with rough and ready estimates of such items as man-hours for which no accurate data are available at all, and there is nothing new in them to anyone who has any acquaintance with industrial statistics."[30]

The most scathing critique, however, was that by Archibald MacLeish:

> "The infantile cowardice of our time which demands an external pattern, a non-human authority, has manufactured a new nurse. And that nurse is the Law of Physics. One mechanistic nipple replaces another. The economic deteriminism of Marx gives way to the scientific imperative of Mr. Scott...All that is required of man in the Technocratic World is to submit to the laws of physics, measure all life by the common denominator of physical energy, discard all activities which are not susceptible of physical mensuration, and wait for the 'next most probable energy state' -- the millenium. It is a picture shrewdly painted to appeal to American babbittry with its childish longing to believe in Science and Scientific Truths and Scientific Thinkers. But it is about as attractive to a man of human appetites as a patent antiseptic gargle. And about as nourishing."[31]

To Howard Scott, the most damaging publicity was the revelation uncovered by the New York Herald Tribune investigative journalist Allen Raymond, who discovered that contrary to impressions held by Scott's research associates Walter Rautenstrauch, M. King Hubbert and others, "Doctor" Scott had never earned an advanced academic degree.[32]

Within weeks, a somewhat embarrassed Rautenstrauch announced that Scott had been ousted as Director of the Energy Survey of North America, that the engineering research group at Columbia University with which the technocratic group had been associated had been "formally taken over" by the Department of Industrial Engineering and would "hereafter be undertaken as a scholarly enterprise of the university which up to this time had merely been host to the technocracy group." Scott responded by stating that "My past does not matter as far as technocracy is concerned. The idea is bigger than any individual. The work will go on."[33]

The breakup of the committee appeared to many observers, especially the eastern press, to signal the end of technocracy; the "technocraze" was over, they believed. In fact, it was not over. Technocracy continued and indeed grew, albeit in a different form, particularly in the Midwest, the Far West and in western Canada. Specifically, by late 1932 and early 1933, Technocracy had become a widespread movement. Independent and uncoordinated technocratic organizations emerged spontaneously, articulating programs that differed in many respects, but uniform in their view that power must be unequivocally vested to the engineers.

Now excluded from Columbia in March 1933, Howard Scott and his associates formed a separate body incorporated as Technocracy, Inc. M. King Hubbert was named Director, Division of Education, and began writing a technocracy study course, intended to be the authoritative and definitive statement of technocracy doctrine and a text for guiding neophytes through technocratic theory.[34] Organizing activities of Technocracy, Inc. were directed by William Knight, an aeronautical engineer associated with an American subsidiary of a German aircraft company. The Technocracy, Inc. insignia, reproduced on page twenty-three, was called the monad and signified the Technocracy, Inc. concern with balance between production and distribution.

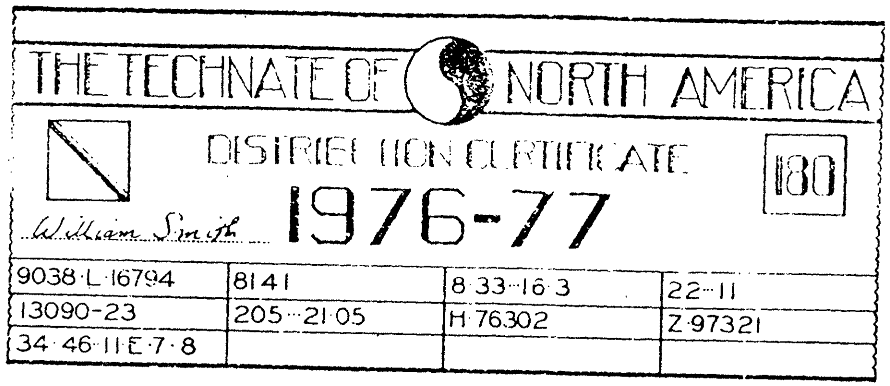
Under the direction of Knight, Technocracy, Inc. shifted toward a para-military organization. Howard Scott replaced his flamboyant, non-conformist Greenwich Village dress with Knight's new technocracy uniform: a tailored, double-breasted suit, gray shirt and blue tie, with a monad insignia on the lapel. Akin reports that one writer present at the time noted that "all the Technocrats were saluting him [Scott] in public."[35]

Scott, Hubbert and others continued to develop the Technocratic blueprints in greater detail, and Hubbert in particular maintained his empirical research activities on energy and mineral consumption, production, and employment. In 1937 Technocracy, Inc. released further details on its plan to replace money with energy certificates. Energy certificates would be issued, the total amount of which would "represent the total amount of net energy converted in the making of goods and provision of services." The aspect of energy to be measured was its ability to do work (availability), not its heat content.[36] Net energy was to be calculated as follows:

> "All operating, replacement, maintenance, and expansion costs (in energy) of the Continental complex, all costs of commercial services and provisions (such as local transportation, public health, and minimum housing space for each individual) are deducted before the net energy is arrived at...The conversion of human energy does not enter into this calculation since it amounts to below two percent of the total consumer energy."[37]

Distribution of energy certificates (an example of which is illistrated on page twenty-three) was socialistic -- an equal part of the total net energy would be allocated to every adult above twenty-five years of age, and special allowances were envisaged for younger individuals. Debt would no longer exist. According to Technocracy, Inc.

