APPLICATION OF THE PRINCIPLE OF MINIMIZATION OF ENTROPY IN THE ACHIEVEMENT OF STEADY-STATE SOLUTIONS FOR DYNAMIC SYSTEMS

by

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Dissertation submitted to the Graduate Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

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March, 1975

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ACKNOWLEDGMENTS

I would like to express my sincerest appreciation and gratitude for the assistance and guidance given me by the following persons:

Dr. Dinshaw Contractor, Department of Civil Engineering, who, as my faculty advisory committee chairman, provided the principal advice for this dissertation.

Dr. Richard Walker, Head of the Department of Civil Engineering and member of my faculty advisory committee, for his interest and for the opportunity to pursue the interdisciplinary research program that underlies this dissertation.

Dr. Frank Ehrenthal and Dr. Robert Dyck, Division of Environmental and Urban Systems, for their interest as members of my faculty advisory committee and for their instruction and advice concerning the application of entropy minimizing policies in urban and regional systems.

Dr. John Hassler and Dr. Peter Clark, Department of Chemical Engineering, for their interest as members of my faculty advisory committee and for their advice concerning thermodynamic analysis, laser-fusion technology, and systems dynamics.

Dr. William Lehmann, Director of the Office of Scientific Research, United States Air Force, for providing the personal sponsorship that made this educational opportunity possible.

Major General Maurice Reilly, Commanding General, Headquarters Command and former Director of Civil Engineering, Headquarters, United States Air Force, for his support and approval of my educational assignment.

Lieutenent Colonel Thomas West, Directorate of Personnel, Headquarters, United States Air Force, for his assistance in arranging the sponsorship and approvals that made this opportunity possible.

Dr. Leno Pedrotti, Head of the Department of Physics, Air Force Institute of Technology, for his interest and advice on matters relating to laser-fusion technology.

Dr. Walter Beam, Director of Laboratories, Office of the Assistant Secretary of the Air Force for Research and Development, for his interest and advice concerning matters of decision theory.

Mr. William Gough, Division of Controlled Thermonuclear Research, United States Atomic Energy Commission, for his interest and fusion technology data support. Mr. Gough's own work with the concepts of Fusion Torch and achievement of a steady-state world system has greatly influenced this dissertation.

The United States Air Force, for financial support of my educational program.

Dr. Frank Ehrenthal and his wife, Julie, for their wonderful hospitality and for providing an ideal study environment during the last months of my research and dissertation preparation.

Mr. Charles Steger, fellow interdisciplinary PhD candidate in the Department of Civil Engineering, for his interest and proof-reading assistance.

My wife, Pilar; my daughter, Tamara; and my son, Robin; for their encouragement and patience throughout the course of my academic program.

TABLE OF CONTENTS

PAGE

CHAPTER 1

INTRODUCTION

A. The Limits to Growth

Until about the year 1800 the world population maintained a relatively stable level of approximately 500 million people.[1] This stability resulted from equalizing birth and death rates and, to some extent, on the relatively steady technological influences of an agrarian cultural system. Since 1800 the world population has grown to nearly 4 billion persons. At present growth rates the world population will double in less than 30 years; thus supporting projections of world populations of 7 billion in the year 2000, 14 billion in the year 2030, etc. This upsurge has complex foundations, but in its basic form reflects a growing imbalance between rising birth rates and decreasing death rates in the poor sectors of the world.

Paul Ehrlich and John Holdren have estimated that more than 10 million persons starve to death annually,[2] with the number assumed to be growing exponentially. When a present problem of such incredible magnitude is continuing unsolved, the prospect of dealing with doubly large populations in the near future has truly horrifying implications. Beyond the primary concern of basic survival are an unlimited number of problems relating to population impact: housing, public services, employment, etc. In general, exponential population growth is generating adverse impact throughout the environment.[3]

Civilization has always had resource management problems; economic geography essentially reflects the spatial aspects of resource availability and utilization. Though the ethic of resource husbandry and environmental awareness has ancient roots,[4] modern industrial societies have tended to think solely in terms of an inexhaustible natural resource/artificial substitute base. Recent experience with large scale environmental problems has created a realization that many resources are being depleted at rates which: (1) are reducing many critical renewable resources (such as marine life) below levels required to assure their perpetuation; and (2) are depleting non-renewable resources (such as hydrocarbons) to levels of virtual exhaustion. Due to industrial standardization the world economy has come to rely on enormous amounts of a relatively few resources; and finds it increasingly difficult and costly to assure continued supply or substitution.[5]

As in the case of resource consumption, a world-wide debate is being carried on concerning the significance of environmental pollution. The "industrialist" contends that the earth has an infinite capacity to absorb pollution and that correction of any particular local problem is a matter of economics and technology. The environmentalist contends that pollution is a manifestation of fundamental weaknesses in the industrial culture and that pollution is already causing macroscopic effects in the local and regional environments which could jeopardize the stability of the entire world ecosystem, thus endangering continued support of life in general. Of primary concern has been air and water quality as related to protection of food supply and public health. Management of radioactive and other highly dangerous industrial wastes, despoilment of vast amounts of land solely to recover some minute amount of scarce material or energy, and gross abuse of human resources are other aspects of pollution receiving increasing concern.

History has provided ample illustration of the propensity for resource competition to generate violence among men. Resource competition is influenced adversely by population and pollution, which are growing exponentially, thus suggesting an exponential increase in the potential for world conflict. The prospect for major violence is further aggravated by the high degree of interdependence characteristic of the international industrial economy, the increasing size of the poor majority in the world population, the increasing disparity between controlling wealth of an elite minority and the poverty of the majority of world society, plus increasing awareness of these inequities as a result of improved world-wide mass information media.

In order to maintain their economic and political advantage, the wealthy nations maintain an enormous military might which, in terms of nuclear arsenals alone, is conservatively estimated as possessing the equivalent of 20 tons (TNT) of destructive power for every member of the world population.[6] The Southeast Asia War and recent terrorist activities have demonstrated all too clearly present human culture's great potential for self-destructive violence.

These ecological problems (identified by William Gough as the population, entropy, and war "traps"[7]) reflect growth trends which have closely paralleled the growth of industrialism; leading to the suspicion that all three "traps" are a direct consequence of the character and degree of industrial activity. Until quite recently maximum industrial growth was almost universally deemed to be the highest socio-economic objective of a nation. The "Limits to Growth" debate initiated by the Club of Rome via the research efforts of MIT's Systems Dynamics Group[8] now challenges the concept of unlimited industrial growth as perhaps the most critical danger facing the long term survival of life on earth.

Although over 100 years ago John Stuart Mill warned of the inherent danger of unchecked industrial growth, until recently the consideration of alternative policies was largely ignored or derided. One of the few benefits accruing from present world problems is the increasing pressure to: (1) question the foundations and ramifications of modern industrially-oriented culture; and (2) investigate alternative policies. The most seriously considered alternative to present industrial growth policy is steady-state policy. Herman E. Daly sees justification for this alternative as follows:[9]

> The World is finite. The ecosystem is a steady-state. The human economy is a subsystem of the steady-state ecosystem. Therefore, at some level and over some time period the subsystem must also become a steady-state, at least in its physical dimensions of people and physical wealth. The steady-state economy is therefore a physical necessity.

Implicit in this justification is the preservation of a healthy biosphere, the careful husbandry of resources, and a general attitude of trusteeship with respect to future generations.[10]

The "Limits to Growth" debate is focusing world-wide attention on the concept of a steady-state world system; at present, however, the concept is embryonic.[11] In order to develop a basis for effective steady-state policy, Daly has asked:[12]

1. At what levels should stocks of wealth and population be maintained constant?

2. What is the optimal level of maintenance throughput

for a given level of stocks?

3. What is the optimal time horizon or accounting period over which population and wealth are required to be constant?

4. What is the optimal rate of transition from the present industrial growth economy to the steady-state economy?

5. What means are appropriate for attaining the steady-state goals?

B. Summary of Research Objectives

The objectives of the research reported herein have been the investigation of Daly's questions using the principles of thermodynamics in conjunction with Forrester's Systems Dynamics modeling and DYNAMO simulation techniques. Extensive evaluation of Forrester's World Dynamics simulation model using various policy alternatives shows them all to degenerate in accordance with the dictates of the Second Law of Thermodynamics. Two fundamental policy criteria are established for world society: (1) maximization of the future horizon for mankind; and (2) satisfaction of basic quality-of-life requirements for all members of human society. An optimization principle for satisfaction of these criteria is derived from the interrelationships which are found to exist between three physical laws (Einstein's relativistic mass-energy law and the First and Second Laws of Thermodynamics), non-equilibrium thermodynamics (Ilya Prigogine's Theorem of Minimum Entropy Production as the defining condition for a steady-state system) and a cultural law (the Golden Rule). Policy based on the Minimization of Entropy Principle is presented as the optimal means for defining, achieving, and maintaining long-term steady-state systems both locally and globally. The Minimization of Entropy Principle is offerred as an ecologically suitable alternative to the "Invisible Hand" criterion upon which industrial culture is founded.

It is further shown that the "Golden Rule" shares identically the fundamental criterion of "reversibility" with the thermodynamic concept of equilibrium. This common criterion allows both concepts to be used as unambiguous, ideal standards for determining actual system effectiveness; one in terms of cultural behavior and the other in terms of physical behavior. Recognition of this relationship (which reflects the tendency of natural systems to seek optimal stability conditions in the most efficient manner) is advanced as a means for pragmatically achieving optimal steady-state solutions for cultural-physical systems; specifically:

1. Use the Minimization of Entropy Principle with respect to the equilibrium standard when making decisions that

essentially involve physical behavior.

2. Use the Principle of Cooperative Behavior with respect to the Golden Rule standard when making decisions that essentially involve cultural behavior.

The effects are identical: the minimization of system "friction"; or, conversely, the maximization of system "welfare". This cultural-physical relationship is suggested as the foundation for the comprehensive Cultural Physics that will be needed for mankind to make the transition to an optimal, long-term steady-state mode of existence.

These findings are embedded as policies in Forrester's World Dynamics model and used to demonstrate the conceptual feasibility of achieving truly long-term steady-state solutions satisfying desirable quality-of-life goals. In order to demonstrate the practical potential of the Minimization of Entropy Principle with respect to present problems, the principle is related to the concept of Thermodynamic Potential and advanced as a means of evaluating Total Energy Systems. This type of thermodynamic analysis provides immediate opportunity for both developed and underdeveloped societies to make significant and timely strides towards the type of technological base that is required for transition to a steady-state world system. Two application schemes are presented as examples which represent the range of both Total Energy System technology and analytical procedure.

1. A manually calculated decision tree analysis for a wind source Total Energy System emphasizing technology that can be utilized world-wide (often with indigenous labor and material resources) to satisfy isolated or small scale energy and other resource management needs.

2. A DYNAMO simulation model for a laser-fusion Total Energy System offering the ultimate range in energy resource technology for large scale, high quality needs.

The study is closed with a discussion of a topic warranting further research.

CHAPTER 1 FOOTNOTES

1. John McHale. The Ecological Context. New York: George Braziller, 1970, p. 94.

2. Paul R. Ehrlich and John P. Holdren. "Impact of Population Growth", in Herman E. Daly (ed.). Towards a Steady-State Economy. San Francisco: W.E. Freeman, 1973, p. 81.

3. ibid., p. 76.

4. For example, the Sumerians in 3000 B.C. John W. Bjerklie. "Engineering of Energy Effects with an Expanding World Population". Proceedings of the 5th Intersociety Energy Conversion Conference, Vol. I. Washington, D.C.: The American Chemical Society, 1970, p. 6-1.

5. This point is aggressively debated by many economists and geologists who argue that advancing technology and new discoveries will more than meet the challenges of decreasing reserves and increasing demand. See Hans Brems, Labor, Capital, and Growth. Lexington, Mass: Lexington Book co., 1973, p. 173. For a rebuttal emphasizing the enormous complications facing future resource procurement if present policies continue, see Dennis L. Meadows and Donella H. Meadows (eds.) Toward Global Equilibrium: Collected Papers. Cambridge, Mass: Wright-Allen Press, 1973, pps. 305-6.

6. William C. Gough. "Environmental Interrelationships", (draft) in the Environmental Engineer's Handbook. Philadelphia: Chilton Book Co., 1972, p. 33.

7. ibid.

8. Jay W. Forrester. World Dynamics, Cambridge, Mass: Wright-Allen Press, 1971; Donnella H. Meadows et. al. The Limits to Growth. New York: Universe Books/Potomac Associates, 1972; Dennis L. Meadows and Donnella H. Meadows (eds) Toward Global Equilibrium: Collected Papers, 1973; and Dennis L. Meadows et. al. Dynamics of Growth in a Finite World, 1974...both published by Wright-Allen Press.

9. Daly, op. cit., p. 153.

10. William Ophuls. "Leviathan or Oblivion?" Daly, op. cit., p. 233.

11. The main emphasis of the research reported in this study has been the use of thermodynamic concepts in defining and optimizing cultural and physical systems. In Thermodynamics there is an important distinction between equilibrium and steady-state (as will be discussed in detail later). The point to be made here is that usage (such as by Meadows) of equilibrium, dynamic equilibrium, and stationary-state are synonomous with the thermodynamic concept of steady-state.

12. Daly, op. cit., p. 155.

CHAPTER 2

MINIMIZATION OF ENTROPY

A. MIT World Dynamics Models

In 1970 the Systems Dynamics Group at MIT initiated development of a series of simulation models which attempt to holistically study the dynamics of world policy. The original model was developed by Jay W. Forrester using the Systems Dynamics methodology he had successfully applied earlier with respect to industrial and urban dynamics. Forrester's associate, Dennis L. Meadows, headed a program that made detailed investigations of various sectors of the world system which were then incorporated as refinements to Forrester's model. The refined models, however, essentially confirmed the conclusions of the original model.

The MIT models use DYNAMO computer simulation techniques to study the interaction between five important cultural activities: population, natural resource utilization, food production, industrial capital investment, and pollution. To simulate interaction of these variables, the models incorporate concepts derived from such disciplines as demography, economics, agriculture, industrial technology, and psychology via some 50 feedback modifier relationships influencing the differential rates that define the status of the five cultural activity levels.

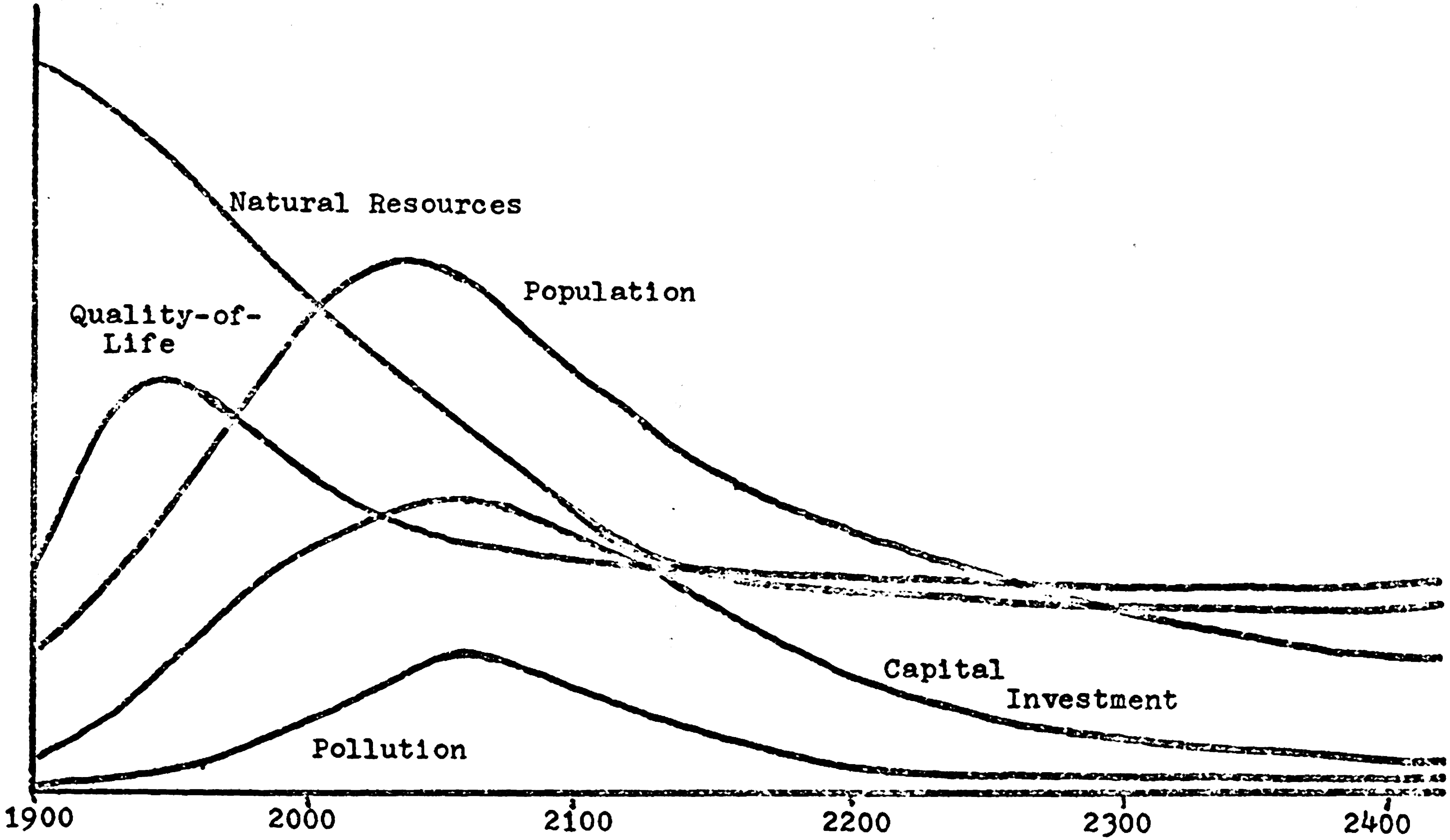


Figure 1. Projected Future Based on Present
World Policy Modes

Figure 1[14] is Forrester's interpretation of the policy mode being used by the present, industrially-oriented world system. The model projects the most probable future of the world system assuming present policies continue unchanged. Over the next few years capital investment and population rise exponentially, while natural resources drop steadily. This simulation depicts a classic case of a biological system overshooting the carrying capacity of its environment. As a consequence of this overshoot, the system rapidly brings about its own self-destruction. Additionally, the overshoot greatly reduces the carrying capacity of the environment for future generations. In the case of Figure 1, increasing pollution and declining resources undermine the ability to support population and capital investment after 2020. A steady-state condition is reached about the year 2200; however, this steady-state is characterized by low natural resource, population, capital investment, and quality-of-life levels. In particular, almost non-existent capital investment suggests a very primitive, food gathering culture; one totally vulnerable to natural misfortunes such as a long-term drought.