THE PROPOSED ENERGY CERTIFICATE

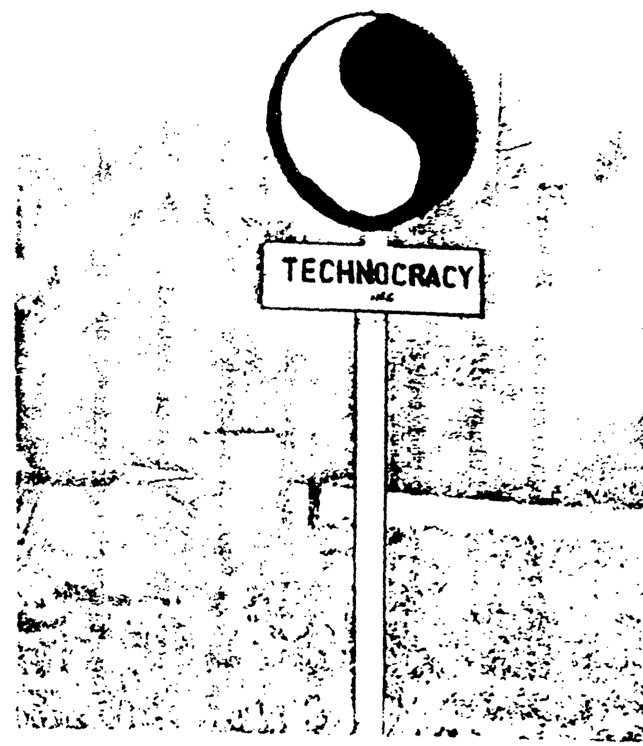


The Distribution Certificate

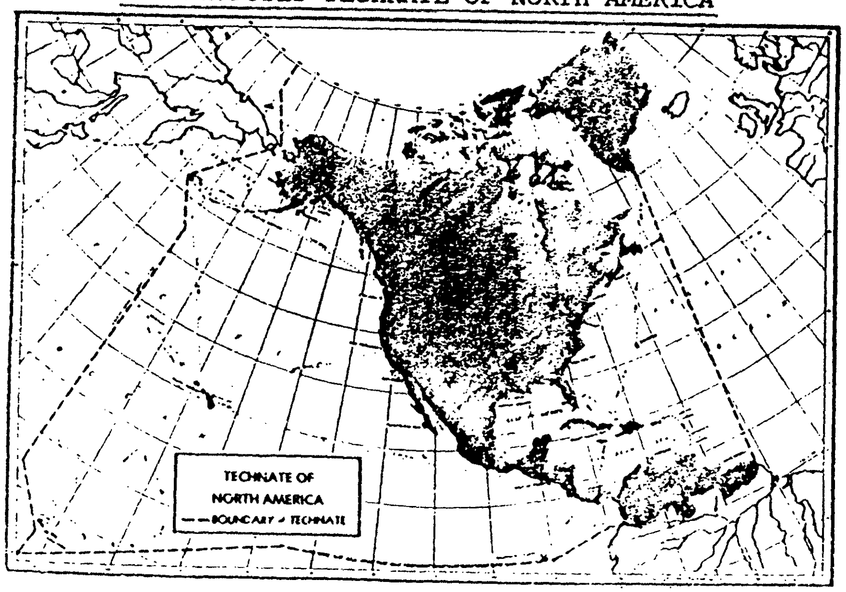
IT IS a Medium of Distribution
A Continental Accounting System
24 Hour Inventory
Identification and Record of Holder
Guarantee of Security

IT IS NOT a Medium of Exchange
Subject to Fluctuation of 'Value'
Subject to Theft or Loss
Subject to Hoarding or Gambling
A Means to Wealth or Prestige
A Means of Creating Debt

THE MONAD OF TECHNOCRACY, INC.



THE PROPOSED TECHNATE OF NORTH AMERICA



Taken from Technocracy, Inc., Technocracy: Technological Social Design; Savanah, Ohio, 1975.

> "The certificate will be issued directly to the individual. It is non-transferrable and non-negotiable, and therefore it cannot be stolen, lost, loaned, borrowed or given away. It is non-cumulative, therefore cannot be saved; and it does not bear interest. It need not be spend but loses its validity after a designated time period."[38]

When individuals purchased goods and services, certificates would be surrendered and perforated appropriately, thereby making record-keeping relatively straightforward.

Because the engineers of Technocracy sought to organize and direct economic activity within a geographical region nearly self-sufficient in resources and with a highly developed technology, the geographical boundaries of the Continental Technate were to include Canada, the United States, Mexico, and portions of South America to the north of the Amazon River basin (the geographical boundaries of the Technate are reproduced on page twenty-three). An additional reason for this choice of boundaries was that to the Technocrats, hydrology was very important; a system of rivers and inter-connecting canals was envisaged to provide abundant hydroelectric power, low energy-cost water transportation of bulk commodities, and raised water tables in drier portions of the Continent. Incidentally, Technocracy also proposed to limit population growth, prohibit immigration, and for reasons of efficiency permit only one language, a position that won considerable political support in Western Canada.[39]

In the late 1930's, the Technocratic movement was still active (both Technology, Inc. and the Continental Committee on Technocracy), and was marked by considerable local independence. Los Angeles, Denver, Washington state, and British Columbia had particularly active local organizations. Occasionally continental conventions were held. Interest in Technocracy, Inc. gradually waned, however, as the forecasted disasters failed to materialize, the New Deal gained popularity, and other radical third-party political movements allowed a restless people alternative direct and immediate political actions. The paramilitary and isolationist developments within Technocracy, Inc. resulted in statements by Howard Scott that leaders of Canada and the United States must be "notified in no uncertain terms" not to become involved in World War II, and that "Americans who conspire to make war off this Continent are guilty of Continental Treason."[40] Later Scott announced that "neither Canada nor the U.S. could discuss war without permission of this organization." In response to the perceived goal of Technocracy to "overthrow the government and constitution of this country by force," and because of Technocracy's opposition to conscription, on June 21, 1940, Canadian Prime Minister Mackenzie King announced in Parliament that an Order-in-Council had been issued which banned Technocracy, Inc. in that country.[41]

Scott's views mellowed little, if at all, in later years. To an audience at the University of British Columbia, Scott preached that one must choose either for or against Technocracy:

> "If you don't make your decision now, if you hesitate and waver, after the manner of the intellectual liberal, you will have your decision made for you at the muzzle end of rifles in the hands of thirty-six million unemployed that there will be in the next depression."[42]

Technocracy, Inc. continued as an organization throughout the 1940's, 1950's, and 1960's.[43] Howard Scott died in 1970, and was succeeded as Continental Director by John T. Spitler. Technocracy, Inc. is still active today, particularly in the West, where three magazines are published regularly: The Technocrat in Long Beach, California, The Northwest Technocrat in Seattle, Washington, and Technocracy Digest in Vancouver, British Columbia.[44] Its continental headquarters reside in Savannah Ohio. M. King Hubbert, well-known today as a petroleum geologist, retained an association with Technocracy until the late 1930's.[45] It is worth noting, incidentally, that Hubbert's much-publicized accurate prediction in 1956 that U.S. annual oil production would peak somewhere around 1970 was based on his analysis of bell-shaped curves, a research procedure he initiated while serving as Director, Division of Education, at Technocracy, Inc.[46] Although presently retired, Hubbert still maintains an active interest in issues addressed by the Technocrats in the 1930's.[47]

IV. Comparison and Assessment

There are obvious similarities between the fascinating Technocrats of the 1930's and recent adherents of energy value theories, even though the political and economic contexts differed dramatically. Some of the similarities and differences are worth examining in greater detail. I begin with similarities.

First, both Technocrats and energy analysts believe the authoritative laws of nature are not properly appreciated and respected in contemporary democratic and economic affairs, and that the possible consequences of continued lack of respect could be disastrous. This attitude tends to generate mistrust and occasionally contempt for democratic and market systems. In his 1931 Harpers Magazine article, Howard Scott argued:

> "What does price mean in a country where 0.44 of a simple pound of coal can do the work that the average man can do in eight hours? It matters not a rap what men think, wish, or desire. We are face to face with a law of nature...There are no physical factors in existence which would prevent the efficient operation of this continent on an energy basis. The only thing that does prevent it is our devotion to a shibboleth-price; and it remains to be seen whether we shall pay for our devotion with our lives."[1]

Similarly in 1977, net energy analyst Michael Common chimed that "...people's preferences cannot alter the laws of nature,"[2] and in 1978 science writer Malcolm Slesser added "The price system does have one disadvantage. It is possible to conduct one's entire affairs without regard to the physical world."[3]

Second, antipathy towards the price system extends to economists. Both Technocrats and net energy analysts have singled out economists as myopic apologists of the status quo who are unaware of the primacy of the laws of nature. According to Howard Scott,

> "It has been our great misfortune that in our disaster the only people that we have had to look to for guidance -- now that distrust of the banking fraternity has become so widespread -- have been the economists. These have ranged all the way from such stock market necromancers as Irving Fisher to the emotional popular economists who dream of a new state founded on a Russian model. Fundamentally the economists, Marxians, and all are as archaic as the bankers, for they are tied hand and foot to a conception of price."[4]

In the Technocracy Study Course M. King Hubbert called economists apologists for businessmen; in particular, he singled out the "professional apologists for our status quo" at the Brookings Institution.[5] More recently Howard T. and Elisabeth C. Odum charged that "...the economists have not been educated in energetics and therefore have not understood the second law of energy and the fact that energy is not reused."[6] Science writer Malcolm Slesser criticizes economists, since they "tend to take technological progress for granted as if they could buy their way around the laws of thermodynamics."[7] Hence, antipathy toward economists is common both to Technocrats and net energy analysts.

A third basic agreement among Technocrats and certain net energy analysts concerns the choice of prescription to replace the inadequate money price system: an energy standard. The Technocrats, it will be recalled, strongly advocated the notion that a central planning authority should issue energy certificates to individuals on an egalitarian basis. The reasoning underlying egalitarianism in Technocracy is derived from the energy depravity of man -- the energy degradation cost of maintaining a human being substantially exceeds his ability to repay. According to Hubbert,

> "...we can abandon the fiction that what one is to receive is in payment for what one has done, and recognize that what we are really doing is utilizing the bounty that nature has provided us. Under these circumstances we recognize that we all are getting something for nothing, and the simplest way of effecting distribution is on a basis of equality, especially so when it is considered that production can be set equal to the limit of our capacity to consume, commensurate with adequate conservation of our physical resources."[8]

Similarly, in 1975 net energy analyst Bruce Hannon suggested that the government should distribute energy coupons to individuals. Hannon's notion was not as explicitly egalitarian: although the federal government would own energy resources and would sell individuals energy coupons,[9] Hannon does not specify how purchasing power would be distributed.

Fourth, a principal agreement among the Technocrats and recent energy theory of value adherents is that energy and manhours have been substituted as inputs. For example, the Technocrats reported in 1933 that "Technology has now advanced to a point where it has substituted energy for man-hours on an equal basis,"[10] while in 1975 Bruce Hannon noted that "in general, most United States industries are trading labor for energy -- that is, becoming more energy-intensive and less labor intensive."[11]

However, primarily because social and economic conditions varied dramatically in the 1930's and 1970's, some very important differences exist between the Technocrats and recent energy analysts. These differences are especially apparent in their analyses of unemployment. The Technocrats attributed unemployment to an "underconsumptionist" condition, while net energy analysts cite it as being due to energy scarcity and an allocation problem. In particular, Scott and his fellow Technocrats viewed the extensive unemployment of the late 1930's as a result of automation and energy-labor substitutability. Believing that future energy supplies would be abundant and that more energy-labor substitutability was inevitable, they concluded that the problem facing North America was to devise a measurement system of distribution for abundant goods and services to a people whose labor, sweat and toil was no longer necessary. Once production was balanced with consumption through the use of energy accounting and energy certificates, sustained prosperity could emerge. Abundance and prosperity would be the norm. By contrast, the perceived energy scarcity, high energy prices and substantial unemployment of the mid-1970's meant to Bruce Hannon and his fellow net energy analysts that energy conservation was the most important policy initiative. Because of energy-labor substitutability, either regulated or price-induced shifts in consumer demand away from energy-intensive goods would result in reduced unemployment. Moreover, since net energy analysts often noted that pollution was directly related to energy and heat consumption, less energy consumption implied potential beneficial environmental effects. Hence, in terms of principal emphasis, Technocrats viewed energy certificates as solving the problem of aggregate demand and overall distribution, while more recent adherents of energy theories of value view energy certificates as facilitating allocation between labor and increasingly scarce energy.

A second major difference between the Technocrats and recent energy theory of value adherents concerns their perception of the international environment. Technocracy presented itself in the U.S. during an isolationist period in U.S. foreign policy when autarky seemed feasible. The Technocrats, for example, defined geographical borders of the North American Continental Technate in such a way that they believed energy self-sufficiency would be possible. Also, the Technocrats sought to prohibit immigration and to allow only the English language. By contrast, recent net energy analysts fact a situation where energy and environmental problems appear inherently global in scope, and where self-sufficiency refers to the "spaceship earth" rather than to any single country or continent.