Figure 2[15] is a policy simulation Forrester used to demonstrate the conceptual feasibility of a high quality-of-life steady-state world system. In this simulation current world policies were changed as follows:

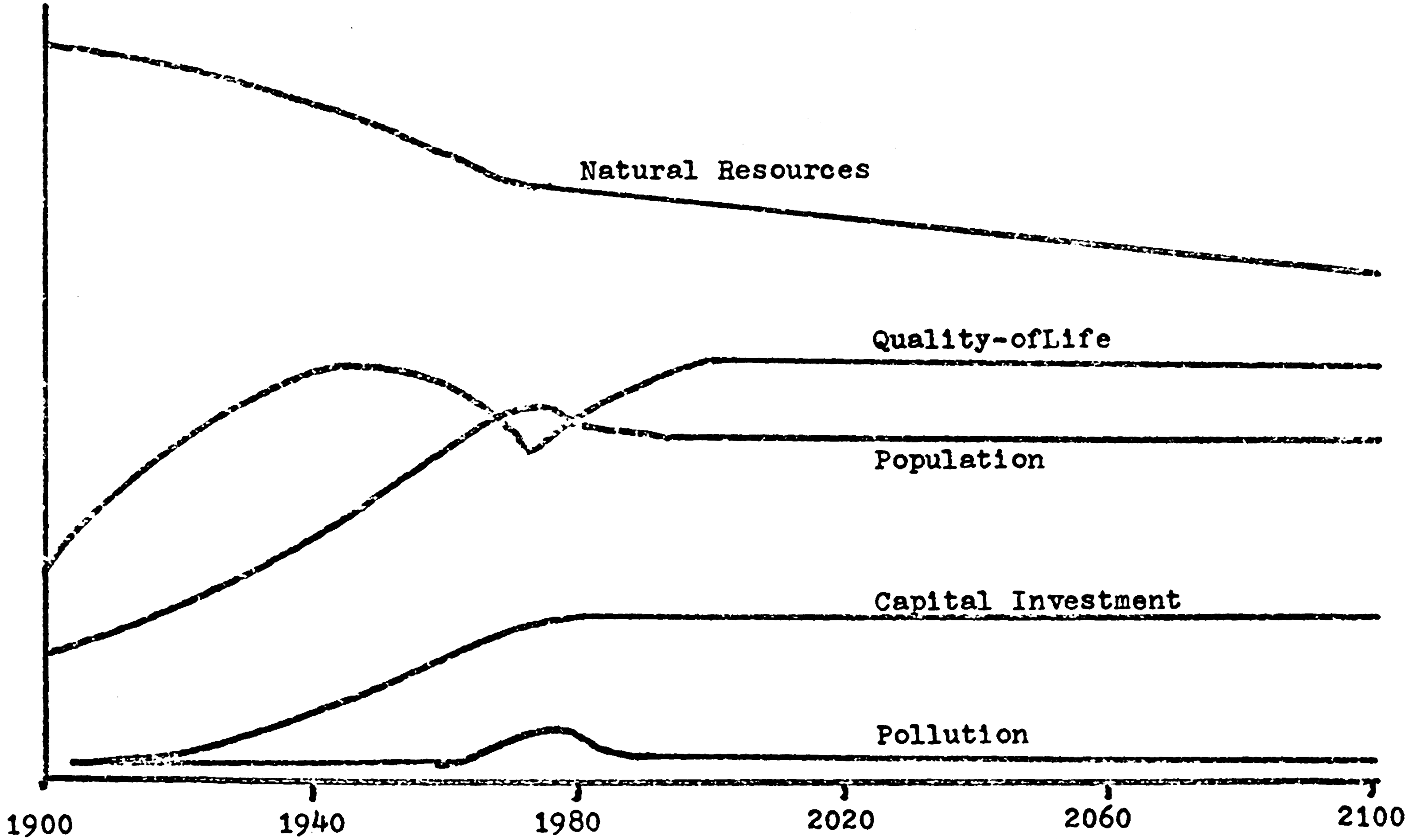


Figure 2. Projected Future Based on Forrester's
Hypothetical Steady-State Policies

Natural-resource-usage reduced 75%
Pollution generation reduced 50%
Capital investment generation reduced 40%
Food production reduced 20%
Birth rate reduced 30%

Figure 3 extends Forrester's "optimal steady-state" policy simulation beyond the year 2100 to the year 3000.[16] Around the year 2200 the steady-state is disrupted and the system begins a decline such that by 2700 there is essentially no technological base supporting human culture. In spite of the high quality-of-life of the small remaining population, such a culture would have difficulty maintaining itself indefinitely due to natural variations (such as climate-induced environmental changes) which would disrupt the delicate balance the low technology culture maintains with its local environment. Such changes would likely require adaptation to a nomadic culture of a significantly lower quality-of-life level. As mankind's history has demonstrated, this type of culture can only be improved via the use of technology which: (a) provides life support "savings" in terms of the ability to store food, materials and energy resources; and (b) allows a work "multiplier" which provides "time savings" needed to allow development of cultural support functions beyond those related to primitive subsistence. Thus, a paradox apparently exists in that:

1. Some minimum amount of technology is needed to allow human culture to evolve beyond the precarious stage of

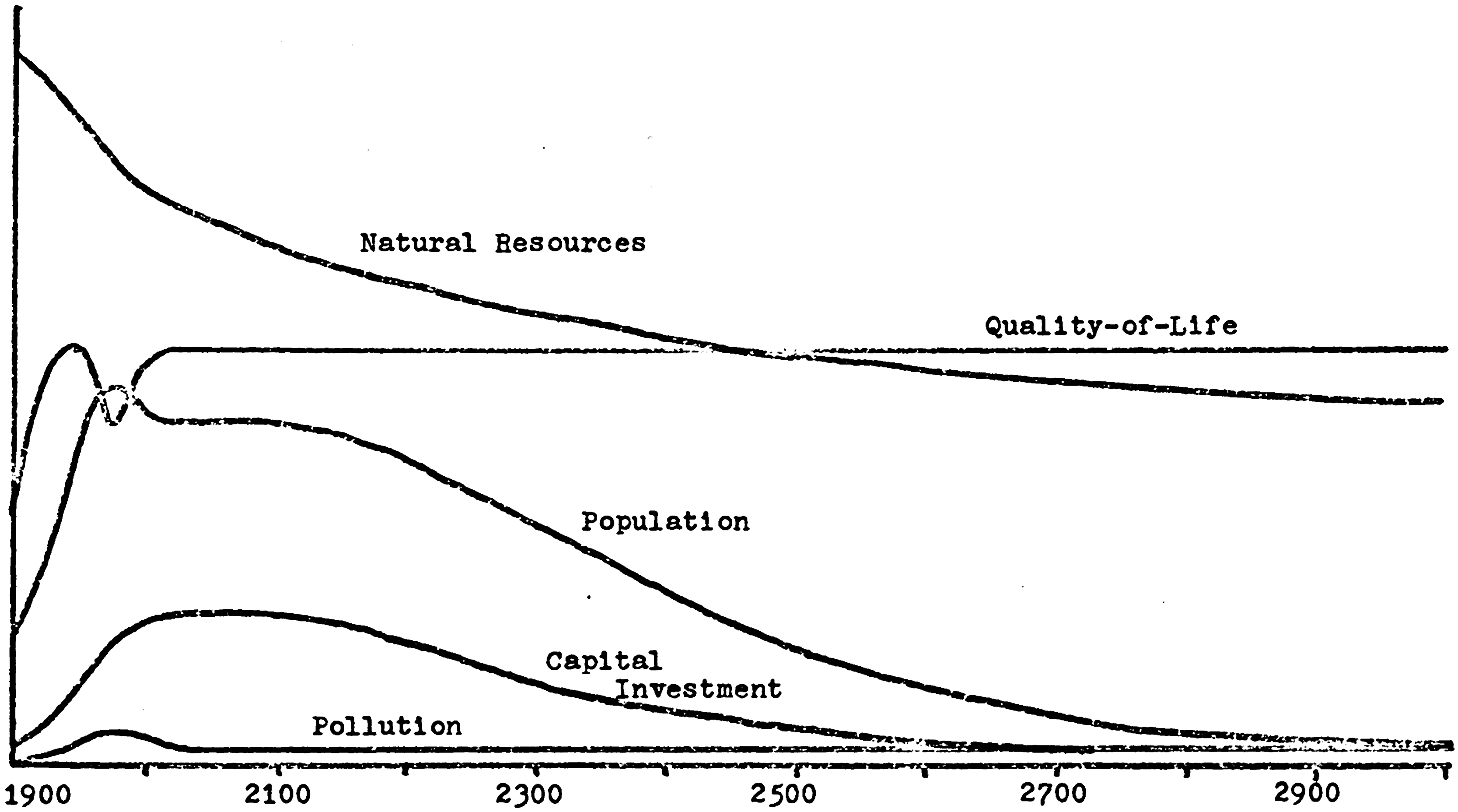


Figure 3. Long-Term Projection of Forrester's Steady-State Policy Solution

of primitive subsistence.

2. Unconstrained technological development, at least as characterized by modern industrialism, will ultimately cause an even more precarious future for mankind; one which may at best be equivalent to mankind's original primative culture.

B. Implications of the Second Law of Thermodynamics

The world system simulations illustrated in Figures 1 and 3 reflect classical interpretations of the Second Law of Thermodynamics:

1. Continuous and inevitable degradation of natural resource stocks into entropy (pollution).

2. Inevitable degradation of life support to a primitive level of subsistence and eventual extinction.

C. Fundamental Problems Facing Mankind

1. How to insure a satisfactory quality-of-life for the maximum number of future generations.

2. How to insure a satisfactory quality-of-life for all members of the current world population.

Thermodynamics in general, and the concept of entropy and the Second Law in particular, provide an essential foundation upon which to construct an understanding of answers to these problems.

D. Derivation of Maximum Future Horizon Policy Criterion

1. Subject to specified quality-of-life constraints and assuming a relatively finite resource base and a closed global system:[17]

"Original" Resources	=	"Unused" Resources	+	"Used" Resources

or,

"Constant" Total Resources	=	"Future" Potential	+	"Past" Consumption

thus,

Future	=	Constant	-	Past

The objective is to find a function which optimizes the "Future" while satisfying quality-of-life goals such as adequate food, shelter, health care, etc; all of which require some degree of "consumption."

2. Physical systems of all varieties, including human societies, can be characterized as thermodynamic systems. All physical activity (work) or potential activity (ability to do work) must obey the laws of thermodynamics, especially:

a. The First Law/Conservation Law: <u>Mass-energy can neither be created nor destroyed</u>; i.e., any production input drawn from the environment (natural resource depletion) must eventually return to the environment as an equivalent amount of entropic waste (pollution).

b. The Second Law/Entropy Law: The entropy of a closed system increases inevitably and irreversibly; i.e., every natural process uses resources in some manner that inherently has some unavoidable inefficiency that results in an increase in entropy somewhere in the system.

c. Einstein's Relativistic Mass-Energy Law:

$$E = mc^2 \qquad \text{where: } m = \frac{m_o}{\sqrt{1 - v^2/c^2}}$$

= relativistic mass
m_o = rest mass
c = speed of light
v = actual system speed
$\sqrt{1 - v^2/c^2}$ = relativistic correction factor

By the binomial expansion:[18]

$$E = m_o c^2 \left(1 + \frac{1}{2}\frac{v^2}{c^2} + \frac{3}{8}\frac{v^4}{c^4} + \ldots \right)$$

When[19] $v \ll c$, (i.e., for normal conditions of human ecology)

$$E = m_o c^2 + \frac{1}{2} m_o v^2$$

This expression suggests the following relationships:

Conserved Total Mass-Energy	=	Rest, Potential, Free, or Available Energy	+	"relative", Bound, Unavailable, or Kinetic Energy
	=	Negentropy	+	Entropy
	=	Thermodynamic Potential or Availability	+	Thermodynamic Degradation or Unavailability
Constant Total Resources	=	Valued, Usable, or Accessible Resources	+	Wasted, Unusable, or Inaccessible Resources

= Future Potential + Past Consumption

Total Existence[20] = Future + Past

Summarizing:

(....First Law....) (...........Second Law..............)

(.............Relativistic Mass-Energy Law..............)

These relationships provide a fully holistic foundation for the evaluation and understanding of any physical system.

3. If the global objective is to maximize the future horizon (subject to quality-of-life constraints):[21]

$$m_0 c^2 = E - \tfrac{1}{2} m_0 v^2$$

Future = Total Existence - Past

Future Potential = Constant Total Resources - Past Consumption

Negentropic Resources = " - Entropic Wastes

$$N = C - S$$

Taking derivatives with respect to time:

$$\frac{dN}{dt} = 0 - \frac{dS}{dt}$$

Multiplying both sides by (-1):[22]

$$-\frac{dN}{dt} = \frac{dS}{dt}$$

Integrating with respect to a time interval:

$$-\int \frac{dN}{dt}.dt = \int \frac{dS}{dt}.dt$$

For microscopic phenomena:

$$- \delta N = \delta S$$

For macroscopic phenomena (employing the principle of induction):

$$- \Delta N = \Delta S$$

Thus, a decrease in "N" leads to a commensurate increase in "S". Since time (dt) is ever-on-going (irreversible), maximization of "N" (Future Potential or the Future) requires the minimization of "S" (Past Consumption), which in turn requires minimization of the entropy production rate (dS/dt).

In determining policy for the long-term future it is first necessary to establish a planning horizon: 100 years, 1000 years, 1,000,000 years, etc. This horizon then determines the entropy rate that must be controlled to achieve that horizon. The more distant the horizon, the lower the entropy rate.[23]

If one assumes that the only rational horizon (with respect to current society's trusteeship towards future generations) is the maximum attainable, then the entropy rate must be the minimum attainable. As a consequence, <u>minimization of entropy increase</u> becomes the fundamental policy criterion for achieving the maximum longevity for humanity. In turn, however, the minimum entropy rate is constrained by the concept of "quality-of-life" ... which reflects some degree of need to use resources to support life. Industrial culture has defined "quality-of-life" in highly entropic terms. Steady-state culture must re-define "quality-of-life" such that it can be satisfied under low entropy conditions.

E. Derivation of an Optimal Welfare Policy Criterion

The objective of the following derivation is the identification of a policy criterion which enables an individual to readily make decisions in a complex, information-deficient environment in a manner that contributes to: (a) the optimal welfare of the individual decision-maker, (b) the optimal welfare of the total society, and (c) the maximum horizon for future generations.

1. The Invisible Hand

Recognition that even the most mundane social and technical decisions involve an infinite variety of potential complications led Adam Smith to formulate the concept of the "Invisible Hand" (currently in vogue as "Rational Selfishness"). The Invisible Hand concept assumes that overall system welfare is maximized when each individual attempts independently to maximize his own self-interest without regard for the impact of his actions on others. Indeed, a corollary to the concept implies that the system (and by association, the individual) will actually suffer as the result of altruistic behavior.[24] While the Invisible Hand was readily adopted by laissez-faire capitalism, Smith actually attempted to define a reasonable decision criterion for the average person who was increasingly challenged by the growing complexity of capitalist culture. While seldom publicly expounded as a policy criterion (Ayn Rand and Alan Greenspan are exceptions)[25], the Invisible Hand is easily detected in western culture.

2. Feedback Mechanisms in Dynamic Systems

Systems Dynamics provides a useful vehicle for understanding the inherent invalidity of the Invisible Hand and related policy criteria. Systems Dynamics is an analytical method that concentrates on understanding the feedback mechanisms that determine the state of a system over time. Each system variable (such as the individual decision-maker) possesses positive and negative feedback relationships with respect to all other system variables.[26] Positive feedback mechanisms are growth-generating functions. Because of the Conservation Law (First Law) an addition to one component of a system must be accounted for by a decrease in another component. Because of the Entropy Law (Second Law) such transactions have some degree of inherent inefficiency (irreversibility, which is reflected as "friction" loss or "cost" of making the transaction) which tends to increase at a rate greater than the actual transaction rate. In thermodynamic terms this inefficiency is reflected as an unavoidable increase in entropy (pollution) in the world system. Since the general consequence of the Invisible Hand policy criterion is the attempt by each practicing individual to maximize his consumption or accumulation, the criterion creates a highly entropic positive feedback mechanism that tends to cause the system to overshoot the carrying capacity of the system. When this growth overtakes the system constraints (as illustrated in Figure 1), the overgrown system collapses back to some primitive steady-state level. During this degradation, individual welfare falls in direct proportion to the decay of the system. Further, world-wide experience indicate that the welfare of most individuals is not satisfied even in the growth phase of the cycle.

In contrast to the inherently unstable positive feedback mechanism, negative feedback loops are stabilizing functions. A negative feedback mechanism attempts to suppress deviations from the stable mode of the system. A steady-state is essentially defined when the positive and negative mechanisms are in balance, thus allowing a relatively constant value to be maintained for the system activity levels (such as population).[27]

3. Prigogine's Theorem of Minimum Entropy Production

In 1945 Ilya Prigogine presented the Theorem of Minimum Entropy Production as the defining condition for a steady-state with respect to specified constraints in the linear region near thermodynamic equilibrium. In recent years his theorem has been extended to all thermodynamic phenomena, including open biological systems.[28] I.W. Richardson further demonstrated that achievement of a macroscopic steady-state must result from a process in which subsystems first achieve steady-state configurations with respect to their local environments.[29]

Before proceeding to the final stage of this derivation, it may be helpful to summarize the points made thus far:

a. The Principle of Minimization of Entropy is the governing policy criterion for maximizing the long-term future for human culture.

b. Both individual (local) and system (global) welfare are ultimately degraded by the action of unchecked, growth-oriented policy (such as the Invisible Hand), since such policy creates an inherently unstable positive feedback mechanism that endangers the entire world system.

c. Negative feedback phenomena are required to stabilize a system. If the negative feedback can neutralize the positive feedback a steady-state is achieved, at least temporarily. However, negative feedback mechanisms (death, for example) are not inherently beneficial to the individual.

d. Prigogine's Theorem of Minimum Entropy Production is recognized as the necessary and sufficient condition for a long-term (stable) steady-state system for all varieties of thermodynamic phenomena, including living systems. Also, achievement of a global steady-state is a hierarchical process that must begin with the achievement of micro steady-state conditions ... starting with the individual.[30]

Thus a potential paradox exists in achieving an optimal steady-state world system. The macro steady-state is required for the optimal welfare of all members of the world system, but it cannot be achieved except as the culmination of achievement of local steady-state conditions by at least a statistically significant proportion of all subsystems, starting at the individual level.

In order for the individual to optimize his welfare, the system must function so that it both provides for his quality-of-life needs and protects him from entropic exposure. Since it appears unlikely that such a system can be established by fiat from above (as by a central world authority), a mechanism is required that can develop the steady-state world system starting from the local level upwards. Cooperative effort is the required criterion for this mechanism. The <u>Principle of Cooperative Behavior</u>

assures efficient satisfaction of essential needs and it also insures minimization of cultural "friction" or entropy and is therefore presented as the fundamental criterion for defining optimal welfare policy. The Principle of Cooperative Behavior, as will be demonstrated below, is directly related to the Principle of Minimization of Entropy. To quote Meadows:[31]

> We are convinced that realization of the quantitative restraints of the world environment and of the tragic consequences of an overshoot is essential to the initiation of new forms of thinking that will lead to a fundamental revision of human behavior and by implication, of the entire fabric of present-day society.

F. The Golden Rule and Thermodynamic Equilibrium

Kurt Baier has identified the fundamental mechanism of the Golden Rule to be "reversibility" ... by which he means that the "behavior in question must be acceptable to a person whether he is at the 'giving' or 'receiving' end of it".[32] There is a striking similarity between Baier's interpretation of the Golden Rule and the thermodynamic concept of equilibrium. The defining condition for thermodynamic equilibrium is also "reversibility" ... i.e., that a transaction from one state to another is completely frictionless ... its thermodynamic potential is conserved throughout the transaction and, as a consequence of this conservation (which represents perfect efficiency), the system could reverse itself and return to its original state without additional investment of energy. Such a perfect system could do useful work as it changed from one state to another ... and could continue to do so indefinitely (i.e., a perpetual motion machine).

The condition linking moral "reversibility" and thermodynamic "reversibility" is the total absence of "friction" in the dynamic behavior of the system. Friction is essentially a measure of transaction efficiency and is accounted for in thermodynamics by the concept of entropy. The Second Law of Thermodynamics implies there are no perfect systems in nature ... that each and every transaction has an inherent inefficiency that increases the entropy of its associated system. This inefficiency or entropy manifests itself as some form of "wasted" resource or opportunity (pollution). The Social Sciences do not have a similar concept, but the manifestations of "cultural friction" or "cultural entropy" are clearly evident in every aspect of social behavior.

It is further noted that thermodynamic equilibrium is an ideal state ... one not actually achieved in nature. Yet the concept is used daily in virtually every professional-level thermodynamic analysis as an ideal, unambiguous standard against which an actual thermodynamic design or performance can be compared. Importantly, thermodynamic equilibrium's ideal character has in no way reduced its value for practical action; rather, without such a "perfect" standard it would be difficult, if not impossible, to obtain useful assessments of alternative schemes for thermodynamic systems.

Similarly, the Golden Rule can be interpreted as an ideal standard for the evaluation of cultural performance. As in the case of its thermodynamic counterpart, there is no loss of value in the fact of its strictly ideal character; rather, without such a clearly defined, unsurpassable standard there could only be a purely arbitrary basis for evaluating alternative cultural behavior modes. Curiously, in contrast to the experience in thermodynamics, the meager amount of literature analyzing the Golden Rule largely criticizes -- and sometimes rejects the entire concept -- because of its ideal character.

These two ideal standards, thermodynamic equilibrium and the Golden Rule, are argued to be the physical and the cultural formulations of the same natural law: The Goal of Maximum Stability.[33] A thermodynamic state becomes more stable as it approaches equilibrium; while a cultural system's stability is directly dependent on the degree that it approaches Golden Rule perfection. In each case the system's success in approaching the maximum effectiveness of the ideal standard is measured by the degree to which it is able to minimize "friction". Significantly, thermodynamic equilibrium is defined when the production of entropy is not only minimal but is also of absolute zero value.[34] Recognition that such optimization requires cooperative rather than competitive behavior was the subject of a recent interdisciplinary symposium report titled: Synergetics: Cooperative Phenomena in Multicomponent Systems.[35]

G. Application of Steady-State Stability Criteria

In practical application, the individual decision-maker may use:

1. The Principle of Minimization of Entropy to determine the proper course of action when dealing with essentially physical aspects of his system. His thermodynamic analysis compares and rates each alternative against the ideal equilibrium standard.

2. The Principle of Cooperative Behavior to determine the proper course of action when dealing with essentially cultural aspects of his system. His behavioral analysis evaluates each alternative with respect to the ideal Golden Rule standard.

There is an obvious disparity in the practical application of the two principles. There are readily identifiable units and means of measure available in thermodynamics; since, in comparison to cultural systems, physical systems are, in actuality, relatively simple. Measurement of cultural behavior is a most difficult problem; yet Kurt Baier suggests a solution when he emphasizes: "Anyone who engages in non reversible behavior is doing something wrong..."[36] In support of Baier's point it must be recognized that man's intuitive power -- when uncluttered by intellectual entropy -- is infinitely more powerful than present mechanistic analytical tools.[37] Thus, it is argued that the decision-maker who subscribes to the Golden Rule can, in fact, evaluate the most complex behavioral problems by concentrating on understanding the ramifications or "costs" of irreversibilities identified in various alternatives. Man is fully capable of looking beyond the potential short term gains of irreversible behavior and seeing how feedback mechanisms will ultimately work against him. Thus, men can form an increasingly cooperative culture in which the actual difficulty of behavioral decision-making will be greatly reduced.