A third difference between Technocrats and net energy analysts regards the concept of net energy. Although both used the term "net energy", their notion of it differed significantly. To modern energy analysts, net energy is essentially the energy remaining for use outside an energy system after deducting all the energy embodied in the system and all the energy required by the system for operation and maintenance. To the Technocrats, however, net energy was a smaller number.

It is the modern energy analyst's net energy figure, minus the energy consumption embodied in public provision of numerous services within that system, such as local transportation, public health, and minimum housing space.

Fourth, the political success of Technocracy was quite different from that of net energy analysis. Although the Technocratic movement enjoyed a sudden rise to prominence in the 1930's, its proposals for government rule by technocrats and distribution via energy certificates never received extensive support. This is not surprising, for in a democracy it is inherently difficult to obtain widespread agreement with a notion of government by a selected elite, however knowledgable they may be. Writing in 1933, Virgil Johnson stated that

> "The people of these states may be in a pretty bad pickle, but they are probably not prepared to call in any men on horseback, even if these are all messiahs with an M.E."[12]

But Al Smith, reflecting on the presidency of Herbert Hoover, offered I think the definitive reason why Technocracy never gained hold as a political movement:

> "As for substituting engineers for political leaders in running the country, I cannot refrain from mentioning the fact that we have just finished an era of government by engineers in Washington."[13]

Modern adherents of an energy theory of value may never have been as organized politically as were the Technocrats, yet in 1974 net energy analysis was enthusiastically advocated by a respected United States Senator and was successfully legislated into federal law. Today it is a mode of policy analysis common amongst engineers and technologists. In brief, net energy analysts appear to be more successful in policy analysis and influence than were their ancestors, the Technocrats. Reasons for this difference might include the facts that net energy analysts have not been as obviously elitist, net energy analysts have adherents with professional credentials (the lack of which seems to have hurt Scott and the Technocrats), and net energy analysts have had the support of many in the allied and better-organized environmental movements.

Finally, although there are various differences and similarities between them, net energy analysts have undertaken computations which can be viewed as a natural extension of Technocratic thinking. Specifically, the gross energy requirement calculations of modern energy analysts can be viewed as the most ambitious attempt to date to fulfill Howard Scott's dream of completing an Energy Survey of North America. Such calculations yield estimates of the direct and indirect energy embodied in all goods and services, and thereby lay the groundwork for implementing an energy theory of value. Scott would likely have marvelled at the detailed 362-order input-output tables of the U.S. economy and the even more disaggregated regional Canadian I/O tables, but even he would probably have been rather uneasy about the energy data. Recall that Scott and his fellow Technocrats sought to measure production costs on the basis of the degradation of energy quality, not on the basis of heat (enthalpy). Modern energy analysts might respond by saying that they agree with Scott's views, but data availability and at times lack of underlying scientific knowledge presently preclude implementation of complete economy-wide energy quality accounting.

V. Concluding Remarks

In the previous sections of this paper I have described recent variants on the energy theory of value (particularly net energy analysis), provided a brief history of the extremely interesting Technocratic movement in the U.S. and Canada, and then compared and contrasted the Technocratic and recent energy theories of value. The merits of doing any additional economic analysis of these energy theory of value movements here are to a great extent limited, since political associations such as Technocracy and the allied net energy-environmental movements in large part reflect widespread frustrations, ideologies and divergent group interests, rather than consistent economic arguments. Moreover, like many political movements, Technocracy was dominated by a highly visible leader, Howard Scott, and flavored by his personality, rather than being led by the rules of logic and on the basis of intellectual foundations constructed with scholarly rigor. Nonetheless, the idea of an energy theory of value has risen to prominence from time to time, and it seems appropriate to comment on why this phenomenon recurs.

Energy theories of value occur from time to time for a number of reasons. First, when the market pricing system is perceived to be functioning extremely poorly, alternative institutions will be discussed and considered. This certainly was the case in the 1930's, and to some extent again in the 1970's when energy shortages suddenly appeared. Moreover, the environmental movement so popular in the 1970's taught the public that the market pricing mechanism often failed to internalize important externalities such as pollution. Since in many industrial processes pollution is closely related to heat and energy consumption, it is understandable that discontent with excessive pollution could lead to a view that energy use is correlated with environmental damage, that much energy is "wasted", and that consumption of scarce energy ought to be reduced considerably.

A second and closely related reason why energy theories of value may occur from time to time is that the layer of public belief in consumer sovereignty is, I suspect, in fact quite thin and can easily be pierced. From time to time the public has indicated its willingness to accept "expert guidance" and regulations to protect innocent consumers from "exploitation" by greedy and "unprincipled" market participants. Public belief in the notion that consumption and production patterns of today's firms and consumers adequately provide for the welfare of future generations of consumers not yet born is certainly not strong. Mistrust in the ability of the pricing mechanism to allocate apparently finite energy sources over time may make more plausible an energy theory of value, particularly when energy sources are dominated by imperfectly competitive firms.

A third reason why energy theories of value recur is because the public well understands that there <u>is</u> something special about energy. However, these special features of energy do not, I believe, imply any need for an energy theory of value. Let me briefly consider three specious arguments offered in support of an energy theory of value. First, consider this argument: "Energy is unique and natural as a measure of value, for it provides an unambiguous and unchanging measurement unit, namely, the measurement of physical work." That the production and output of a nation's economy should be measured in terms of energy consumed and/or transformed is understandable, for if one is willing to view production as the completion of a task requiring work, then it may seem eminently reasonable to measure work the way physical scientists do, namely, in terms of the amount of energy degraded. In a number of industries (such as petrochemicals, aluminum, metallurgy, iron and steel, and electric utilities) it is possible to define tasks in a physical manner so that "output" can be measured in terms of energy degraded or materials transformed. But many, indeed an increasing number of activities in modern post-industrial economies, are not amenable to precise physical task definition and energy quality measurement. For example, the outputs of activities in wholesale and retail trade, consulting, finance, insurance and real estate, services, the government sector, the performing arts, and in educational institutions are extremely important, are highly valued by society and are not easily measured by energy degradation. In brief, while many tasks can be well-defined in physical terms and can therefore be measured in work or energy units, the outputs of a large and growing number of activities in service-oriented economies are not amenable to accurate energy degradation measurement.

Now consider a second specious argument often offered in support of an energy theory of value: "Since energy is homogeneous, measurement of production based on an energy standard would avoid what Howard Scott called the 'rubber yardstick' features of the conventional monetary pricing mechanism.[1] Hence energy measurement would avoid 'adding apples and oranges'." This argument seems to be a premise of almost all net energy analysts, even those who may not subscribe to an energy theory of value. While it is of course the case that the Btu is a well-defined physical unit and is homogeneous, it is quite a differnt matter to state that society is indifferent to a thousand Btu's of natural gas and a thousand Btu's of coal, i.e. that their value to society is identical. What is being confused here is the unit of measurement which is homogeneous, and the phenomena being measured (values). Value is a multi-dimensional phenomenon. Attributes such as weight, cleanliness, safety, heat content, security of supply, amenability to storage, relative costs of conversion and cooperating end-use technology, and capacity to do useful work are all important; the various energy types (coal, crude oil, natural gas, electricity) differ in their attribute combinations, and so their value to society also varies. In terms of value, a Btu of coal is not necessarily the same as a Btu of crude oil or a Btu of electricity. When energy analysts undertake to evaluate projects using the criterion of net energy, various energy types are aggregated using Btu conversion rates, i.e. it is assumed that all Btu's are identical in value to society. Clearly, this is inappropriate. Problems of adding "apples and oranges" or coal and crude oil would not be solved by changing from dollars to energy units.

A third argument in defense of an energy theory of value is more subtle: "There are no substitutes for energy. Hence it is imperative that scarce energy stocks be valued and allocated on the basis of net energy content." There are a number of problems and errors in such an argument. It is simply not the case that there are no substitutes for energy. The rate of energy degradation can be reduced in numerous ways, for example, by use of increased home insulation, more fuel efficient automobiles, more energy efficient appliances, replacement of conventional oil or gas home furnaces with heat pumps, and many others. While each of these examples of energy substitution involves increased use of physical capital equipment which also embodies energy, undoubtedly it is the case that there are numerous possibilities for which the net impact on the rate of energy degradation is negative, i.e. energy-capital substitution possibilities are numerous. According to the Second Law of Thermodynamics, there are ultimate limits to the extent to which energy-capital substitutability can take place, but at the present time second law efficiency measures for many tasks are on the order of 10 to 15%. These low second law efficiency measures partly reflect particular and somewhat inappropriate assumptions (for example, the absence of friction and the infinite passage of time), but their low values also indicate that a great deal of technological potential still exists for energy conservation.[2]

Although numerous technological opportunities exist for energy-capital substitutability, a substantial proportion of them may be unattainable for economic reasons. Other things being equal, energy efficient appliances are more costly than the less energy efficient models. Home insulation is not free. Many fuel efficient motors require greater maintenance and fine tuning than the less fuel efficient engines. Although driving 55 miles per hour consumes less fuel than at 65 miles per hour, slower driving exhausts a greater amount of scarce time. Solar panels require use of scarce and costly minerals and ores. Clearly, energy is not the only scarce input; capital, labor, minerals and other material inputs are also scarce. According to economic analysis, value is determined both by demand and by production costs incurred through the combined wise use of all scarce inputs, not just energy. Hence, while in some sense energy may be an ultimate limiting factor, for the foreseeable future energy is but one of many scarce inputs. Indeed other resources could be depleted long before energy exhaustion is approached.[3]

In summary, this third specious argument in support of an energy theory of value is attractive, for there is something special and unique regarding energy.

However, such uniqueness does not imply any need for an energy theory of value. Many activities in our economy today are not amenable to accurate measurement in terms of energy degradation, problems of adding apples and oranges, or coal and natural gas are not avoided by converting from dollars to energy units, and it is simply not the case that energy is non-substitutable.

There are other reasons why the public may from time to time become receptive to physical science-based energy theories of value. One reason is that economic analysis is admittedly still rather vulnerable. It is no secret that real world markets are quite different from the perfect markets typically envisaged by economic analysts. While recent econometric models represent great achievement and may be viewed by some as being enormously successful, significant problems still remain.[4] Because of data availability and sheer size constraints, the econometrician, like the net energy analyst, faces difficult choices in relating the micro-economic process analysis data at the level of an individual firm or plant to macro-economic phenomena such as national input/output coefficients, employment, output, and inflation. In economics as in energy analysis, the bridge from micro to macro is somewhat precarious. Moreover, as is well-known by most engineering economists, econometric models are typically naive in their specification of environmental and technological constraints.[5] A great deal of work, joint among physical scientists and economists, needs to be done in modeling more accurately and convincingly the physical and environmental constraints to economic activity. Even more important, perhaps, is the fact that to both engineers and economists, factors affecting the complex and uncertain process of technological progress are still largely unknown.

Finally, when all is said and done, energy theory of value movements are likely to arise in a democratic society simply because individuals with strong convictions will have different sets of value, and from time to time these value judgments will concern the allocation of scarce energy resources over time. According to Nicholas

Georgescu-Roegen,

> "All this calls for a radical change of the values everywhere. Only economists still put the cart before the horse by claiming that the growing turmoil of mankind can be eliminated if prices are right. The truth is that only if our values are right will prices also be so. We had to introduce progressive taxation, social security, and strict rules for forest exploitation, and now we struggle with anti-pollution laws precisely because the market mechanism by itself can never heal a wrong."[6]

Footnotes: Section I

1. Senator Mark Hatfield, "Net Energy," The Congressional Record, Vol. 120, Part 5, March 11, 1974, p. 6076.

2. Federal Nonnuclear Energy Research and Development Act of 1974, Public Law 93-577, 93rd Congress of the United States, December 31, 1974, Section 5(a)(5).

3. Martha W. Gilliland, "Energy Analysis and Public Policy," Science, Vol. 189, No. 4208, 26 September 1975, pp. 1051-1056.