The use of irreversibility as a criterion of inherent inadequacy of a system's behavior can be readily applied also to physical system evaluation. For example: when an industry complains that it cannot afford to prevent serious pollution (as in the case of toxic by-products, poor design, poor durability or maintainability, or incompatibility with other system elements), the analyst (and society in general) must take this reaction as likely identification of even more critical problems such as basic inappropriateness of the industry, its products, its methods, or location. In this manner it will be possible to track problems to their sources rather than being limited (as at present) to trying to patch up their impact. Such corrective, entropy minimizing policy (which must be cooperative to succeed) is essential to effective and timely transition to a steady-state world system.

CHAPTER 2 FOOTNOTES

13. Aurelio Peccei. The Chasm Ahead. London: Macmillan, 1969.

14. ibid.

15. ibid., p 120. While his results infer a long-term steady-state solution, Forrester comments on the long-term prospect of this simulation as follows: "Resources are still declining slowly and in time will depress the system unless there is sufficient recycling of waste products and substitution of less critical materials."

16. As Forrester and Meadows stressed, no absolute interpretations should be given dates or variable magnitudes. The models are highly aggregated in order to study basic global dynamic phenomena. Only relative interpretations with respect to basic system structure and variable interaction can be made. The horizon year 3000 is chosen as adequate to test long-term effects of a policy mode. A 1000 year projection may seem excessive in terms of our normal planning horizons, but it is hardly an excessive horizon for the future potential of the human race. This is perhaps the most urgent message resulting from the Limits to Growth research efforts.

17. An isolated system allows no mass or energy transfer across its boundaries - a thermos bottle, for example; an open system, such as biological systems, allows both mass and energy transfer; a closed system allows energy transfer but not mass transfer. In the present case, the earth receives solar energy and radiates long wavelength radiation into space, but with few exceptions (such as meteorites and space vehicles) there is no mass transfer.

18. H.R. Hulme. Nuclear Fusion. London: Wykeham, 1969, p. 3.

19. E.A. Guggenheim. "Five Tenuously Related Questions", in E.B. Stuart, B. Gal-Or, A.J. Brainard (eds.). A Critical Review of Thermodynamics. Baltimore: Mono Book Co. 1970, pps. 211-215. "...the formula of special relativity reduces to the pre-relativistic classical formulae (for conservation of mass-energy) when the ratio of every speed (v) to the speed of light (c) is negligible. The terms which become negligible are called relativistic corrections."

20. The argument implying total existence to be constant is obviously difficult to support; yet it is the fundamental interpretation of much of Eastern philosophy, especially Buddhism. Additionally, the Book of Genesis might be interpreted in a similar manner; i.e., the duration of earthly existence between divine creation and destruction is pre-ordained, thus a "constant" value. On this point it is interesting to note the compatibility between the Second Law and the Book of Genesis. For a detailed discussion, see Henry M. Morris. Biblical Cosmology and Modern Science. Grand Rapids, Mich: Baker Book Co., 1970. Eastern philossphy seems less influenced by the entropy concept, yet it is clearly evident in Japenese Buddhism. Lewis R. Lancaster in Philosophy East and West, April 1974, pps. 209-214.

21. One of the several thermodynamic forms of this derivation is $A = E - TS$, where (A) is the thermodynamic potential or availability; (E) is the original energy content of the closed system (a conserved or constant value); (S) is the entropy; and (T) is the system base temperature ... taken as constant and equal to unity in the case of the world system.

22. This inversion is made in order to show consumption of resources as a negative function. The conclusion of this derivation is supported for all cases of physical phenomena, starting with the infinitesimal case, by a derivation from Hamiltonian physics using the principle of least action. Robert B. Lindsay and Henry Margenau. Foundations of Physics. New York: Dover, 1957, pps. 120-141.

23. D.H. Meadows.(op. cit., p. 177) infers a similar conclusion: "How long should the equilibrium state exist? The longer a society prefers to maintain the state of equilibrium, the lower the rates and levels must be."

24. Smith's argument (which was intended for the market place ... but was subsequently adapted to cultural activity in general) was that the resulting maximum competitive effort would eliminate the marginal members of an activity through a mechanism similar to what would later be known as "survival of the fittest". This struggle would force each member to eventually find his optimal position in the system. Smith's assumption was that the system's welfare would be maximized when all members were performing functions for which they were optimally qualified. Since such a system would maximize production Smith assumed that the respective "shares" of production wealth returned to individuals would be maximized.

25. Allan J. Mayer et al. "Greenspan - Atlas Jogs." Newsweek, Feb. 24, 1975, pps. 60-61.

26. A real system essentially is influenced by an infinite number of feedback mechanisms or degrees of freedom. However, even in DYNAMO simulation - which is particularly free of mathematical limitations - the analyst must drastically reduce the real system to some finite (usually small) number of variables. A major problem in Systems Dynamics is that the analyst can never be certain that the variable relationships he neglects may be critical to his analysis. Interestingly, the entropy concept has been developed in information theory and decision theory as perhaps the most effective means for dealing with this problem. E.T. Jaynes. "Information Theory and Statistical Mechanics." Physical Review, vol. 106, 1957, pps. 620-630.

27. A stable steady-state in thermodynamics is defined when all positive and negative feedback rates related to a particular activity level equalize each other, thus allowing the activity level to be constant over an indefinitely long period of time. This time independent stability requires the minimization of entropy production; or, alternatively, minimization of positive feedback mechanisms. An unstable steady-state is one in which the positive-negative feedback rates are only temporarily in balance. In such systems a minor perturbation can cause an instability leading the system either to a higher or a lower steady-state level. Maintenance of any higher level steady-state will require ever greater resource throughput, thus hastening ultimate degradation of the system to a primative steady-state level.

28. F. Schlögl. "On the Statistical Foundation of the Thermodynamic Evolution Criterion of Glansdorff and Prigogine." Annals of Physics, vol. 45, 1967, pps. 155-163. Ralph J. Tykodi. Thermodynamics of Steady-States. New York: Macmillan, 1967, pps. 170-174. W. Peier and A. Thellung. "On a Microscopic Foundation of the Principle of Minimum Entropy Production." Physica, vol. 46, 1970, pps. 577-586. See Bibliography for references to Prigogine's work.

29. I.W. Richardson. "On the Principle of Minimum Entropy Production." Biophysical Journal, vol. 9, 1967, pps. 266-7. This observation is of considerable practical importance in global analysis since it allows simple summation of component entropies to approximate the global entropy. Prigogine has observed in chemical systems that the state of minimum entropy production is established much sooner in the subsystems than in the total system. Ilya Prigogine. in Jiri Zeman (ed.). Time in Science and Philosophy. New York: Elsevier, 1971, p. 96.

30. Because entropy is a strict summative concept, once it is generated at the micro level it must be fully accounted for as a contribution to the macro level (i.e., entropy cannot be destroyed, only its rate of production can be managed). Thus, to minimize entropy at the global level requires minimization of entropy at all lower levels. As Richardson notes, this type of optimization would require an infinite central control capacity if it were dependent on management from any level but the micro level. ibid.

31. D.H. Meadows. op. cit. p. 194.

32. Kurt Baier. The Moral Point of View. New York: Random House, 1965, p. 108.

33. This goal is implied in both the Second Law and in the Principle of Least Action; i.e., a system left to itself will seek maximum stability in the most efficient or least costly manner.

34. $dS/dt = 0$ for equilibrium; while for a steady-state, dS/dt is a minimum value with respect to some set of system constraints (which restrain the system from reaching equilibrium). Prigogine has formulated an important extension of this concept for subsystems; but acknowledges that ultimately (in the case of the cosmic system) the classical definitions hold. P. Glansdorff and I. Prigogine. Thermodynamic Theory of Structure, Stability and Fluctuations. New York: John Wiley, 1971, p. 288. "...for all these various situations, the Second Law of Thermodynamics still remains valid."

35. H. Haken (ed.). Synergetics: Cooperative Phenomena in Multi-Component Systems. Stuttgart, Germany: B.G. Teubner, 1973. Symposium examples range from lasers (Haken) to biology (Prigogine) to social systems (Weidlick).

36. Baier. op. cit. As is discussed in Appendix A, it is curious that the Golden Rule should be so universally recognized as the fundamental law governing cultural behavior, yet at the same time be so widely neglected. M.S. Forbes. "Universal Truth Universally Unfollowed", Forbes, 1 February 1975, editorial page. It is possible that this paradox stems from the realization by most individuals and groups that they really do not understand how their lives are governed by the dynamics of the world system and as a consequence tend to concentrate myopically on their own short-term prospects using decision criteria similar to the

Invisible Hand. As D.H. Meadows (op. cit., p. 196) has observed: "Our present situation is so complex and is so much a reflection of man's multiple activities, that no combination of purely technical, economic, or legal measures and devices can bring substantial improvement." Also: "Only real comprehension of the human condition at this turning point in history can provide sufficient motivation for people to accept the individual sacrifices and changes in political and economic power structures required to reach an equilibrium state." ibid., p. 198.

37. Jay W. Forrester has based much of his Systems Dynamics concept on the need to use computer simulation as a means for dealing with problems of counter-intuitive behavior in managing large, dynamic systems. It is argued here that modern culture's emphasis on mechanical analysis has stunted man's inherent intuitive analytical power. As a practical matter, unless all of mankind can be pulled together under a common minimization of entropy ethic using a communications vehicle similar to de Chardin's concept of the "noosphere" there is little likelihood of reaching the long-term steady-state or avoiding the catastrophic overshoot being identified by the World Dynamics models. In short, those who would rely on solutions from central authorities must redirect their attention toward policies which provide stability and purpose-in-life at the micro level. Minimization of Entropy policies are not counter-intuitive.

CHAPTER 3

STEADY-STATE WORLD SYSTEM

A. World Dynamics Minimization of Entropy Model

The Principle of Minimization of Entropy was embedded as a modification to Forrester's World Dynamics model in order to test the conceptual feasibility of obtaining long-term steady-state solutions for the world system. Figure 4 illustrates operation of the optimal policy model until the year 3000. (Appendix B contains the computer listing for this model plus the fourteen policy tables used as the basis for the optimization procedure.) When compared to Figure 3 it is clear that a significant improvement in the long-term stability of the world system has been achieved. The system hypothesized in Figure 4 is assured at least 1000 years of high quality-of-life, steady-state performance. The modeling actions underlying this achievement are summarized as follows:

1. Forrester's model was initially tested for various policy alternatives without changing the basic structure of his model. Sensitivity analysis found his model to be critically influenced by the totally irreversible character of the natural resource sector. This characteristic was found to be responsible for the relatively rapid degradation of even the most hopeful policy alternatives. No alternative

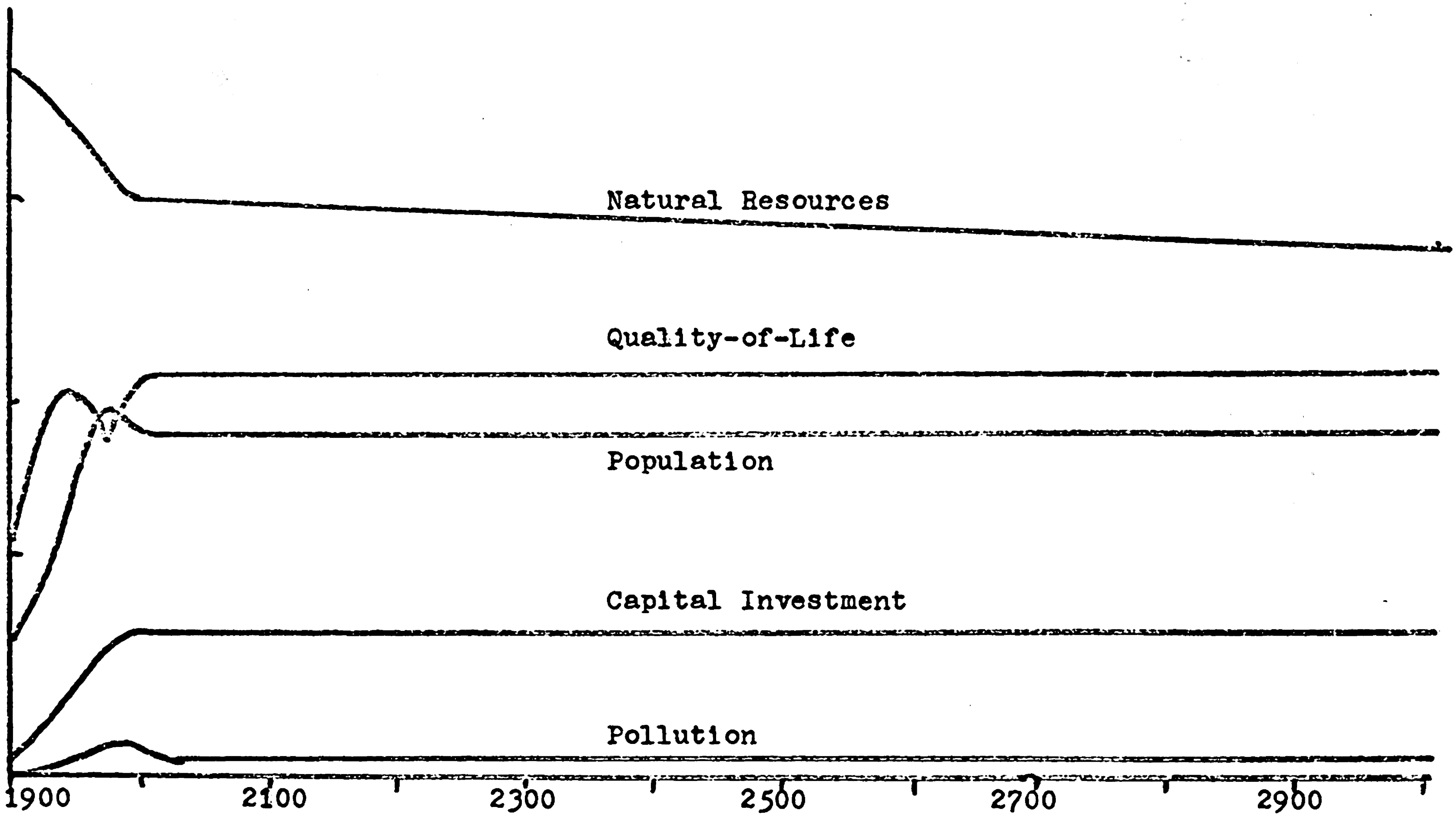


Figure 4. Long-Term Steady-State World System Resulting from use of Entropy Minimizing Policies

policy set could be found that performed better than the policies illustrated in Figures 2 and 3. As a consequence of the sensitivity analysis, the natural resource sector was modified to allow feedback of a small proportion of the natural resources used. This modification allowed significant improvement in the long-term performance of the model. The conclusion can be drawn that some degree of natural resource recovery (by recycling or cascading) is essential in achieving steady-state solutions for the world system.

2. The World Dynamics model was next investigated using FORTRAN rather than MIT's DYNAMO simulation language. Use of FORTRAN made it possible to incorporate into the model an optimization technique known as Goal Programming.[39] Goal Programming is a particularly attractive technique in that it allows rational decision-making with respect to a complex set of unlike, often conflicting, goals and constraints. Thus, it is better suited for real world decision-making than the conventional, single objective optimization techniques normally used in systems analysis. However, Goal Programming is essentially an extension of the Simplex method of linear programming and, therefore, is not ideally suited for the World Dynamics model (in which the variables all have non-linear relationships). The main reason, however, for rejecting the use of Goal Programming and other standard optimization techniques is that they all are es-

entially "one-shot" methods; i.e., the condition of the system is evaluated and all decision variables are changed to the optimum solution in one time instant. Since the real world does not function in such a manner, it was decided to return to the DYNAMO modeling system and develop an optimization procedure using the continuous feedback mechanisms which reflect real world operation.

3. Early simulations with the World Dynamics model using minimization of entropy policy indicated the conceptual feasibility of achieving optimal, long-term steady-state solutions. Specifically, if all members of the world population were to simultaneously subscribe to Minimization of Entropy policy criteria there could be a rapid (virtually instantaneous) transition to the optimum steady-state world system. Recognizing, however, that the majority of the world's population experience a low quality-of-life existence that may inhibit their ability to respond to the promise of policies radically different from those presently in force,[40] it was deemed necessary to introduce a feedback mechanism that would reflect the tendency of threatened classes of persons to act in a manner that attempts to relieve their immediate hardship, but which (in "vicious circle" fashion") further undermines their ability to survive. Conversely, once the quality-of-life goals are satisfied, it is assumed there will be increasing motiva-

tion to use Minimization of Entropy policy. A representative quality-of-life policy feedback table is illustrated as Figure 5a for the birth rate sector. When quality-of-life goals (defined arbitrarily as unity) are met the individual decision-maker follows a policy that attempts to maintain birth rate at a level which insures the optimal steady-state mode for the world system. If the quality-of-life goes up, the decision-maker tends to further constrain his birth rate policy in order to minimize the entropy that is, in some degree, inherent in quality-of-life levels. In order to insure propagation of the race at a desired population level, the minimum birth rate policy is approached asymptotically. However, if quality-of-life goes down, the affected decision-maker responds by sharply increasing his birth rate policy -- apparently out of instinctive fear for survival.[41] A consequence of this type of policy table is that a steady-state world system cannot be expected until quality-of-life at the micro level achieves some essential level of satisfaction. Meadows reaches a similar conclusion:[42]

> We recognize that world equilibrium can become a reality only if the lot of the so-called developing countries is substantially improved, both in absolute terms and relative to the economically developed nations, and we affirm that this improvement can be achieved only through global strategy.

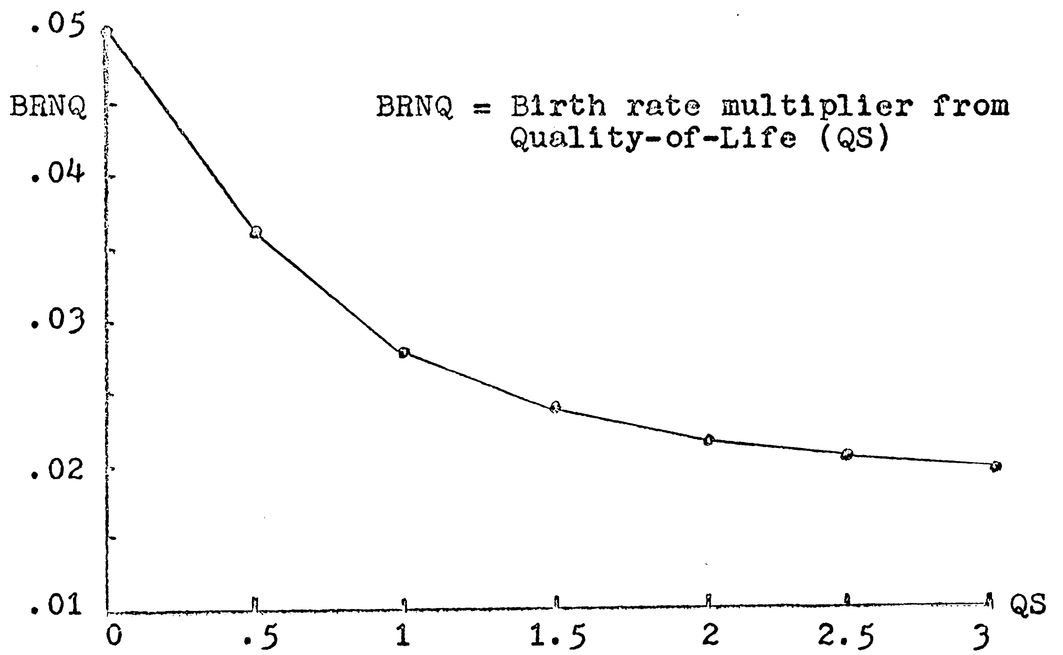


Figure 5a. Quality-of-Life Policy Tables

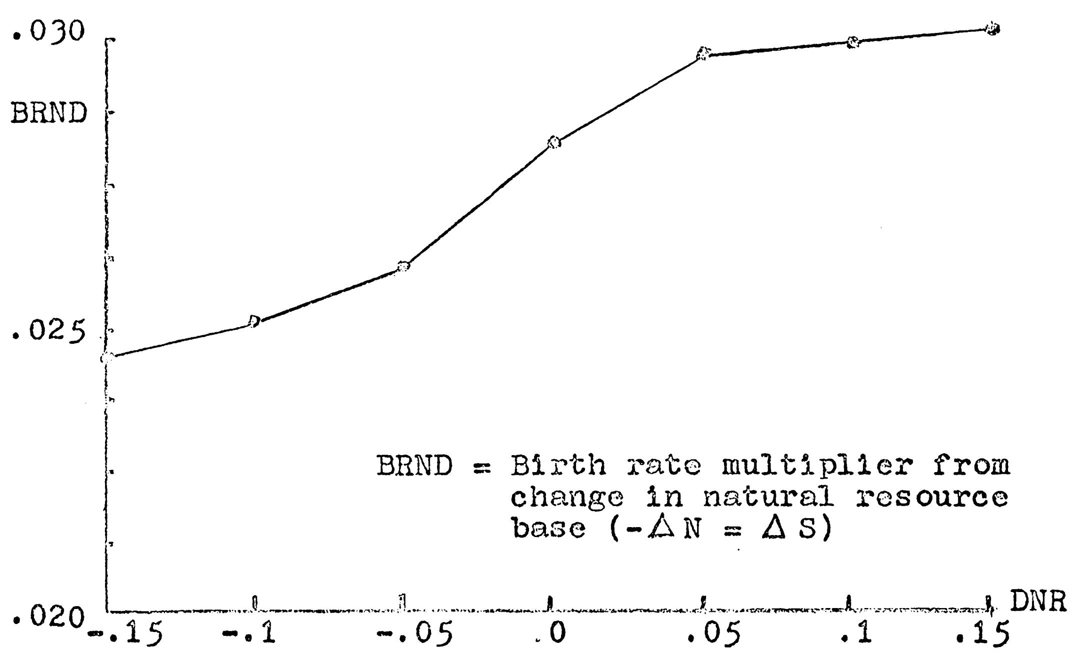


Figure 5b. Minimum Entropy Policy Table

4. Figure 5b illustrates the associated minimization of entropy policy table for the birth rate sector. The governing mechanism for this type of table is the rate of change in the natural resource base. If the rate of change approaches zero the birth rate policy is maintained at a level which insures the optimal steady-state mode. If the rate is negative (i.e., the rate of resource depletion is increasing) policies are encouraged which reduce birth rate. Conversely, in the event that the rate of resource regeneration actually exceeds the rate of usage (i.e., stockpiling of recycled materials), birth rate policies may be allowed to increase in order to adjust to the increased level of "stocks" or "carrying capacity" of the system.[43] As in the case of the original MIT models, these tables are intended to reflect only the physical implications of cultural activity.

5. Various sensitivity analyses were made with respect to the World Dynamics Entropy Minimization model. Of particular interest are the following observations:

a. The model is sensitive to less-than-full optimization policies. Figure 6 is an aggregated representation of seven simulation runs in which various combinations of six out of seven policy variables are optimized using minimization of entropy criteria, while the seventh retains Forrester's original criterion. The conclusion drawn is

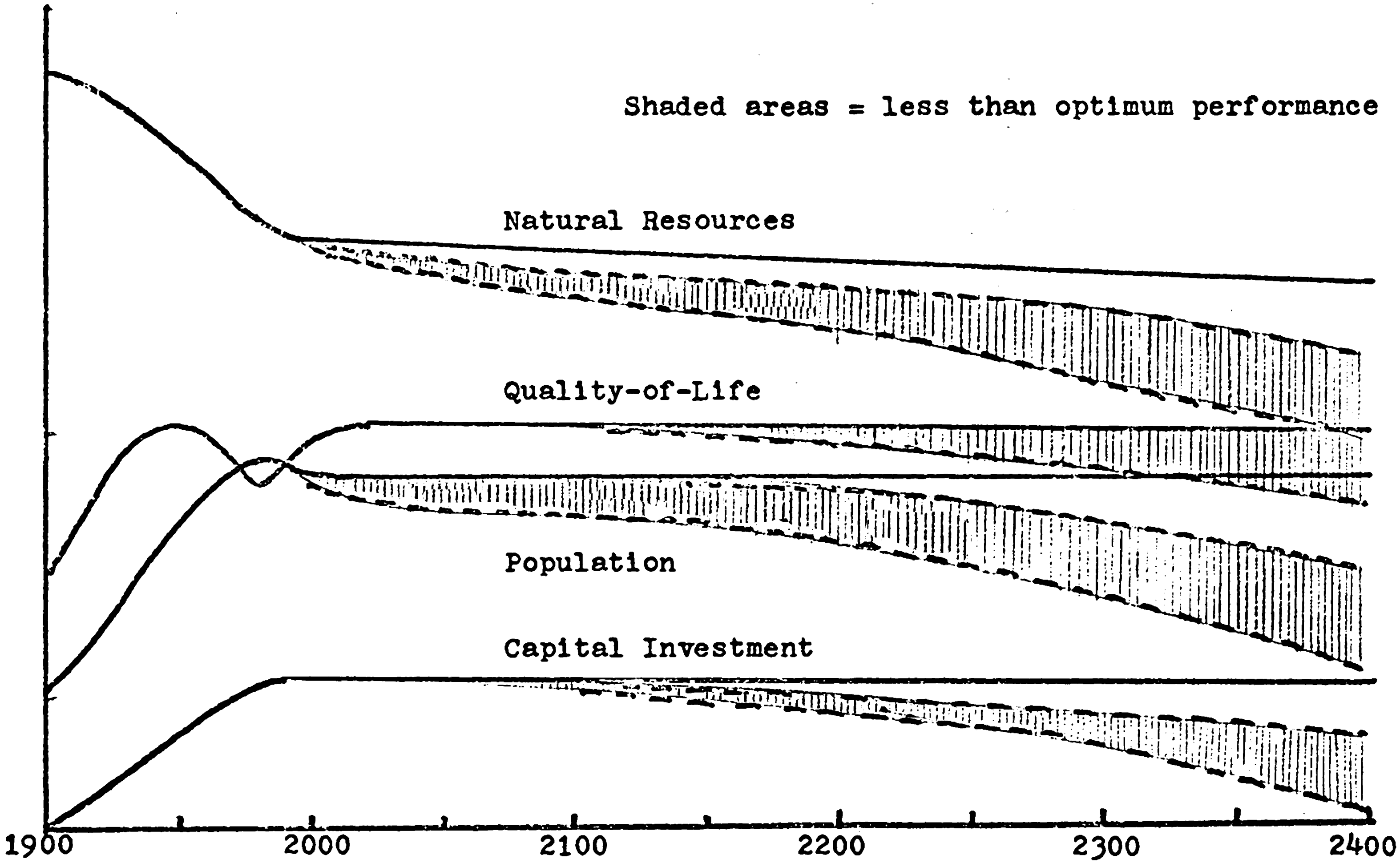


Figure 6. Sensitivity to less-than-holistic Application of Minimization of Entropy Policies.

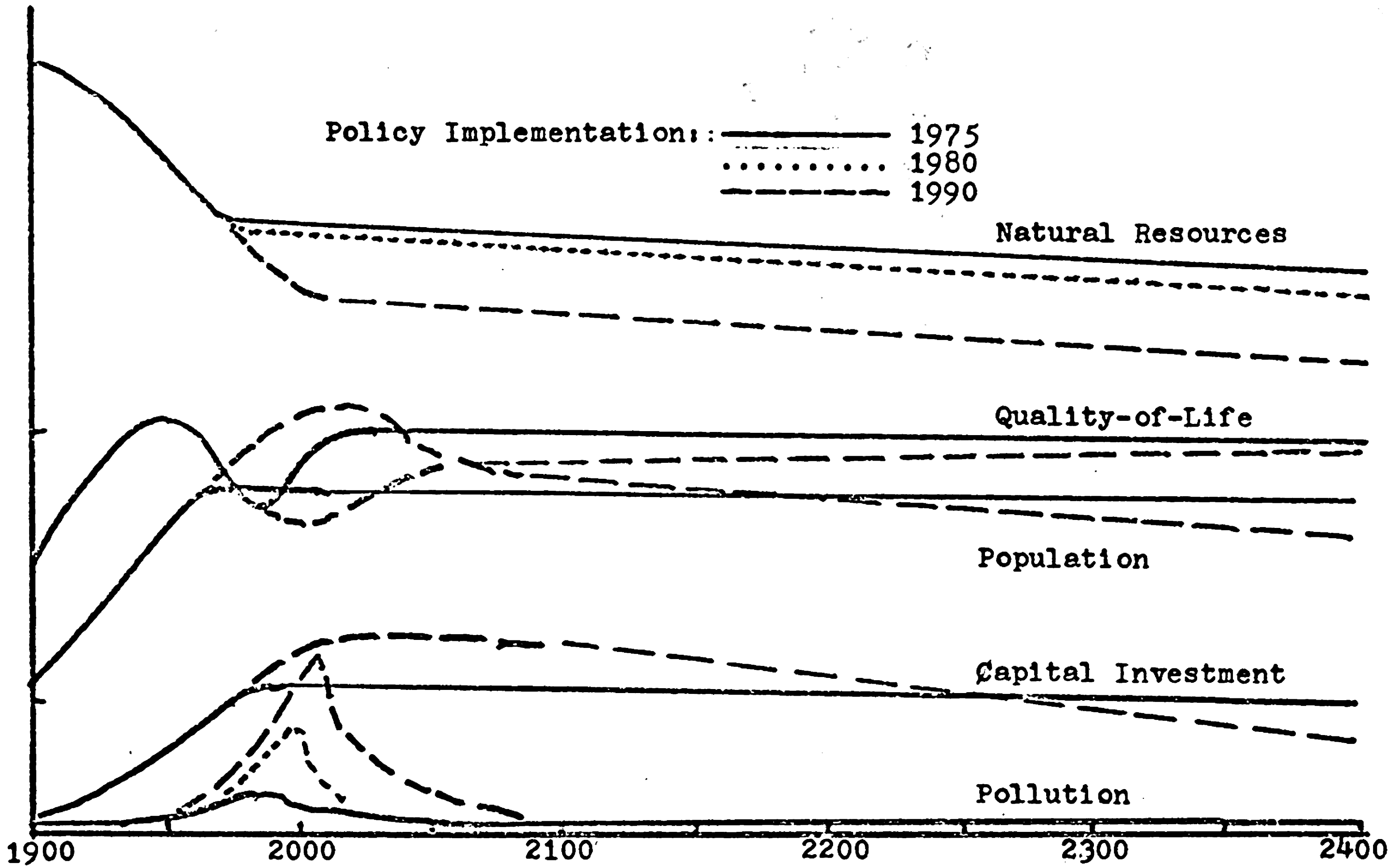
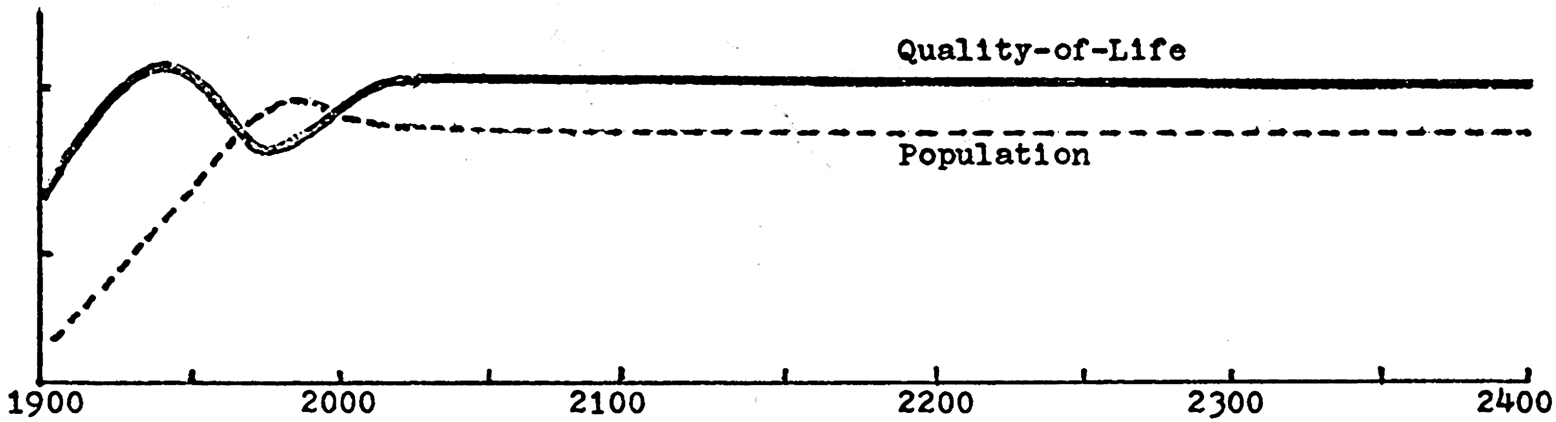


Figure 7. Sensitivity to Time Delays in Policy Implementation



(a) QS = 1.0

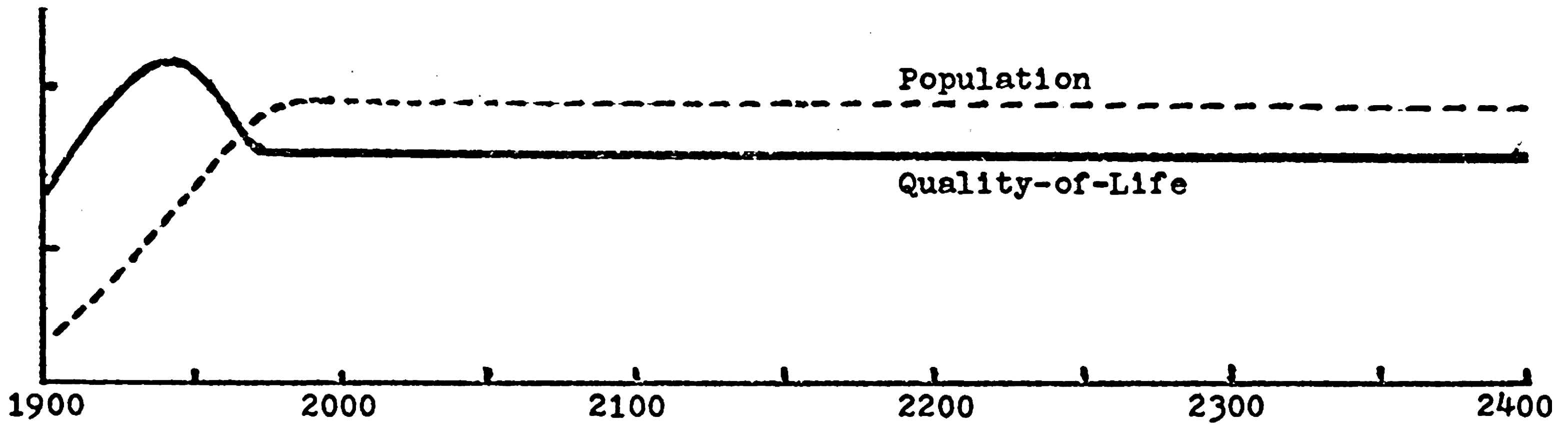


Figure 8. Sensitivity to Quality-of-Life Standards (QS)

That, since the system variables are all fundamentally linked, only a holistic approach can succeed in achieving optimal steady-state conditions.

b. Figure 7 represents the impact of delaying implementation of minimization of entropy policy from 1975 (solid line) to 1980 (dotted line) or 1990 (dashed line). As would be expected, delay is increasingly detrimental to the long-term quality of the steady-state world system.

c. Figure 8 represents the influence of quality-of-life constraints on allowable population levels; i.e., the higher the quality-of-life goal, the lower the allowable population level.

Thus, the potential ability of minimization of entropy policy (emphasizing resource recovery and husbandry) to achieve a high quality-of-life, long-term,steady-state world system has been demonstrated. The minimization of entropy policy criterion provides for both the maximum horizon for future generations and a satisfactory quality-of-life for all members of the world system.

B. Validity of the World Dynamics Simulation Models

The World Dynamics models are embryonic attempts to study a problem that must soon be understood if mankind is is to be assured survival. It is not yet possible to use these models for predicting the future with any certainty.

At present, the most useful aspects of the World Dynamics models can be summarized as follows:

1. Ability to construct models that approximate the mental models decision-makers actually use; and then test how these models agree with real world experiences. In this regard, the MIT models have already had an enormous educational impact on policy-makers world-wide. If world scale conflict can be avoided, it is quite possible that the world-wide "Limits to Growth" research effort may succeed in creating, on the part of world leaders, the understanding and motivation needed to develop effective steady-state oriented policy.

2. Ability to study basic hypotheses concerning growth dynamics, growth constraints, and the possible ramifications should these limits be exceeded.

3. Ability to identify essential requirements that must be satisfied for the achievement of steady-state conditions at both the local and the global levels. This study has demonstrated that thermodynamic principles are the fundamental criteria for the achievement of any steady-state solution.

4. Ability to investigate alternative policies for transition to steady-state conditions.

5. Ability to develop a refined understanding of the technical aspects of cultural dynamics; with the object-

ive of establishing a comprehensive Cultural Physics. The thermodynamic concepts stressed in this study are conducive, if not essential, to such a development.

6. To quote Meadows:[44]

> Although all major world issues are fundamentally linked, no method has yet been discovered to tackle the whole effectively ... (The Systems Dynamics approach) permits us to define the balances that must exist within human society, and between human society and its habitat, and to perceive the consequences that may ensue when such balances are disrupted ... man's tenure on earth will be longer if he can learn to formulate his goals and manage his affairs so that short-term solutions do not decrease long-term options.

C. Implications of a Steady-State World System

Minimization of Entropy policy for the optimal steady-state world system suggests that research programs, planning, and resources management policies be oriented towards the following considerations:

1. Natural resource depletion be minimized by:

a. Use of "renewable" or recoverable resources

b. Use of comprehensive or multi-purpose schemes to maximize use of resources ... thereby reducing unnecessary duplication of resource inputs.

c. Emphasizing energy and materials technologies which are able to add to key resource reserves.

2. Pollution be minimized by:

a. "Cascading" or "stepping down" waste products from one level as resource inputs to other users.

b. Maximizing use of resources whose wastes can be used for other processes.

c. Maximizing use of resources whose eventual entropic waste can be readily absorbed or neutralized by the environment.

d. Minimizing or eliminating processes whose environmental impact can not be effectively neutralized.

e. Emphasizing technologies which improve capabilities to maintain a healthy biosphere.

3. Population be maintained at a constant level, commensurate with environmental carrying capacity, by:

a. Determining desired average life span ... whose reciprocal gives the death rate. For zero population growth, birth rate equals death rate.

b. Emphasizing a negative growth policy for the short-term, in order to allow expeditious transition to steady-state world conditions.

4. Capital Investment durability be maximized with respect to needs of society by:

a. Reducing discard or depreciation rates.

b. Decreasing the impact of capital investment on resource depletion and pollution generation.

c. Maintaining sufficient capital investment to sustain societies relatively unprotected from the misfortunes of nature.

5. Quality-of-life be defined as a trade-off between benefits gained from technology versus entropic costs incurred by use of the technology, with emphasis given to:

a. Cultural orientation to conservation and comprehensive use of resources.

b. Crediting non-material, cooperative behavior factors more effectively.

c. Social technology which works with (rather than against) nature.

Perhaps the most difficult problem in defining the character of a large scale steady-state culture is what it will be like as a physical structure. Yet identification of this structure is critical to determining the character of the entropy rates that must be minimized in order to achieve the steady-state. Using Plato's Republic or Thomas More's Utopia as classical examples, it is argued that many attractive, essentially organic, philosophical statements regarding optimal steady-state societies have been advanced down through the ages; yet, when reduced to physical concepts, these proposals have invariably tended to suggest physical structures and institutions diametrically opposed to their original humanitarian objectives.[45] A consequence of this design inadequacy has been a general discrediting of the basic validity of the concepts of utopia and the stable steady-state.[46] In modern experience, this paradox is manifested in our apparent inability to effectively develop and manage large systems ... whether in private enterprise or in government. The thermodynamic concepts introduced in defining the process for achieving and maintaining stable steady-state systems offers possible answers to this problem.

Taking each community (of whatever size) to be a subsystem of the total world system, it follows that the world system can only reach steady-state stability when all subsystems have achieved steady-state stability with respect to their local situations (which are assumed to be of infinite physical variety). Therefore, any serious attempt at transition towards a steady-state world system must first concentrate on micro level subsystems. Possibly the greatest inertia facing transition to the steady-state world system is the problem of "bigness".[47] Modern industrial culture is clearly committed to the ethic: "The bigger the better" ...or its technical equivalent: "economy of scale". As Robin Clarke observes:[48]

> Our technologies are designed to eliminate the need for people and to maximize the need for capital... the type of technology we use places great emphasis on the economy of large scale operations and is often poorly adapted to decentralized, local situations ... con-

temporary technology is as badly suited to accelerating development (of poor societies) as any that can be imagined.

Clarke further warns:[49]

Technical innovation (in industrial society) becomes very expensive, people become totally dependent on the existing system; the system itself, through centralization, becomes highly liable to both technical accidents and the activities of saboteurs. The last have only to remove a weak link in the chain to cause chaos over many interlinked systems covering hundreds or thousands of square kilometers. Centralization also precludes the use of diffuse energy sources, such as solar and wind power...