4. R.S. Chambers, R.A. Herendeen, J.J. Joyce and P.S. Penner, "Gasohol: Does It or Doesn't It Produce Positive Net Energy?", Science, Vol. 206, 16 November 1979, pp. 789-795.

5. Bruce M. Hannon, "The Energy Cost of Energy," Urbana, Illinois: Energy Research Group, University of Illinois, processed paper, revised, June 1980.

6. For a review of this debate and for a reprint of some of the principal papers, see Energy Accounting as a Policy Analysis Tool, Serial CC, Subcommittee on Energy Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, Second Session, June 1976. Hereafter I will refer to this reprint of papers as Energy Accounting Hearings, and to pages within that document.

7. See, for example, Business Week, "The New Math for Figuring Energy Cost," No. 2334, June 8, 1974, pp. 88-89, and the Wall Street Journal, "Energy-Costly Energy is Wasting Resources; Some Analysts Worry," May 3, 1979, p. 1.

8. Hatfield, "Net Energy," p. 6074.

9. Bruce M. Hannon, "An Energy Standard of Value," in "The Energy Crisis: Reality or Myth?", Annals of the American Academy of Political and Social Science, Vol. 410, November 1973, p. 153.

10. Howard Scott, "Technology Smashes the Price System," Harpers Magazine, Vol. 166, January 1933, pp. 131-132.

Footnotes: Section II

1. Malcolm Slesser, Energy in the Economy, New York: St. Martin's Press, 1978, p. ix.

2. Jeremy Rifkin with Ted Howard, Entropy: A New World View, New York: Viking Press, 1980, p. 241, For a review of Rifkin's book, see Kirk R. Smith, "Book Review of Rifkin," Technological Forecasting and Social Change, forthcoming, late 1981.

3. Martha W. Gilliland, "Energy Analysis and Public Policy," Science, Vol. 189, No. 4208, 26 September 1975, p. 1056. Similar arguments can be found in Fred Cottrell, Energy and Society, New York: McGraw-Hill Book Company, 1955, especially chapters eight and ten.

4. Howard T. and Elizabeth C. Odum, Energy Basis for Man and Nature, New York: McGraw-Hill, 1976, pp. 58-59.

5. For discussion of these approaches, see Proceedings of the Energy Analysis Workshop on Methodology and Conventions, 25th-30th August 1974, Stockholm, Sweden: International Federation of Institutes for Advanced Study, pp. 46-56. Reprinted in Energy Accounting Hearings, pp. 171-81; also see Robert Costanza, "Embodied Energy and Economic Valuation," Science, Vol. 210, No. 4475, 12 December 1980, pp. 1219-1224.

6. For further discussion, see Slesser, chapter two; C. Cozzi, "Thermodynamics and Energy Accounting in Industrial Processes," in Energy Accounting Hearings, pp. 325-332; or Ernst R. Berndt, "Aggregate Energy, Efficiency and Productivity Measurement," Annual Review of Energy, Vol. 3, 1978, pp. 224-273 and the references cited therein.

7. One of the best-known industrial process analysis models is that of Dow Chemical Company. For a discussion, see the article "Balance of Power," The Wall Street Journal, Thursday, May 3, 1979, page one. Note also that process models need not involve energy, but typically incorporate optimization subject to specific technological constraints.

8. David Gushee, "Introduction to Energy Accounting as a Policy Analysis Tool," Energy Accounting Hearings, p. 7.

9. John G. Myers and Leonard Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record, Cambridge, MA: Ballinger Publishing Company, 1978, p. 4.

10. Proceedings of Energy Analysis Workshop on Methodology and Conventions, Stockholm, Sweden: International Federation of Institutes for Advanced Study, Workshop Report No. 6, p. 18. Reprinted in Energy Accounting Hearings, p. 143.

11. The first I/O tables for the U.S. were published by Wassily Leontief in 1941. Recently they have been published approximately every four or five years by the U.S. Department of Commerce. See Wassily W. Leontief, The Structure of the American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis, Cambridge, MA: Harvard University Press, 1941.

12. This statement does not necessarily hold, of course, when the system boundary is defined narrowly and excludes energy inputs embodied in agricultural products and in human labor. For an example of a study of gross energy degradation using relatively narrow system boundaries, see R. Stephen Berry and Margaret F. Fels, "The Energy Cost of Automobiles," Science and Public Affairs, Vol. 29, December 1973, pp. 11-17 and 58-60; reprinted in Energy Accounting Hearings, pp. 595-605. Also see the IFIAS statement in the Energy Analysis Workshop on Methodology and Conventions, International Federation of Institutes for Advanced Study, Stockholm, Sweden, 25th-30th August 1974, p. 20. (Reprinted in Energy Accounting Hearings, p. 145.)

13. Bruce Hannon, "System Energy and Recycling: A Study of the Container Industry," New York: American Society of Mechanical Engineers, 72-WA-ENER-3, 1972.

14. Robert A. Herendeen, "Use of Input-Output Analysis to Determine the Energy Cost of Goods and Services," Document No. 69, Urbana, Illinois: Center for Advanced Computation, University of Illinois, 4 March 1973 (Reprinted with additional remarks in Energy Accounting Hearings, pp. 101-110); Eric Hirst and Robert Herendeen, "Total Energy Demand for Automobiles," Paper 730065 delivered at the International Automotive Engineering Congress, Society of Automotive Engineers, January 1973 (Repringed in Energy Accounting Hearings, pp. 589-94); Clark W. Bullard III and Robert A. Herendeen, "The Energy Costs of Goods and Services," Energy Policy, Vol. 3, December 1975, pp. 268-278 (Reprinted in Energy Accounting Hearings, pp. 651-661).

15. A.M. Perry, W.D. Devine and D.B. Reister, "The Energy Cost of Energy-Guidelines for Net Energy Analysis of Energy Supply Systems," Oak Ridge, TN: Oak Ridge Associated Universities, ORAU/IEA(R)-77-14, August 1977, p. 1.