Clarke, who is a leading advocate of "alternative" or "appropriate" technology, proposes the concept of biotechnology;[50] i.e., using resources at essentially the same rate they are naturally generated in the local environment -- and as an immediate consequence, creating little or no problems of environmental pollution or drain on resource support for future generations. Figure 9 is a schematic illustration of the operating principle for a "biotechnic community" -- the type of community required for expeditious transition to an optimal, long-term steady-state world system. Clarke sees immediate feasibility for such community development world-wide:[51]

Solar and wind energy are found ...universally and, if coupled to the energy which could be obtained by burning timber, they form an interesting distribution pattern over the earth's surface ... In almost any habitable place, energy is or could be available from use of

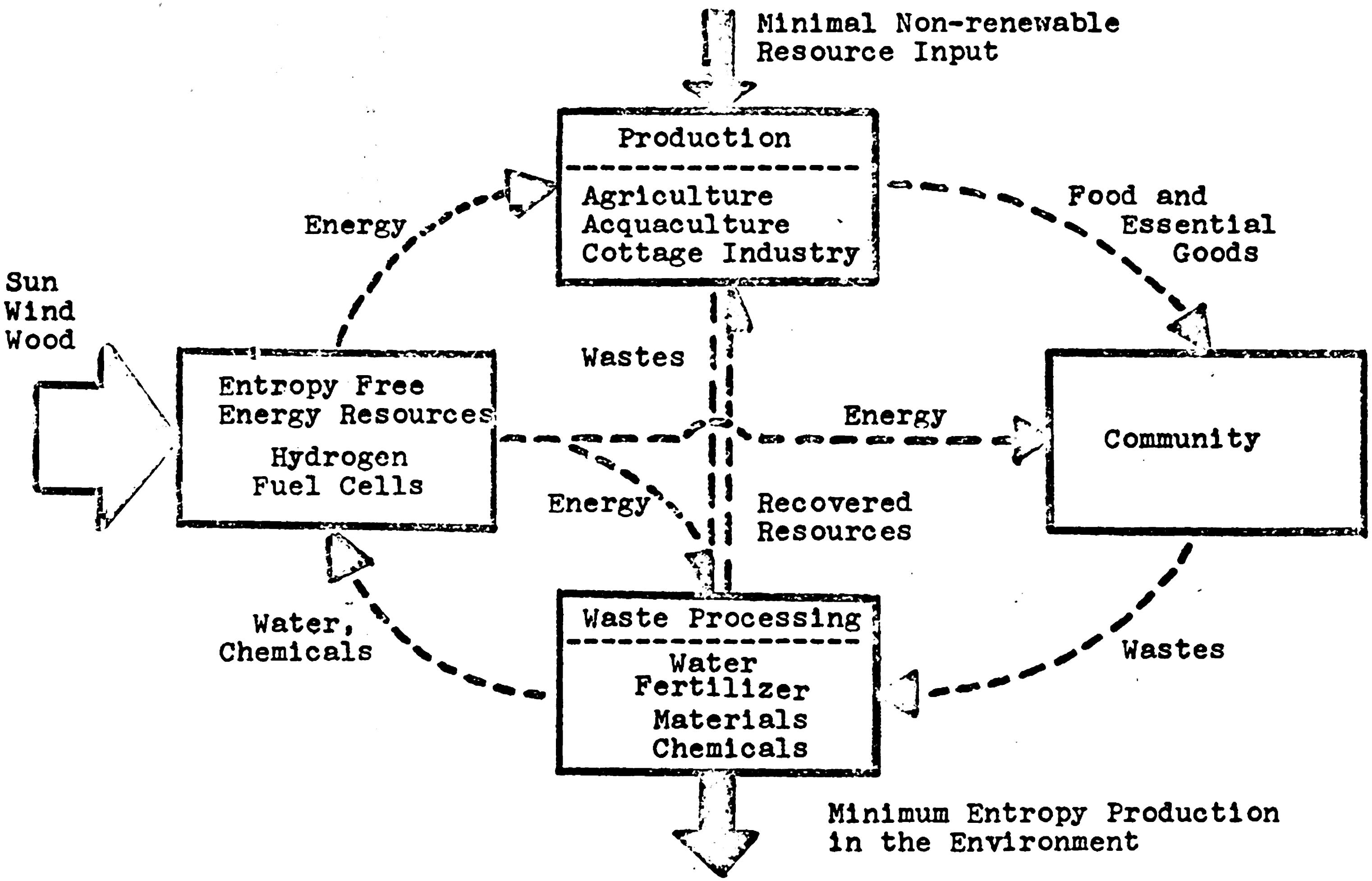


Figure 9. Biotechnic Village Ecological Management

> sun, wind or timber. In places where there is little sun, wind and wood are often common. And where timber and wind are rare, there is usually plenty of sun.

Clarke's concepts of alternative/appropriate technology are absolutely vital to the achievement of world stability. As stressed earlier, attendence to the welfare of the world's underprivileged must be the first step in the transition to the steady-state. The Western concept of industrialized technology is totally impotent in dealing with this problem. For the world's masses of poor to achieve local stability and a satisfactory quality-of-life, they must have ready access to means for effective self-help. Self-help policies require:[52] "...essentially decentralized techniques whose principles are readily understood and controlled by anyone." Such technology can be made rapidly and extensively available at low cost throughout the world. Further, it is fully effective in quickly satisfying basic subsistence needs and has low environmental impact.[53]

While the biotechnic villages or small towns are the basic community models for transition to the steady-state world system, it must be realized that much of the world has been caught up in a massive urbanization movement resulting from industrialism. Consequently, much effort must be made in introducing alternative/appropriate technology into existing urban environments, especially the badly abused central cities. As Clarke notes:[54]

> ...the demands of an alternative technology (in the urban situation) may be different in kind, but not different in principle.

CHAPTER 3 FOOTNOTES

39. Sang M. Lee. "Goal Programming for Decision Analysis of Multiple Objectives." Sloan Management Review, vol. 14, no. 2, winter 72-73, pps. 11-24.

40. This assumption is somewhat difficult to fully justify in that it assumes that the underprivileged are less able to rationalize or moralize than the more privleged classes. On an individual basis there is no reason to make such an assumption; however, on a class basis it reflects the very consequences of being underprivileged... i.e., malnutrition which restricts actual mental development, lack of access to proper education and information, etc. Further, using Abraham Maslow's concept of a needs hierarchy (Motivation and Personality. New York: Harper, 1954), it is argued that persons whose situation requires full concentration at the personal subsistence or security levels have little or no opportunity to attend to higher level community-oriented needs. For an interesting graphic portrayal of this assumption, see: D.H. Meadows. op. cit., p. 24.

41. This phenomenon has frequently been observed in nature. The position taken here is in opposition to Forrester's interpretations that birth rate goes down under adverse conditions. (Forrester. op cit., discussion of the BRCM, BRFM, and BRPM functions) The argument here is that adverse conditions cause both death and birth rates to go up. However, as evident in the poor sectors of world society today, birth rates (postive feedback) are increasing, while death rates (negative feedback) are relatively stable.

42. D.H. Meadows. op. cit., p. 195. Meadows also warns that the search for the steady-state solution " must not lead to a freezing of the status quo. ibid., p. 197.

43. However, since the Second Law ultimately prevails, this increased level of activity will cause a shortening of the future horizon .

44. D.H. Meadows. op. cit., p. 196; p. 218. Dennis Gabor has made a preliminary effort at developing a mathematical procedure with the same goals advanced by Meadows and this study. An interpretation of his conclusions is that in order to insure the maximum freedom of choice in the future the decision-maker must minimize the exercise of his present freedom. This is essentially an alternative statement of the Principle of Minimization of Entropy.

Dennis Gabor. "Open Ended Planning" in Erich Jantsch. Perspectives in Planning. Paris: Organization for Economic Cooperation and Development, 1968, p. 344: "The novelty in the present paradox is only that the maximum in question, where it is best not to exercise the freedom, is not a maximum of material goods, social justice, etc., but the maximum of freedom itself... it cannot be denied that there is something fundamentally paradoxical in the concept of freedom."

45. I.F. Clarke. "Prophets and Predicators: The Primacy of Plato." Futures, vol. 4, no. 1, March 1972, pps. 75-80. "The Utility of Utopia". Futures, vol. 3, no. 4, Dec. 1971, pps. 396-401.

46. John Stuart Mill provided an often quoted rebuttal to the detractors of the steady-state: "It is scarcely necessary to remark that a stationary condition of capital and population implies no stationary state of human improvement. There would be as much scope as ever for all kinds of mental culture, and moral and social progress; as much room for improving the Art of Living and much more likelihood of its being improved, when minds cease to be engrossed in the art of getting on." Daly. op. cit., p. 13. Implicit in the argument for a steady-state world system is a "Utopian" philosophy. There are some students of society who have concluded that mankind has "lost its innocence" and has resigned itself to a dismal present ... devoid of any interest or hope for a better future for either themselves or posterity. (Interestingly, the Second Law is often used to support such positions). Judith Shklar. "The Political Theory of Utopia: From Melancholy to Nostalgia". in Utopias and Utopian Thought. F.E. Manuel (ed.). Boston: Beacon Press, 1967, p. 101. Kenneth Boulding has countered with the observation that there is a great deal of historical evidence to suggest that a society which loses its identity with posterity and which loses its positive image of the future loses also its capacity to deal with present problems ... and soon falls apart. Kenneth E. Boulding. "The Economics of the Coming Spaceship Earth", Daly op. cit., p. 129. Elsewhere Boulding notes that, historically, Utopians have been motivated by a strong escapist urge: "... desiring to leave behind all the inequity, insecurity and destructiveness that (present) systems manifest and produce." Carole Fisher. Toward Utopia: Considerations For Advancing the Urban Evolutionary Process. unpublished Master's Major Paper, Virginia Polytechnic Institute, Blacksburg, Va. July 1973, p. 2. Boulding observes that, even though Utopia is not free of unfavorable connotations, it is of enormous importance in directing the energies of man. "If we move anywhere,

it is because the reality we perceive does not conform to our ideal. The nature of the ideal more than anything else determines our direction of movement. It is our image of the future which draws into the future, or even which repels us in other directions." Kenneth E. Boulding. *Principles of Political Economy*. Englewood Cliffs, NJ: Prentice-Hall, 1958, p. 418.

47. It is beyond the scope of this study to go deeply into the political aspects of the steady-state as opposed to "bigness"; however, the following references make vital observations:

a. Jean Jacques Rousseau: "Democracy requires a small state." James Madison: "Bigness absolutely precludes democratic rule." J.D. May. "Bigness, Technology and Democracy" *Search*, vol. 5, no. 6, June 1974, p. 249.

b. Aristotle: "Most persons think that a state in order to be happy ought to be large; but even if they are right, they have no idea of what is a large and what is a small state... to the size of states there is a limit, as there is to other things, plants, animals, implements; for none of these retain their natural power when they are too large or too small, but they either wholly lose their nature or are spoiled." D.H. Meadows. *op. cit.*, p. 161.

48. Robin Clarke. "The Pressing Need for Alternative Technology". *Impact of Science on Society*, vol. 22, no. 4, 1973, p. 260.

49. *ibid.*, p. 264.

50. *ibid.*, p. 267.

51. *ibid.*

52. *ibid.*, p. 268.

53. As an example of the disparity between industrial culture's inherent inefficiency and the appropriateness of biotechnic culture, Clarke notes that, where the United States uses an average of 10 calories of energy resources to produce one calorie of food, "primitive" agriculture obtains 15 calories of food for every calorie of energy resource used in farming. *ibid.*, p. 261. John Jeavons, who has developed a "biodynamic" form of low technology, low energy agriculture, stresses that mechanized agriculture simply is incapable of providing the food needs of the world ... only organic methods can satisfy the great deficiencies that exist in the world's food production system....such methods provide 5-15 times usual commercial

yields at only a fraction of the resource investment. Yet, he notes (in reference to seeking financial support for further research): "...the Ford and Rockefeller Foundations did respond, but the minute they found out it was an organic method they just bluntly said they were not interested in going back to basics." Peter Wiley. "And Its Organic Too", Falls Church Globe, Falls Church, Va, 3 Jan 1975, p. 4.

54. Clarke. op. cit., p. 270.

CHAPTER 4

APPROPRIATE TECHNOLOGY FOR TRANSITION TO THE STEADY-STATE WORLD SYSTEM

A. Thermodynamic Analysis

As stated by the First Law of Thermodynamics, mass-energy resources are conserved, at least in an essentially closed system such as Earth. Thus, in a quantitative sense it is impossible to have a "depletion" of mass-energy resources; in one form or another, such resources are fully conserved in the world system. The Second Law of Thermodynamics, however, states that mass-energy resources, while conserved quantitatively, are not conserved qualitatively. Further, the Second Law emphasizes that each and every transaction in a real system must involve some degradation of the quality of the mass-energy resources involved. This degradation "cost" is entropy. The difference between the original qualitative value of a resource and its past entropy "expenditures" represents the resource's current quality or potential ability to do useful work.

This ability to do work is known as thermodynamic potential or thermodynamic availability (hereafter refered to as potential). In reality, it is only this qualitative aspect (potential) of mass-energy resources that can be "depleted" or become "scarce". It is therefore necessary to distinguish between the quantitative aspect of a resource (number of BTU's, for example) and the qualitative aspect (number of BTU's/lb). The quantitative aspect is conserved and can be treated in a simple arithmetic fashion. The qualitative aspect is essentially a density function dependent on the relation:

POTENTIAL = ORIGINAL VALUE - IRREVERSIBILITIES

A (BTU/lb) = E (BTU/lb) - T(°F)·S(BTU/lb-°F)

Potential (A) is thus a function of three interrelated variables: energy (E), temperature (T), and entropy (S). Alternatively, for dynamic processes ability-to-do-work (dA) equals recoverable work under ideal (reversible) conditions (dE) minus work lost under actual (irreversible) conditions (TdS).

Stephen Berry has advanced the concept of Thermodynamic Thrift as a general purpose criterion for resource management. This criterion states:[55]

> It is desirable to minimize the consumption of thermodynamic potential in achieving any chosen goal.

Recalling the derivation ($-\Delta N = \Delta S$) from Chapter 2, it is clear that minimization of consumption of thermodynamic potential is a criterion equivalent to the Principle of Minimization of Entropy. Thus, the concept of minimization of entropy is intrinsic in the concept of thermodynamic analysis and synonomous with any policy that attempts to conserve potential or minimize its unnecessary consumption or waste.[56]

Interest in alternative technology leads directly to resource husbandry concepts such as Total Energy Systems, Comprehensive Use of Resources (China)[57], recycling, multi-use systems, cascading, and biotechnic or cooperative feed-back systems. The conservative strength of such concepts is virtually self-evident, yet they have been regularly dis-creditied as not being thermodynamically, economically, or functionally competitive with existing methods. This is particularly surprising since most modern resource tech-nologies exist as series-type networks whose total system efficiencies are routinely less than 5%.[58] The real reason for this paradox is simply that analytical methods are used that consider only the "one-way, single-use" policies of industrial technology. Specifically, such analyses give no credit for multiple use of the same resources, the elimina-tion of redundant prime resource consumption, the reduction of environmental impact, the elimination of unnecessary capital investment, or other "externalities" whose mini-mization benefits the whole system.

There is, then, an urgent requirement to develop a thermodynamic analysis methodology for alternative technol-ogy. Using Carnot's principle of the ideal thermal efficien-cy of the reversible heat cycle:

where: η_c = Carnot or ideal thermal efficiency
T_c = the "cold" temperature (sink)
T_H = the "hot" temperature (source)
A_r = ideal potential (reversible process)
Q = original resource potential

then,[59]

$\frac{T_c}{T_H}$ = the thermal "friction" or loss of potential factor due to Second Law irreversibilities of the process

or,

$$\eta_c = 1 - \frac{T_c}{T_H}$$

IDEAL AVAILABILITY = ORIGINAL VALUE - IRREVERSIBILITIES

$$A_r = Q - Q(T_c/T_H)$$

$$A_r = Q(1 - T_c/T_H) = Q\eta_{ic}$$

This expression represents an ideal standard against which any real thermodynamic system can be compared. This formulation is extended by drawing on a derivation by D.O. Lee and W.H. McCulloch:[60]

$$Y = \frac{y}{A_r} = \text{UTILITY}$$

where,

for a heat cycle:

UTILIZATION = $y = W_u + Q_H$ = USEFUL WORK + HEAT APPLIED USING WASTE HEAT

for a cooling cycle:

UTILIZATION = $y = W_u + Q_c$ = USEFUL WORK + HEAT REMOVED USING WASTE HEAT (absorption)

thus, utility (Y) can be defined as a measure of the total benefit derived from cascaded use of thermal resources in comparison to the ideal maximum obtained in a "single-use" Carnot heat cycle.

Lee and McCulloch emphasize:[61]

> As a general observation, Y can be greater than 1.0 for cascaded systems. The fact that the utility can be greater than 1.0 would seem to imply violation of the laws of thermodynamics, because the energy usage is greater than the availability. However, it should be remembered that: $y = W_u + $ heat applied. In order to satisfy the second law, only the quantity W_u/A_r must be less than 1.0. The fact that the ratio of heat applied to the availability is also present makes it possible for the utility to be greater than 1.0. This ratio (Q/A_r), however, does not involve useful work but rather involves the heat sink of the system and hence does not involve the second law.

In the wind source and laser-fusion total energy system examples that follow, the above derivation has been extended beyond thermal cycles to all thermodynamic transformations. Specifically, when dealing with heat cycles the relation: $y = W_u + Q_H$, is used; when dealing with cooling cycles the relation: $y = W_u + Q_c$, is used; and when dealing with other than heat or cooling cycles (electricity, lasers, Fusion Torch, etc.) the relation: $y = YA_r$, is used, where Y is the efficiency of the non-thermal transformation. In this manner it is possible to develop a potential minimizing algorithm as follows:[62]

$$y = YA_r = W_u + Q_H, = W_u + Q_c$$

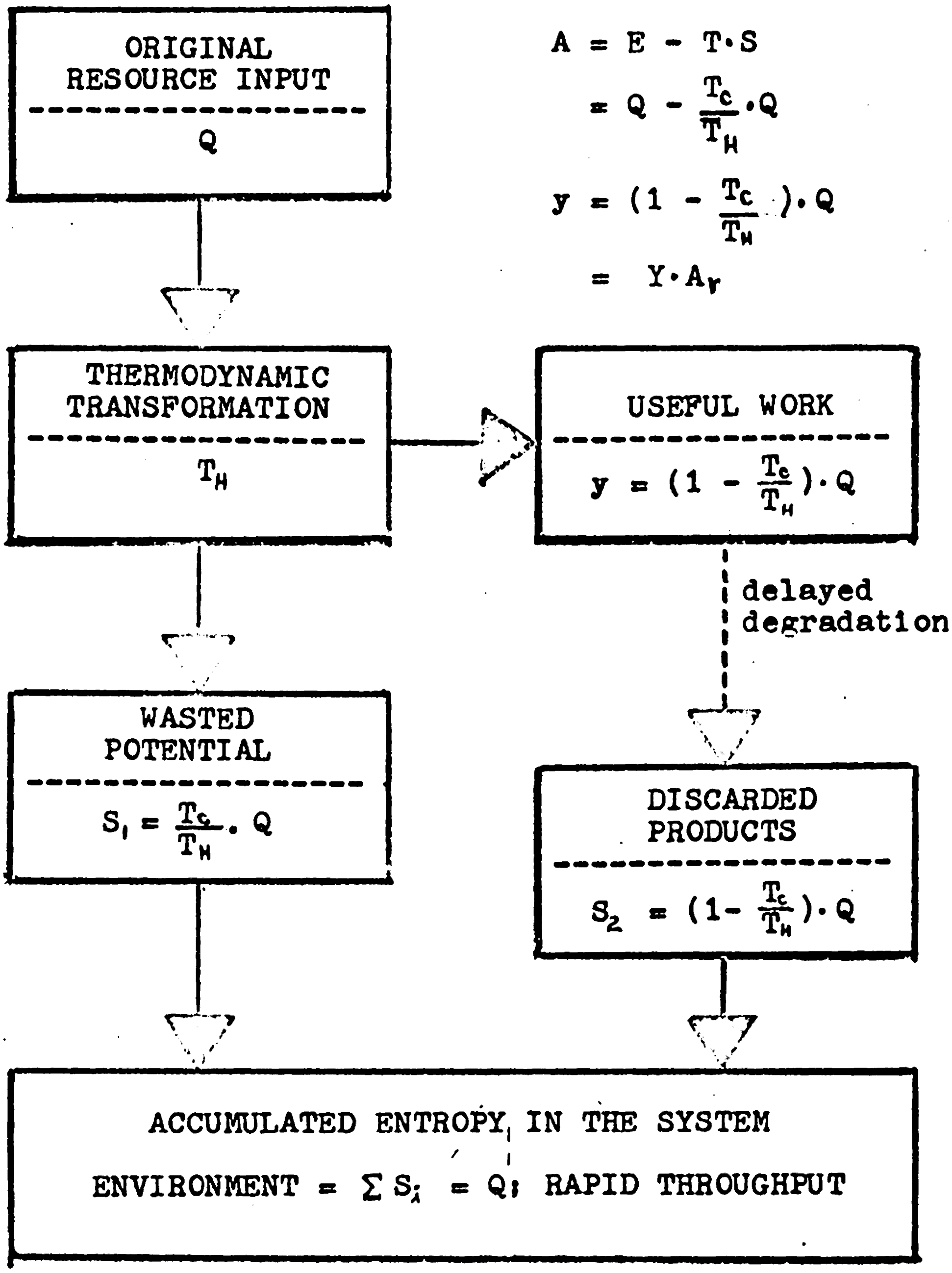
The simulation model sums A and y for each iteration and for each run computes:[63]

$$Y = \frac{\Sigma y}{\Sigma A_r} = \frac{\Sigma W_u}{\Sigma A_r} + \frac{\Sigma Q_H}{\Sigma A_r} + \frac{\Sigma Q_c}{\Sigma A_r}$$

The dual relation for maximizing utility (Y) is the minimmization of entropy production; which in turn is equivalent to minimizing consumption of thermodynamic potential. Negative feedback loops (in the manner employed in the World Dynamics model) can be used to dynamically optimize any thermodynamic system.

B. Thermodynamic Analysis for Total Energy Systems

Figure 10 represents the concept of conventional "one-way, single-purpose" thermodynamic analysis. Resource input (Q) is transformed thermodynamically (by a heat cycle, for example) to provide some degree of useful work. Under existing practice, however, little attention is given to matching the quality of the thermodynamic potential with the qualitative requirement of the demand. As a consequence, if a high quality (1000°C) steam generation process is used to generate electricity for a low quality (50°C) hot water heating demand, the process will require eight times as much initial energy resources (i.e., 12% as efficient)[64] than would be used if waste heat from one of many other possible sources were used.[65] While typical heat cycle efficiencies are in the 20-35% range, the overall efficiencies of most processes are even less due to multiplication of a series of process component inefficiencies. Consequently, thermal pollution loads reflecting inefficiencies of 65-80% are dumped in



$$\text{UTILITY} = Y = \frac{\sum y_i}{\sum A_{r_i}} = \frac{(1 - T_c/T_H)\cdot Q}{Q} = \frac{W_u}{A_r} = \eta_c$$

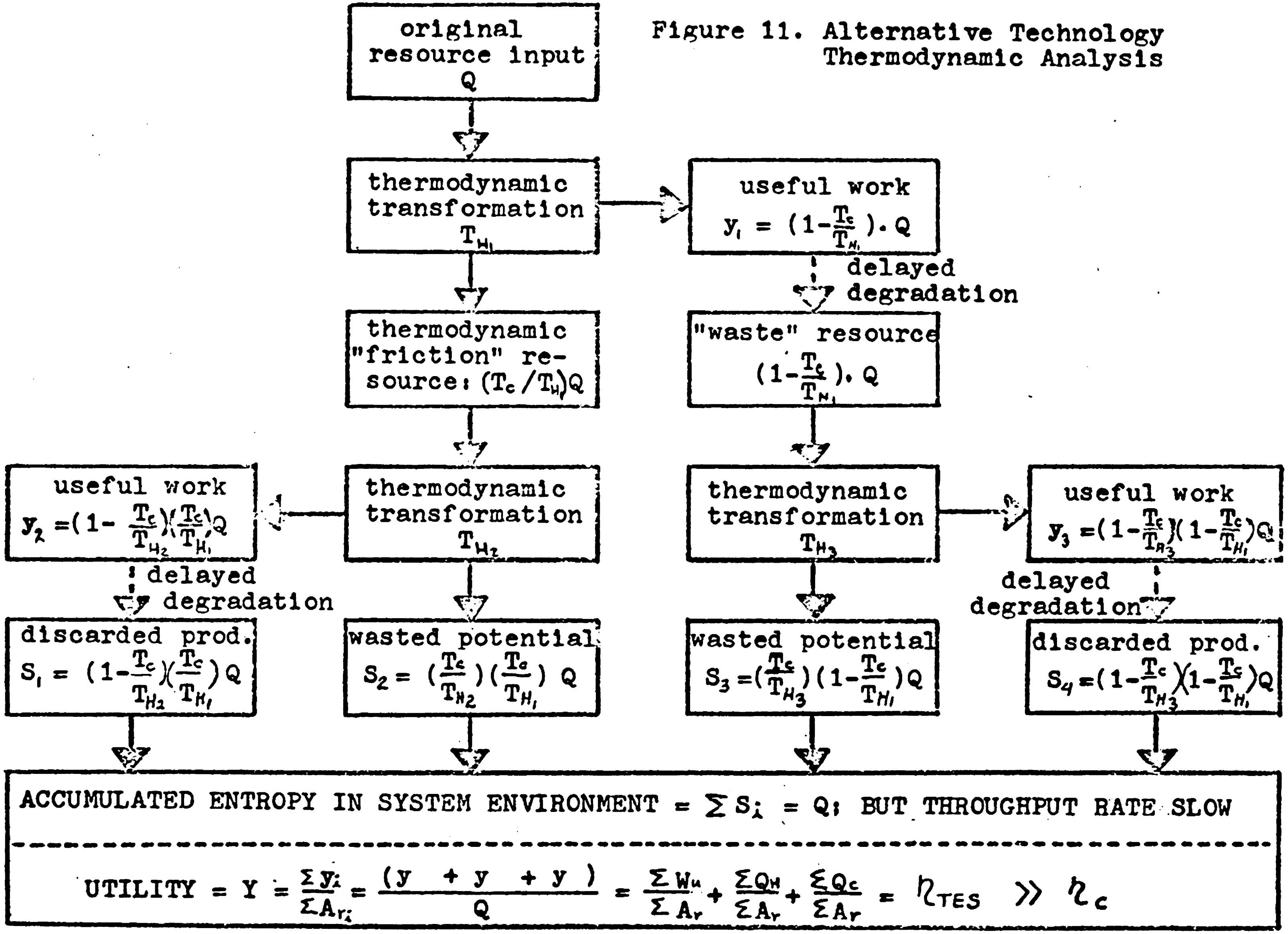
Figure 10. Conventional "One-way, Single-purpose" Thermodynamic Analysis

great concentration into the environment. Battelle researchers have found that these heat loads are creating "heat islands" which have macroscopic adverse impact on regional environments, particularly in metropolitan areas.[66] Thus, the environmental "sink" temperature (T_C) is dependent on the buildup of thermal entropy in the system. Since a heat cycle is directly dependent on the ratio T_C/T_H (i.e., $\eta_c = 1 - T_C/T_H$), the raising of T_C reduces the future efficiency of the process providing useful work; which in turn increases the future pollution rate. This "running down" is a consequence of the Second Law, but it represents a rate totally unacceptable with respect to society's present and future needs.

Figure 11 schematically represents the concept of thermodynamic analysis for alternative technology. The system is designed and operated in a cooperative feedback manner that allows virtually an infinite number of combinations for multiple use of resources. While the input resources (Q) must ultimately find their way to the environmental sink (S) in order to satisfy the First Law and Second Law, the rate of degradation is greatly reduced by:

1. Cooperative planning that in the design stage strives for minimization of unnecessary resource consumption and maximum utilization of those resources that are necessary. As noted earlier, a simple cascaded hot water heating system will use only one-eighth the energy resource input needed

Figure 11. Alternative Technology Thermodynamic Analysis



under conventional practice. Further, such cascading technology is significantly contributing to the minimization of entropy in the environment. (In a sense, cascading systems are using an entropy "free" energy resource...as is also the case when solar, wind and hydro resources are utilized.)

2. The degree of concentration of pollution is greatly reduced. Ideally, the objective of resource management should be to keep cascading resources until their final deposit in the environment is at a quality undifferentiable from that of the environmental "sink" (i.e., if normal atmospheric temperature is 80°F, the final deposit of cascaded resources should be of a quality that closely approaches 80°F). However, since entropy increase directly increases the temperature (T_c) of the environment (which in turn decreases process efficiencies), only the systematic minimization of entropy in all stages of resource utilization processes can insure the long-term effectiveness of the environmental "work-producing-machine" that supports life on Earth. Further, the number of stages in all processes must be minimized in order to avoid the adverse multiplier effects of series processes.

The concepts of Total Energy technology are well developed, having been demonstrated in the initial development of the Tennessee Valley Authority. The TVA succeeded in establishing a highly integrated system which responded to a comprehensive set of socio-economic- environmental needs of an underdeveloped region.

Oak Ridge National Laboratories in recent years has developed a series of detailed studies proposing the use of multipurpose energy resource systems for various power-industrial-agricultural-urban applications. Recognizing that demand for large amounts of electric power is unavoidable in concentrated urban-industrial environments, the Oak Ridge proposals call for coordinating a wide variety of energy-using functions in a manner which optimizes the "cascade" potential of power plant thermal effluent. Figure 12 is a schematic illustration of the functional interrelationships of such systems. The spatial configuration and user mix of any particular system requires a highly cooperative type of planning and operation,[67] which in itself is conducive to transition to a steady-state world system. Potential applications (all of which are presently technically and economically feasible) include:[68]

1. electricity production, coal gasification, and portable fuels such as hydrogen.

2. steam heat and/or hot water for process heat (such as in the production of ammonia and methanol).

3. steam heat and/or hot water for space heating, humidity control and air conditioning.

4 steam heat and/or hot water for surface heating, such as airport runways, roadways, sidewalks, airport fog dispersal and ice-free port facilities.

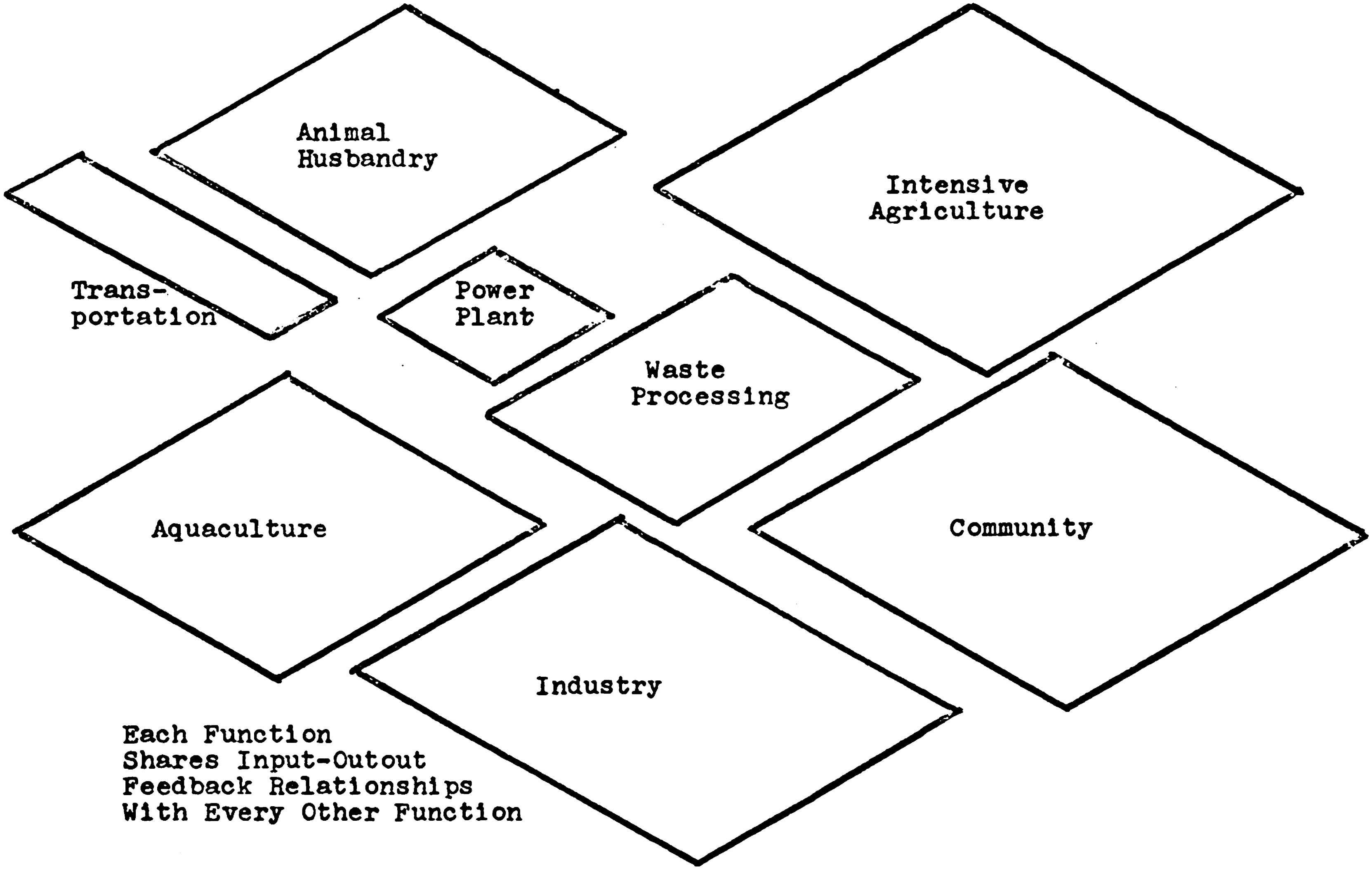


Figure 12. Total Energy Systems Functional Relationships

5. hydro cracking of heavy oils, production of synthesis gas by steam cracking methane.

6. production of acetylene, ethylene and propylene by cracking naphtha.

7. direct iron ore and aluminum reduction.

8. desalting of sea water for municipal, industrial and agricultural uses.

9. recovery of by-products from desalting to support industries producing fertilizers and chemicals.

10. thermal aquaculture, warm sprays for frost protection of orchards and crops; warm water irrigation and humidity control in desert areas.

11 green house heating, cooling, humidity control and irrigation for both plants and animals.

12. desalting liquid sewage, thermal stimulaion of biological activity of micro-organisms in sewage ... thus increasing the capacity and efficiency of the sewage treatment process.

13. groundwater aquifer recharge and surface water aeration.

14. production of autotropic micro-organisms (algae) for protein in areas having a scarcity of water and arable land.

15. production of pulp and rayon from grain wastes.

16. production of PVC plastics and chlorinated hydrocarbons from petroleum stocks.

The technology of a particular culture is directly related to its use of energy resources...to the degree that cultures can be characterized as high, intermediate, or low energy societies. This relationship is readily detected in settlement systems, where function, density, and size characteristics of a settlement are dependent on the quality, quantity, and availability of energy resources. Figure 13 is a matrix showing the interrelationships between settlement characteristics and primary energy resource characteristics. The symbols (+,0,-) indicate in a relative manner the positive, neutral, or negative advantage of using a particular energy source as a primary means of serving a particular type of settlement. (Similar matrix constructions can be developed for more specific features of a settlement complex). Analysis of the matrix will lead to the conclusion that large, high density settlements having sophisticated technical features will need large scale, high quality energy systems (such as fusion). Small scale, low density settlements using alternative technologies, however, should use low cost, low entropy systems such as solar and wind energy. The intermediate scale settlements have a greater range of choice among the energy options, but have less ability to effectively use the ecologically optimal solar and wind options or the high quality fusion systems.

Figure 9, shown earlier, represented the concept of an

Settlement Characteristics		Prime Energy Source						
Function		(+ = Good, 0 = Acceptable, - = Poor)						
Density	Scale	Solar	Wind	Hydro	Geo-thermal	Fossil	Fission	Fusion
Habitation (Urban)								
high	large	-	-	0	0	0	0	+
	medium	-	-	+	+	+	0	0
	small	0	0	0	+	+	-	-
moderate	large	-	-	0	0	0	0	+
	medium	0	-	+	+	+	0	0
	small	+	0	0	+	0	-	-
low	large	0	0	0	0	+	-	-
	medium	+	+	0	-	0	-	-
	small	+	+	-	-	0	-	-
Production (Industry)								
high	large	-	-	0	0	0	0	+
	medium	-	-	+	+	0	0	+
	small	0	0	0	0	0	-	-
moderate	large	-	-	0	0	0	0	+
	medium	0	0	+	+	+	0	0
	small	+	+	0	0	0	-	-
low	large	0	0	0	-	0	-	-
	medium	+	0	0	-	0	-	-
	small	+	+	-	-	0	-	-

Figure 13. Settlement vs Appropriate Prime Energy Source Matrix

ecologically optimal biotechnic village which can be readily established in virtually any locality world-wide. However, it is recognized that much of the world's population presently lives in large, highly entropic, urban regions; and that demographic reduction of such areas faces enormous inertia. The Total Energy concept can be particularly useful in dealing with current urban problems in a manner that is compatible with the transition needs of the steady-state world system. Figure 14 is a schematic representation of the siting concepts associated with the large scale Total Energy systems needed to support urban regions. The basic concepts are those of British "Greenbelt" regional planning theory; i.e., a concentric ring of open space defines and protects the high density metropolitan center. On the transportation corridor leading to another metropolitan area there is a satellite Total Energy complex supporting:

1. the energy needs of this sector of the metropolitan region (electricity, thermal, hydrogen, methane).

2. the purification of waste water and makeup water.

3. the supply of process heat to industry and agriculture. (The satellite is assumed to require close proximity to its major heat demand centers in order to effectively maintain the quality of the steam and hot water.[69])

4. the recycling of resources from urban, industrial and agricultural wastes

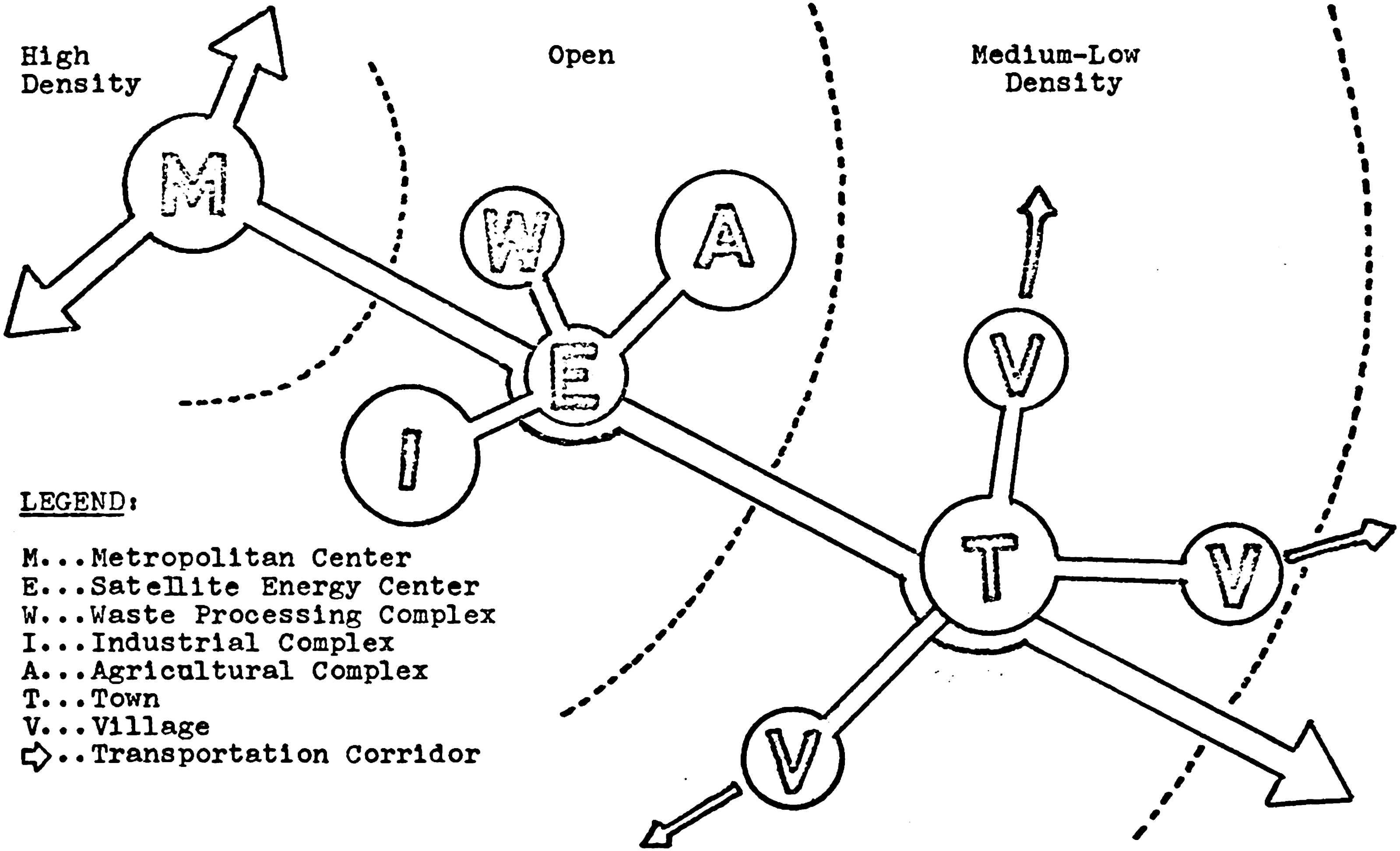


Figure 14. Total Energy System Siting Concept

Frequently, two or more major functions must compete for scarce sites. Where conventional practice allocates a site to one land-use function (zoning), the Total Energy concept requires the integration of as many functions as possible into a comprehensive system allowing maximum utilization of all resources, including land.

C. Decision Tree Analysis for Wind Energy Systems

Wind energy technology has long been established as a major energy source. It is known to have existed in ancient Persia and China,[71] it was highly developed in 17th Century Holland; and until the advent of the Rural Electrification Administration in the 1930's, it provided power for thousands of farms throughout the United States. In 1950, some 50,000 windmills on Midwest farms produced 1.4 billion h.p. of work (equivalent to 11.8 million tons of coal).[72] Commercial scale capacity was demonstrated in 1941, when a 1250 KW wind power plant was placed in operation near Rutland, Vermont.[73] Wind energy is of vital importance in biotechnology due to its availability, technical simplicity, low cost, and entropy minimizing environmental impact.