16. Gilliland, pp. 1053-54. Senator Mark Hatfield, "Net Energy," p. 6074. On this, also see Howard T. Odum, "Energy, Ecology, and Economics," Ambio, Vol. 2, No. 6, 1973, pp. 220-227; reprinted in Energy Accounting Hearings, pp. 19-26.

17. For a review of this debate and for a reprint of some of the principal papers, see the Energy Accounting Hearings.

18. Gilliland, p. 1053 and Hannon, "The Energy Cost of Energy".

19. For example, Chambers, et al., p. 795.

20. David A. Huettner, "Net Energy Analysis: An Economic Assessment," Science, Vol. 192, No. 4235, 9 April 1976, pp. 101-104. Huettner's argument is but a simple restatement of pricing under a labor theory of value.

21. Clark W. Bullard III, "Energy Costs and Benefits: Net Energy," Energy Systems and Policy, Vol. 1, No. 4, 1976, p. 381.

22. Workshop Report, International Federation of Institutes for Advanced Study, Workshop on Energy Analysis and Economics, Lidingo, Sweden, June 22-27, 1975, p. 7. (Reprinted in Energy Accounting Hearings).

23. A.M. Perry et al., "The Energy Cost of Energy: Guidelines for Net Energy Analysis of Energy Supply Systems," p. 3.

24. Michael Webb and David Pearce, "The Economics of Energy Analysis," Energy Policy, Vol. 3, December 1975, p. 331 (Energy Accounting Hearings, p. 86.)

25. For other recent critiques of net energy analysis, see Frank J. Alessio, "Energy Analysis and the Energy Theory of Value," The Energy Journal, Vol. 2, No 1., January 1981, pp. 61-74; William J. Baumol and Edward Wolff, "Subsidies to New Energy Sources: Do They Add to Energy Stocks?", Journal of Political Economy, forthcoming, October 1981; David A. Huettner, "Energy, Entropy, and Economic Analysis: Some New Directions," The Energy Journal, Vol. 2, No. 2, April 1981, pp. 123-130; and Eric J. Hyman, "Net Energy Analysis and the Theory of Value: Is It a New Paradigm for a Planned Economic System?", Journal of Environmental Systems, Vol. 9, No. 4, 1979-1980, pp. 313-324.

Footnotes: Section III

1. For more complete historical studies of technocracy, see William E. Akin, Technocracy and the American Dream: The Technocratic Movement, 1900-1941, Berkeley: University of California Press, 1977; Henry Elsner, Sr., The Technocrats: Prophets of Automation, Syracuse: Syracuse University Press, 1967; Allen Raymond, What is Technocracy?, New York: Whittlesey House, McGraw-Hill Book Co., 1933; Arthur M. Schlesinger, Jr., The Age of Roosevelt: The Crisis of the Old Order, 1919-1933, Boston: Houghton-Mifflin Co., pp. 461-464 and the references on pp. 539-540.

2. Frederick W. Taylor, The Principles of Scientific Management, New York: Harper and Brothers, 1911.

3. Akin, p. 4.

4. Thorstein Veblen, The Engineers and the Price System, New York: B.W. Huebsch, 1921. Pages cited are from the 1963 edition published by Harcourt, Brace & World, Inc., New York (Harbinger Books).

5. Veblen, "A Memorandum on a Practicable Soviet of Technicians," Final Chapter, The Engineers and the Price System, p. 150.

6. Akin, p. 28.

7. Elsner, p. 26.

8. Some of these views were also expressed in 1926 by the Nobel Laureate in chemistry, Frederick Soddy. See Frederick Soddy, Wealth, Virtual Wealth, and Debt: The Solution of the Economic Paradox, New York: E.P. Dutton, 1926, and H.G. Wells, The World Set Free, 1st edition, Collins, Glasgow, U.K., 1914.

9. Elsner, p. 26.

10. Akin, pp. 46-51.

11. Ibid., pp. 56-60.

12. Although Scott popularized the word "technocracy," its origin is unclear. Another engineer, William H. Smyth, earlier used the word in print; see William H. Smyth, "Technocracy: National Industrial Management," Industrial Management, 57, March 1919, pp. 208-212. Smyth's claim to originality was published in a letter to The Nation, Vol. 135, No. 3521, December 28, 1932, p. 646.

13. New York Times, August 6, 1932.

14. Ibid.

15. Raymond, pp. 23-24.

16. Wayne Parrish, "What is Technocracy?", New Outlook, No. 166, November 1932, p. 17.

17. Parrish, p. 18. Rough translation: "Your days are numbered."

18. Time, January 23, 1933, "Science Section," p. 28.

19. New York Times, January 24, 1933.

20. Paul H. Douglas, "Technocracy," The World Tomorrow, Vol. 16, No. 3, January 18, 1933, pp. 59-60.

21. Douglas, p. 61.

22. Stuart Chase, Technocracy: An Interpretation, New York: The John Day Company, 1933, pp. 31-32.

23. Quoted in Raymond, pp. 170-71.

24. Paul Blanshard, "The Gospel According to Technocracy," The World Tomorrow, February 22, 1933, pp. 188-89.

25. "Twenty Five on Technocracy," Common Sense, February 2, 1933, p. 10.

26. Broadus Mitchell, "A Test of Technocrats," The Virginia Quarterly Review, April 1933, pp. 281, 283.

27. The Technocrats had taken great pains to distinguish themselves from other radical groups. Parrish (p. 14), for example, spoke sharply: "Our present system...is fit only for the same museum in which are housed the pathetically inadequate political and economic theories of Plato, Marx and the great host of other diagnosticians and prophets who could not conceive of such a highly industrialized society as that in which we find ourselves today and Fascism, Communism and Socialism are likewise wholly inadequate to cope with our problem."

28. Virgil Jordan, "Technocracy - Tempest On a Slide Rule," Scribners Magazine, Vol. 93, No. 2, February 1933, p. 69.

29. Ibid., p. 66.

30. Ibid., p. 67.

31. Archibald MacLeish, "Technocracy Speaks," The Saturday Review of Literature, January 28, 1933.

32. Certain legends and stories concerning Scott's industrial engineering experience and athletic feats were also found by Raymond to be nothing but pure inventions. Other historical facts, cited by the Technocrats, were likewise called into question. See Raymond, pp. 100-119, 149-59, 168-69, and George Soule, "Technocracy: Good Medicine or a Bedtime Story?", The New Republic, December 28, 1932, p. 178.