Figure 15 represents a Decision Tree Analysis for alternative wind energy system designs. The percentages refer to approximate conversion efficiencies.[74] As illustrated, wind energy can support a much greater range of intermediate

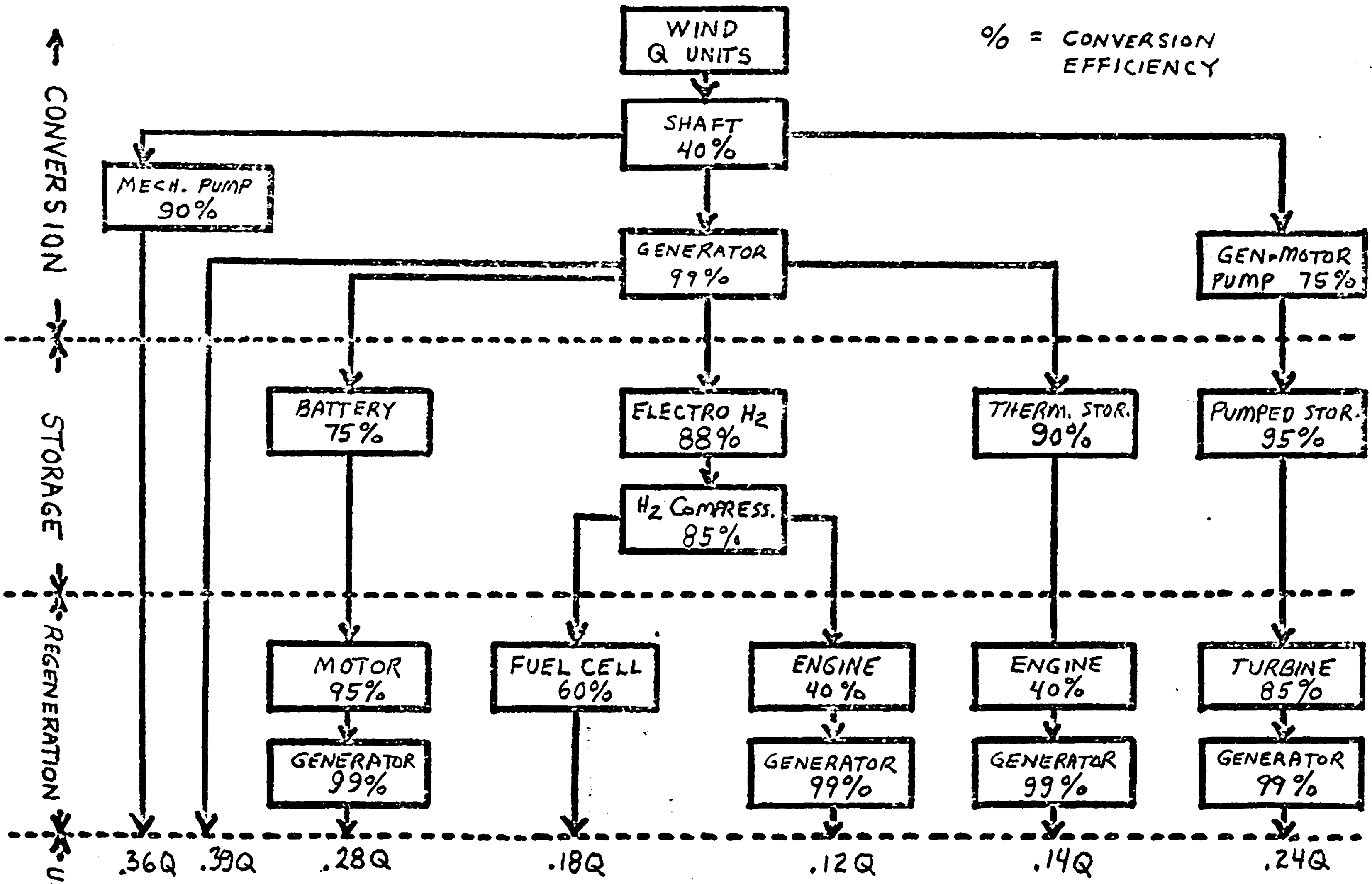


Figure 15. Wind Source Decision Tree Analysis

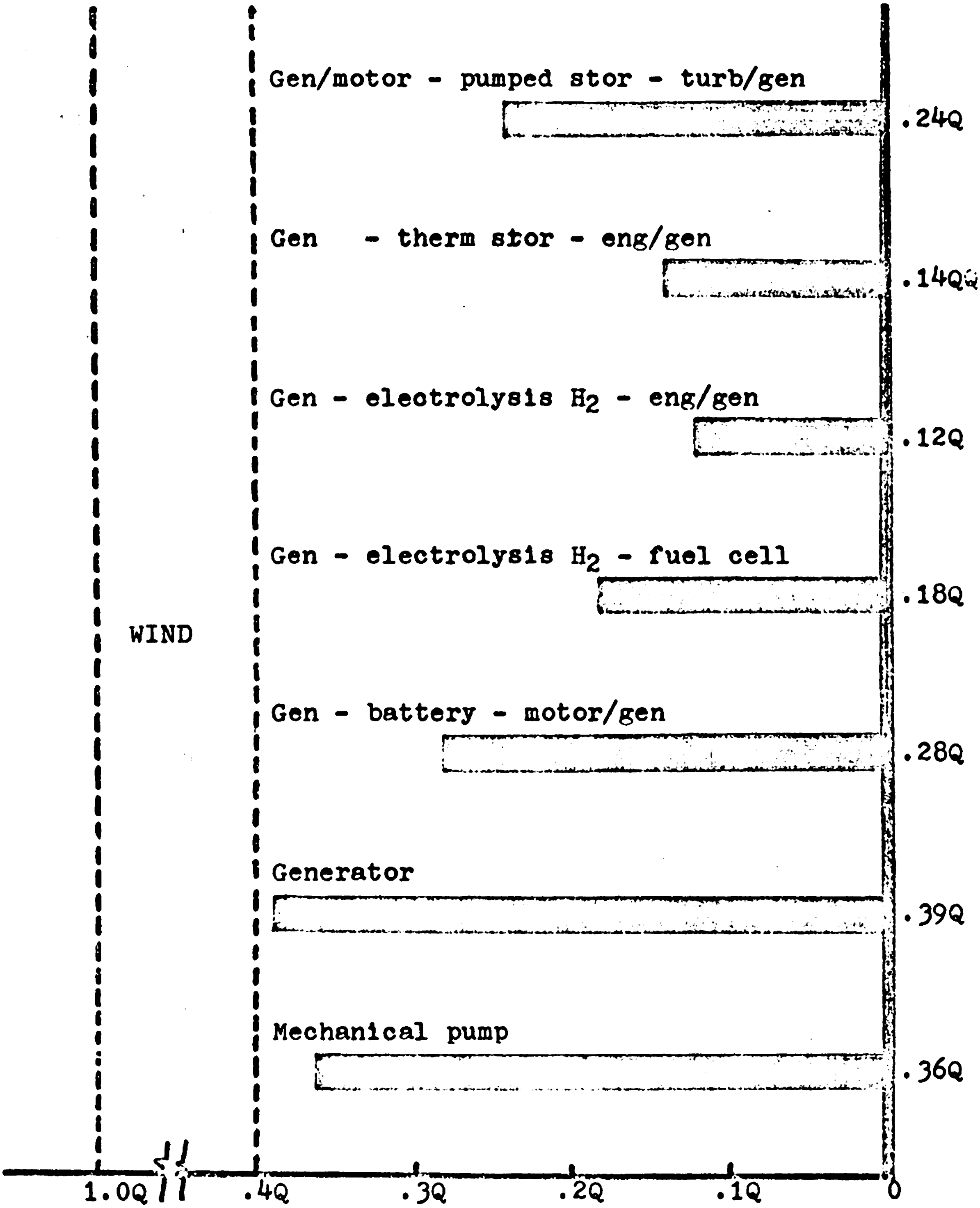


Figure 16. Comparative Evaluation of Utilization of Thermodynamic Potential for Alternative Wind Energy Systems.

energy technology and final use than is generally recognized. Its main drawbacks are: wind reliability, energy storage, and relatively small scale operating potential. Figure 15, however, shows that technological options are available which overcome these limitations, but at a cost in terms of effective use of thermodynamic potential and in terms of the cost of additional technical components (which are usually more expensive than the basic wind conversion components). Figure 16 provides reference to the relative merit of alternative designs in terms of utilization of thermodynamic potential. As noted above, introduction of additional storage and regeneration elements provides important flexibility ... but at a significant additional cost.

As demonstrated in Figures 15 and 16:

1. Wind energy technology has great potential, particularly for biotechnic communities.

2. Trade-offs must be considered between system sophistication and efficient use of thermodynamic potential.

3. Decision Tree Analysis is an effective method for comparative evaluation of relatively simple, essentially linear energy systems. The procedure can be accomplished manually and requires little sophisticated training ... and as such is suitable for the type of "self-help" methods used by biotechnic communities. The procedure can be easily extended to include economic and probability analysis.

D. Laser-Fusion Total Energy System Simulation

As demonstrated in Figure 13, large scale, high density urban and industrial complexes will require a similar type of energy supply. The solar, wind, geothermal and hydro options can each contribute to the energy needs of such complexes, but only in a supplementary manner. The limitations of fossil fuel and nuclear fission options are well recognized.[75]

Controlled thermonuclear fusion technology (hereafter refered to as fusion) appears, after some 25 years of intensive research, to be on the verge of demonstrating technical and economic feasibility.[76] Fusion technology has the following advantages over fossil and fission options:[77]

1. Essentially inexhaustible, low cost fuel reserves (deuterium from oceans) readily accessible world-wide.

2. No combustion products released to the atmosphere; negligible radioactive waste production.[78]

3. Inherent reactor safety (reactions are on a micro scale); no afterheat problems.

4. Minimal biological hazard in event of a natural disaster, aircraft accident, or sabotage.

5. Negligible danger of diversion of weapons grade material for asocial purposes.

6. High efficiency thermal cycles, causing less thermal impact in the environment. (However, there is still suffi-

ciently large production of thermal effluent so as to require Total Energy cascading.)

7. Ability to use magneto-hydro-dynamic conversion technology (allowing lower plant construction cost and operating costs due to design simplicity).[80,81]

8. Potential of laser-driven or electron-beam fusion devices capable of a wide range in power system size and application (including mobile terrestial, sea, and space systems).

Since 1972 a series of research successes (which have significantly reduced laser energy requirements) has greatly increased the prospect of laser-induced fusion reactors for the near future.[82] The simulation example that follows assumes laser-fusion to be more feasible than its chief competitor, magnetically-confined fusion.[83, 84]

Possibly the most unique and important feature of fusion technology is a proven concept known as Fusion Torch. The Fusion Torch converts the kinetic energy of a fusion plasma into various forms of electromagnetic radiation which can be used to vaporize, dissociate, and ionize wastes. Waste products would be converted back to elemental form; thus simultaneously eliminating the problem of disposal of waste products while providing a supply of basic raw materials.[85] Among the unique advantages of the Fusion Torch are:

a. ability to transmutate large volume of exceedingly dangerous reaction products of fission reactors:[86] such as Sr-90, Cs-137, and I-129; can also transmute plutonium to non-weapons grade material.

b. ability to fully separate out medically dangerous elements from urban-industrial-agricultural wastes during recycling process.

c. ability to replenish elemental, high demand products; typically, an urban/industrial refuse feed rate of 2000 lbs/hr through a Fusion Torch would yield the following distribution of elemental resources: oxygen (880 lbs/hr);[87] carbon (660 lbs/hr); iron (132 lbs/hr); hydrogen (96 lbs/hr); silicon (92 lbs/hr); aluminum (62 lbs/hr); copper (28 lbs/hr) sodium (14 lbs/hr); magnesium (5 lbs/hr); and other elements (31 lbs/hr). Additionally, the coolant fluid for the Fusion Torch is capable of generating electricity at 50% efficiency.

d. simplicity of recycle process... all materials are reduced to elemental form. Further, the recycling process inherently provides pure (actually super pure) materials capable of satisfying the stringent requirements of semi-conductors and super-conductors.[88]

e. ability to expand on existing plasma jet technologies, such as chemical synthesis, welding, fusing, cooling, spraying, cutting and reduction and separation processes.[89]

f. ability to apply ultra-high radiation heating (UV or

X-ray) to large bodies of fluids in processes such as water supply purification, desalination of sea water or sewage, sterilization of food products, large volume synthesis of simple food chains (proteins), and production of hydrogen fuels.[90]

Fusion Torch is clearly a vital technology wherever a high-energy culture is being maintained. Fusion Torch is also compatible with the goals of the steady-state world system. In terms of elemental resource recovery Fusion Torch closely approximates a closed materials cycle and reduces environmental impact. It is not, however, free from the stipulations of the Second Law. For each transformation process the original potential of the resources is reduced by the friction factor: T_C/T_H (though this ratio is quite small in the ultra-high temperature Fusion Torch). In spite of its important advantages (particularly the neutralization of deadly wsstes), the Fusion Torch generates a very large amount of thermal waste. Thus, Fusion Torch (and fusion technology generally) is vital to the process of adjusting present high energy, high entropy industrial culture to conditions conducive to establishment of a steady-state world system; but like all dynamic functions -- cultural and technical-- it must be designed and applied in strict accordance with the entropy minimizing character of Total Energy Systems.

Figure 17 is a functional flow diagram for a laser-fusion Total Energy System illustrating the ultimate range of "cascading" potential and resource handling flexibility. The lines represent the flow of thermodynamic potential. Each sector of the system will be described briefly in terms of its functional flows of potential and then related to its associated Systems Dynamics model. The DYNAMO computer model listing is shown in Appendix C.[91]

The laser system (Figure 17) receives electrical input which it uses to drive a lasing device producing photon pulses which are "shot" at a deterium-tritium (D-T) 'pellet being dropped simultaneously into the fusion reactor cavity. The fusion reaction generates high energy neutrons, X-rays and alpha particles which are capable of transfering their energy for useful purposes in a variety of ways:

1. as neutron and/or X-ray radiation for various research and industrial applications (similar in application to Fusion Torch except the latter uses the plasma as the radiation heat source), such as treatment of bulk fluids.

2. as a plasma (an ionized gas) directly converting kinetic energy into electricity in a magneto-hydro-dynamic (MHD) engine.

3. as a plasma providing radiation heat to solid refuse resources or bulk fluids in various processes which produce useful resources in elemental or "purified" forms.

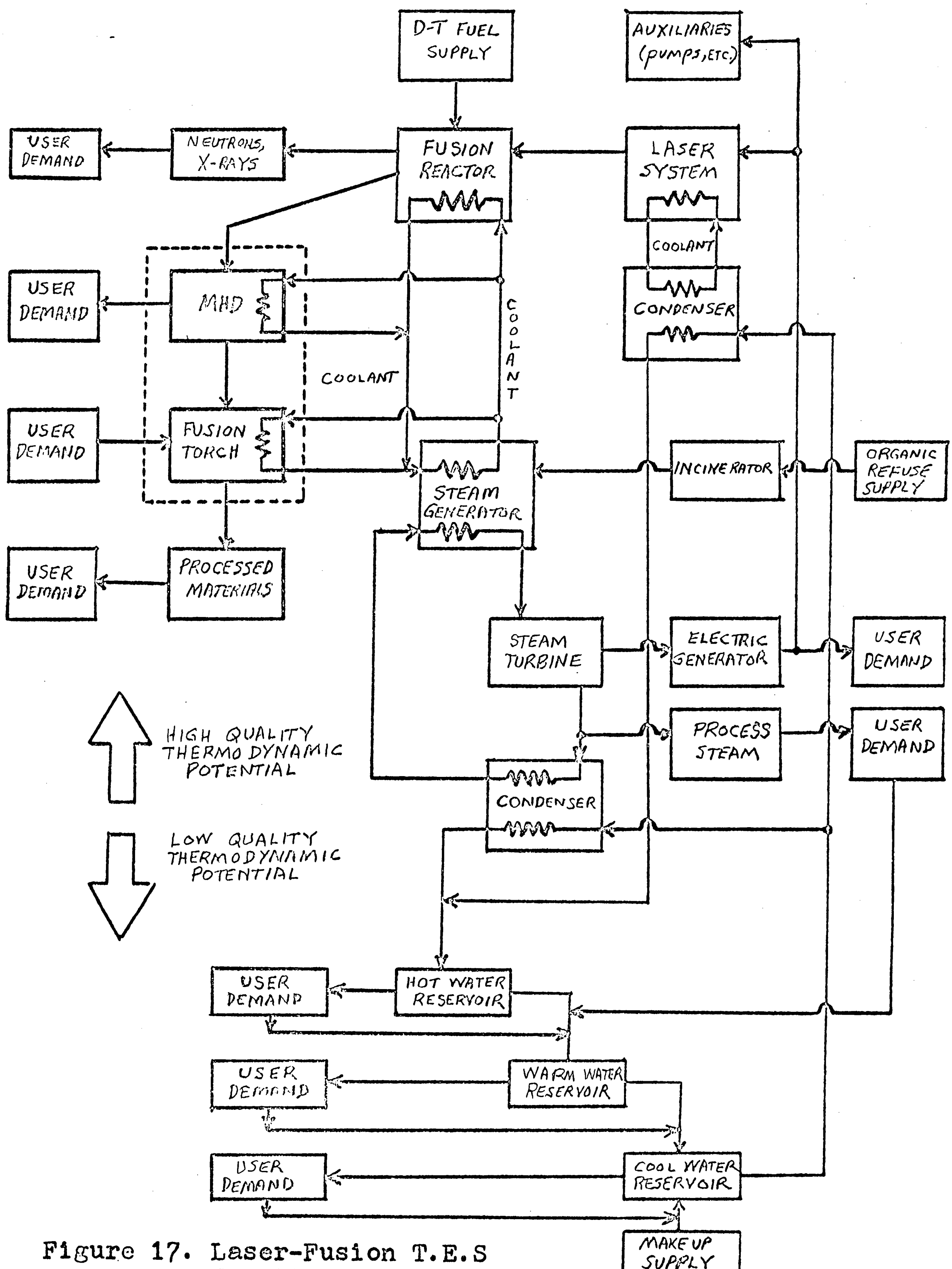


Figure 17. Laser-Fusion T.E.S Functional Flow Diagram

4. as thermal energy delivered from the reactor "blanket" to a heat exchanger.

Each of these conversion devices requires a cooling cycle (which will usually be something other than water; sodium, for example). These cycles remove thermal "friction" generated with each conversion process. The "hot" side of the cooling cycle delivers thermal energy to the steam generator (including heat from the incinerator, which is being fed organic wastes). The steam generator in turn drives a steam turbine system (the functional blocks, such as the one for the turbine, are composite representations of complex multi-component subsystems). The turbine drives a generator producing electricity for: (a) external user demand, (b) the laser system, and (c) various auxiliary elements, such as coolant pumps. The turbine can also be bled for various quality steam processes. The systems condensers pull heat from the "hot" side of the cooling loops; this removed heat is then "cascaded" down through a hierarchy of decreasing quality thermal energy demands, such as hot water, warm water, and ultimately as cool water for various urban- industrial-agricultural uses. Each stage or "thermal reservoir" receives input from: (a) thermal degradation of the next higher reservoir, (b) removed heat from condensers, and/or (c) some percentage of return from using functions (recycling). Ultimately, the thermal effluent is degraded to the base temperature of the system environment ... at which time it is available as a coolant resource for recycle back through the Total Energy System.

Since there are unavoidable losses in the system (evaporation, for example), there will usually be a need for "make-up" water resources from some external source, such as a lake or river. The effectiveness of the Total Energy System (assuming it satisfies demands as a constant function) is to a large degree reflected in how much "make-up" resources it consumes. (Specifically, the "make-up" or $-\Delta N$ tends to neutralize the entropy build-up ΔS in the systems internal environment. The optimal steady-state is obtained when the relation: $-\Delta N = \Delta S =$ Minimum Value, is time independent.)

Figure 18 is the Systems Dynamics model for the Total Energy Systems described above. Each element in the functional flow diagram (Figure 17) is represented as a combination of three model functions:

1. a level function ($\square$ symbol, such as neutron potential NEUTRN.K), which represents the current thermodynamic potential (quality level) of a particular element in the Total Energy System (reactor power level FUSION.K, as another example). In the simulation these levels are determined by integration of associated input and output flow rates (i.e., differential equations). The arithmetic difference between the integration results for these differential equations for some standard time interval determines the positive or nega-

tive change in the value of the levels (i.e., the current thermodynamic potential of the system).

2. input flow rates (symbol, such as neutron supply NEUT.KL, for example). Input is a growth or positive feedback mechanism influencing a level. The input rates, however, are determined in turn by earlier values of some set of system levels which now are being determined by the flow rates... thus illustrating the circular nature of dynamic feedback loops.

3. output flow rates (symbol, neutron demand NEUTD.KL, for example). Output rates are mathematically identical to input rates except that they are negative feedback mechanisms (i.e., decay or equilibrium seeking functions).

Even in the simplified model being discussed, the rate and level relationships become complex; the reactor power level FUSION.K, for example is determined by three input and three output rates. Such complexity justifies the use of computer simulation; indeed, it is unlikely that Total Energy Systems can be effectively analyzed without using computer simulation techniques.