33. New York Times, January 24, 1933, page 1.

34. Copies of the fifth edition of the Technocracy Study Course, New York: Technocracy, Inc., 1940, can be found in many public libraries. The first edition was published in 1934.

35. Akin, p. 101.

36. In the Technocracy Study Course, the physical cost of production is explicitly defined as "the energy degraded in the production of goods and services." (Fifth edition, p. 234.)

37. Technocracy, Inc., "The Energy Certificate," 1938, (twelfth printing, 1963), p. 12. Adapted from an article in Technocracy magazine A-10, July 1937.

38. Technocracy, Inc., "The Energy Certificate," p. 13.

39. See Technocracy, Inc., Technocracy: Technological Social Design, Savannah, Ohio: 1975.

40. As quoted in Elsner, p. 142, 144.

41. This ban was lifted unconditionally on 15 October 1943. See Elsner, pp. 142-145.

42. Quoted by Elsner, p. 198.

43. For a discussion of Technocracy's activities during these decades, see Elsner, Chapters 9 and 10.

44. Articles in these magazines deal with classic issues. For example, the March, April, May 1979 issue of The Technocrat contains articles "Cleaner Coal Conversion" and "Make Way for Social Change;" the April, May, June 1977 issue of The Northwest Technocrat has a front-page picture of a hydro-electric dam, a critique of recent U.S. energy policy, and an article "A New Look at the Physical Trends," while the November, December 1978, January 1979 issue of Technocracy Digest contains a reprint of Howard Scott's classic Harpers Magazine article, "Technology Smashes the Price System," an article "Producing An Abundance," and several news items.

45. Hubbert's publications during this time period include M. King Hubbert, "Future Ore Supply and Geophysical Prospecting," Engineering and Mining Journal, Vol. 135, No. 1, January 1934, pp. 18-21, and M. King Hubbert, Man-hours and Distribution, New York: Technocracy, Inc., 1940.

46. See M. King Hubbert, "Energy from Fossil Fuels," The Smithsonian Report for 1950, Washington, D.C., Publication 4032, 1950, pp. 255-272. Also, M. King Hubbert, "Nuclear Energy and the Fossil Fuels," Drilling and Production Practice, 1956, American Petroleum Institute, 1956, pp. 7-25; M. King Hubbert, Energy Resources: A Report to the Committee on Natural Resources of the National Academy of Sciences - National Research Council, Washington, D.C.: National Academy of Sciences - National Research Council, Publication 1000-D, 1962; "U.S. Petroleum Estimates, 1956-78," Annual Meeting Papers 1978, Production Department, American Petroleum Institute, Dallas, 1978, p. O-1 to O-58; and "Techniques of Prediction As Applied to the Production of Oil and Gas," paper presented to Symposium on Oil and Gas Supply Modeling, U.S. Department of Energy and National Bureau of Standards, June 18-20, 1980, processed.

47. M. King Hubbert, "Testimony on Relation Between Industrial Growth, the Interest Rate, and Inflation," United States House of Representatives, 93rd Congress, Second Session, Hearings Before the Subcommittee on the Environment of the Committee on Interior and Insular Affairs, Serial No. 93-55, Washington, D.C., 1974, and M. King Hubbert, "Are We Retrogressing in Science?", Geological Society of America Bulletin, Vol. 74, April 1963, pp. 365-378.

Footnotes: Section IV

1. Howard Scott, "Technology Smashes the Price System," pp. 141, 142.

2. Michael Common, "The Economics of Energy Analysis Reconsidered," in John A.G. Thomas, ed., Energy Analysis, Surrey, England: IPC Science and Technology Press, 1977, p. 146.

3. Malcolm Slesser, Energy in the Economy, p. 6.

4. Scott, "Technology Smashes the Price System," p. 141.

5. Technocracy, Inc., Technocracy Study Course, pp. 99, 100.

6. Howard T. and Elizabeth C. Odum, Energy Basis for Man and Nature, p. 226.

7. Malcolm Slesser, Energy in the Economy, p. ix.

8. M. King Hubbert, Man-hours and Distribution, p. 28.

9. Bruce Hannon, "Energy Conservation and the Consumer," Science, Vol. 189, No. 4197, 11 July 1975, p. 101.

10. Frank Arkwright, The ABC of Technocracy: Based on Authorized Material, New York: Harper and Bros. Publishers, 1933, pp. 58-59.

11. Bruce M. Hannon, "An Eenrgy Standard of Value," p. 145.

12. Virgil Jordan, "Technocracy - Tempest on a Slide Rule," p. 69.

13. Alfred E. Smith, "The New Outlook," New Outlook, November 1932, p. 12.

Footnotes: Section V

1. New York Times, August 6, 1932.

2. For further discussion of energy-capital substitutability and second law efficiency measures, see Ernst R. Berndt, "Aggregate Energy, Efficiency and Productivity Measurement," and R.S. Berry, P. Salamon, and G. Heal, "On a Relation Between Economic and Thermodynamic Optima," Resources and Energy, Vol. 1, October 1978, pp. 125-137.

3. On this issue, see David A. Huettner, "Energy, Entropy, and Economic Analysis: Some New Direction," Energy Journal, Vol. 2, No. 2, April 1981, pp. 123-130.

4. See Lester Thurow, The State of Economics, unpublished manuscript, MIT, October 1981.

5. On this, see Nicholas Georgescu-Roegen, "Energy Analysis and Economic Evaluation," Southern Economic Journal, Vol. 45, April 1979, pp. 1023-1058, and the references cited therein; also see R.S. Berry, P. Salamon and G. Heal, "On a Relation Between Economic and Thermodynamic Optima," Resources and Energy, Vol. 1, October 1978, pp. 125-137, and Donald J. Hertzmark, "A Proposition on Energy Analysis and Economic Efficiency," Energy Journal, Vol. 2, No. 1, January 1981, pp. 75-88.

6. Nicholas Georgescu-Roegen, Energy and Economic Myths, New York: Pergamon Press, 1976, p. xix.

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