As stated earlier, the Systems Dynamic model is constructed so as to directly reflect the functional flow model of the system being studied. Each Systems Dynamics model block symbol in turn defines an associated DYNAMO simulation model equation. (Appendix C).[92]

The laser-fusion Total Energy System simulation model (Figure 18) illustrates the basic application of the thermodynamic analysis procedure discussed in section A of this chapter. Recalling the relation: Utilization (y) equals Utility (Y) times Optimal Potential (A_γ). Or:

$y_\lambda = W_{u_\lambda} + Q_\lambda$	if the flow rate directly involves waste heat (Q_λ) utilization
$y_\lambda = Y_\lambda \cdot A_{\gamma_\lambda}$	if the flow rate does not directly involve waste heat utilization; Y being equal to a non-thermal efficiency

X_λ is defined as a flow transfer factor reflecting multiple output routes from a particular level. Y_λ and X_λ are dimensionless, while y_λ, W_{u_λ}, Q_λ, and A_λ all have units of energy density (BTU's/lb, for example; though arbitrarily designated "q" in the simulation model). The "cloud" symbols are external sources (supply of resources) or sinks (user demand for resources). Since the environmental "sink" is internal to the model, the efficiency of the system is reflected in the build-up of entropy. In order for the system to continue functioning, entropy build-up must be neutralized by the input of resources from external reserves (sources), such as MAKEUP.K (i.e., cold makeup water tends to "neutralize" the thermal or entropic build-up in the system's environmental sink, which in turn must provide an effectively low temperature (T_c) in order for the system to be able to continue to do work effectively.

Optimization of the Total Energy System is accomplished by:

MAXIMIZING: $$Y_{TES} = \frac{\Sigma y_i}{\Sigma A_{\gamma_i}}$$

$$= \frac{\Sigma(W_{U_i} + Q_i)}{\Sigma A_{\gamma_i}} = \frac{\Sigma W_{U_i}}{\Sigma A_{\gamma_i}} + \frac{\Sigma Q_i}{\Sigma A_{\gamma_i}}$$

As emphasized earlier, maximizing Utility (Y_{TES}) is equivalent to minimizing entropy; which in turn conserves thermodynamic potential and, therefore, contributes to the establishment of steady-state conditions locally and globally. A fully developed optimization model would use negative feedback loops reflecting minimization of entropy policies (as demonstrated in the World Dynamics model). If the maximum value of Y_{TES} solution also satisfies the time independent condition: $-\triangle N = \triangle S$ = minimum value, then an optimal steady-state solution has been achieved.

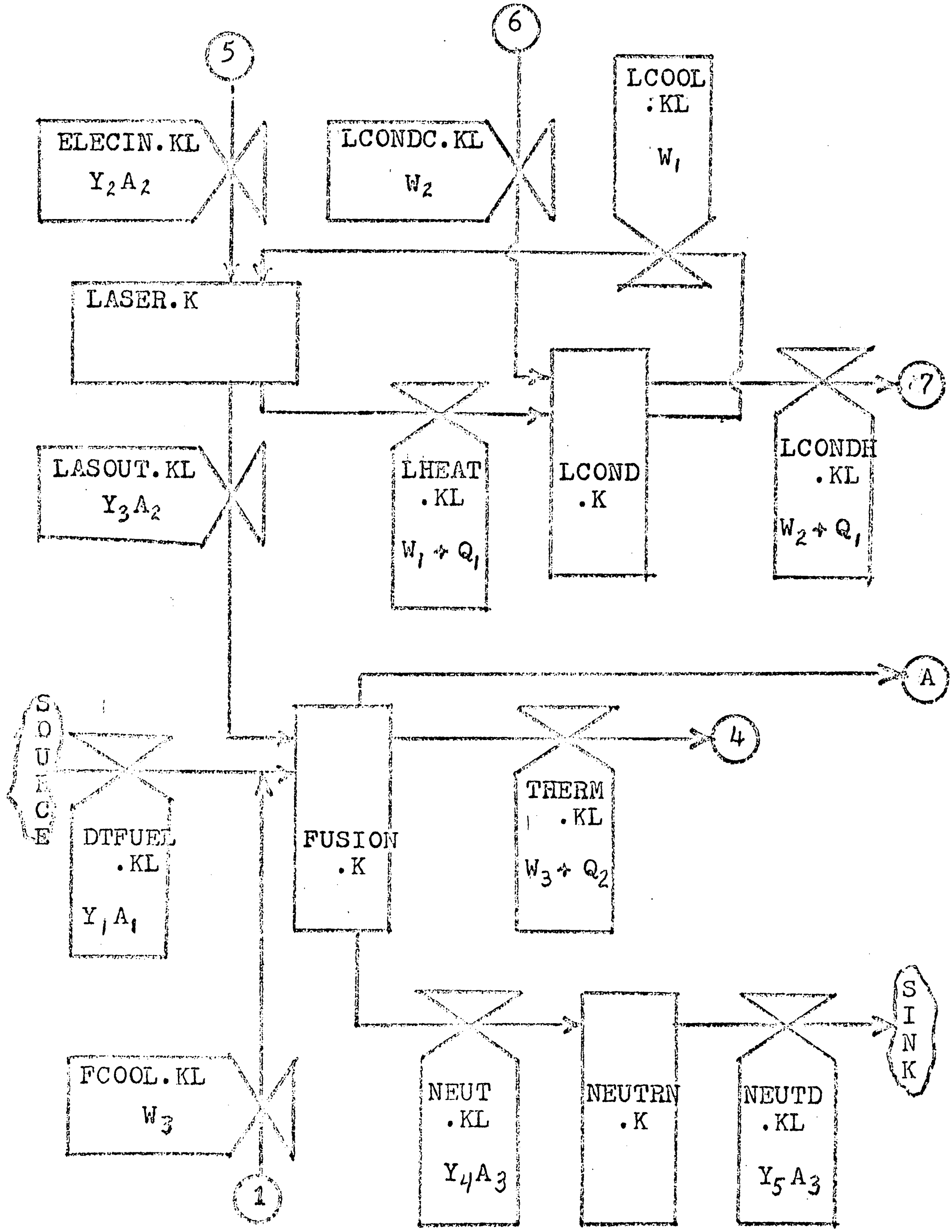
E. Application of Total Energy Systems Simulation Methods

The objective of any Total Energy Systems analysis is the identification of a functional configuration which:

1. satisfies cultural requirements for technology.
2. minimizes entropy production in providing technological solutions.

Figure 19 illustrates the basic concept of Total Energy System design. Each satellite function has input-output relationships with every other function (either directly

Figure 18. Laser - Fusion Total Energy System Flow Diagram for Systems Dynamics Simulation Model. (See legend on page 101)



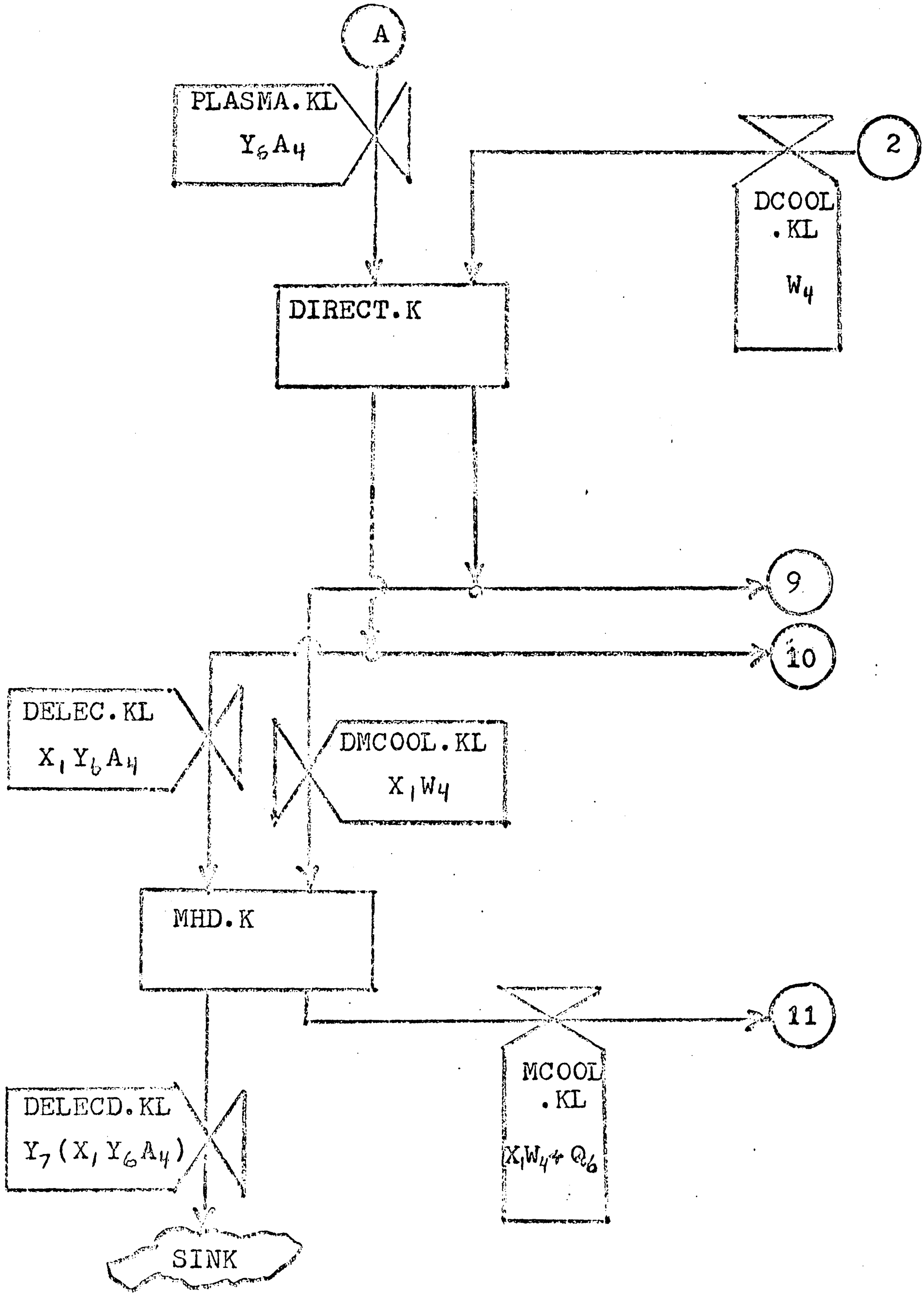


Figure 18. cont.

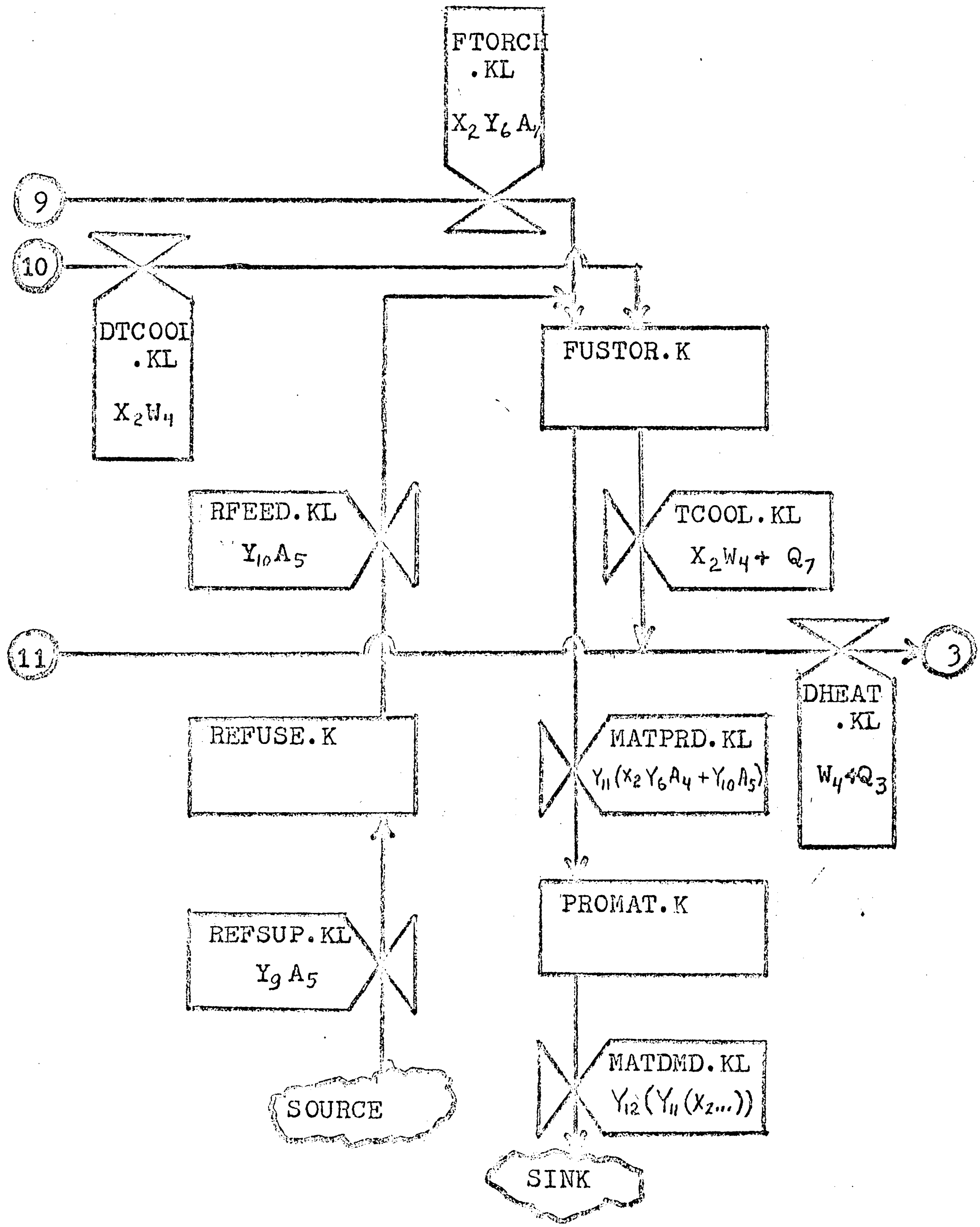


Figure 18, cont.

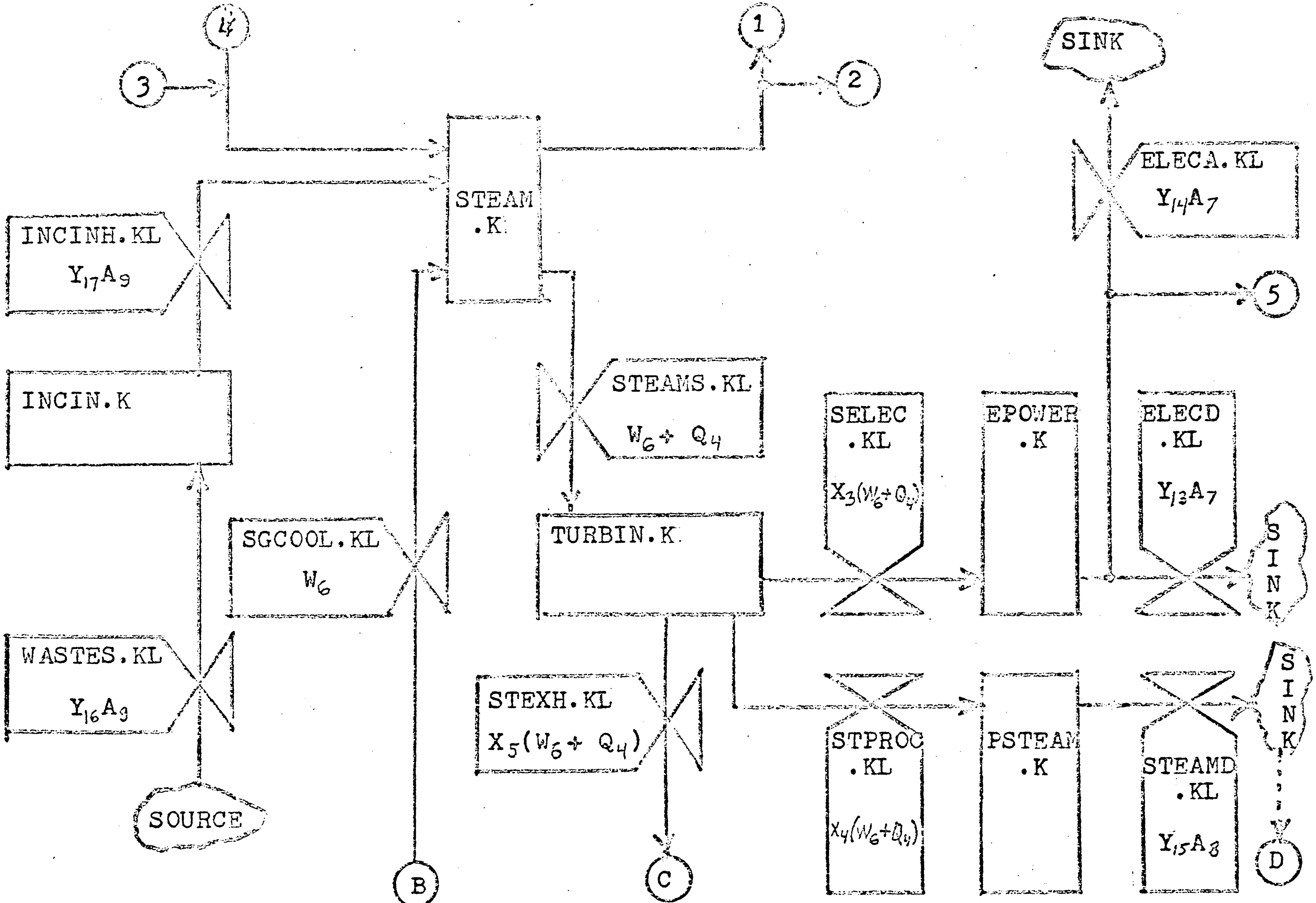


Figure 18. cont.

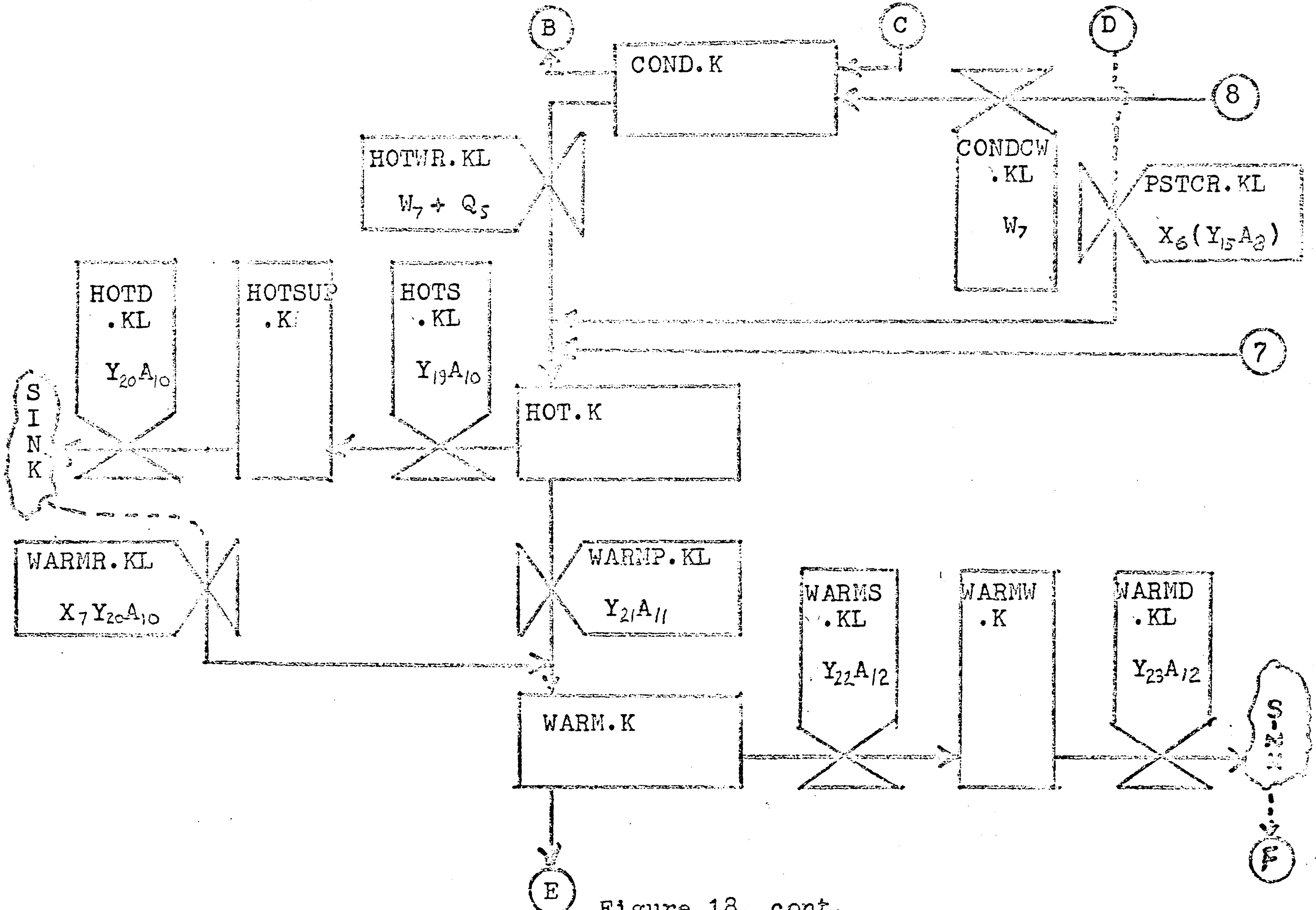


Figure 18. cont.

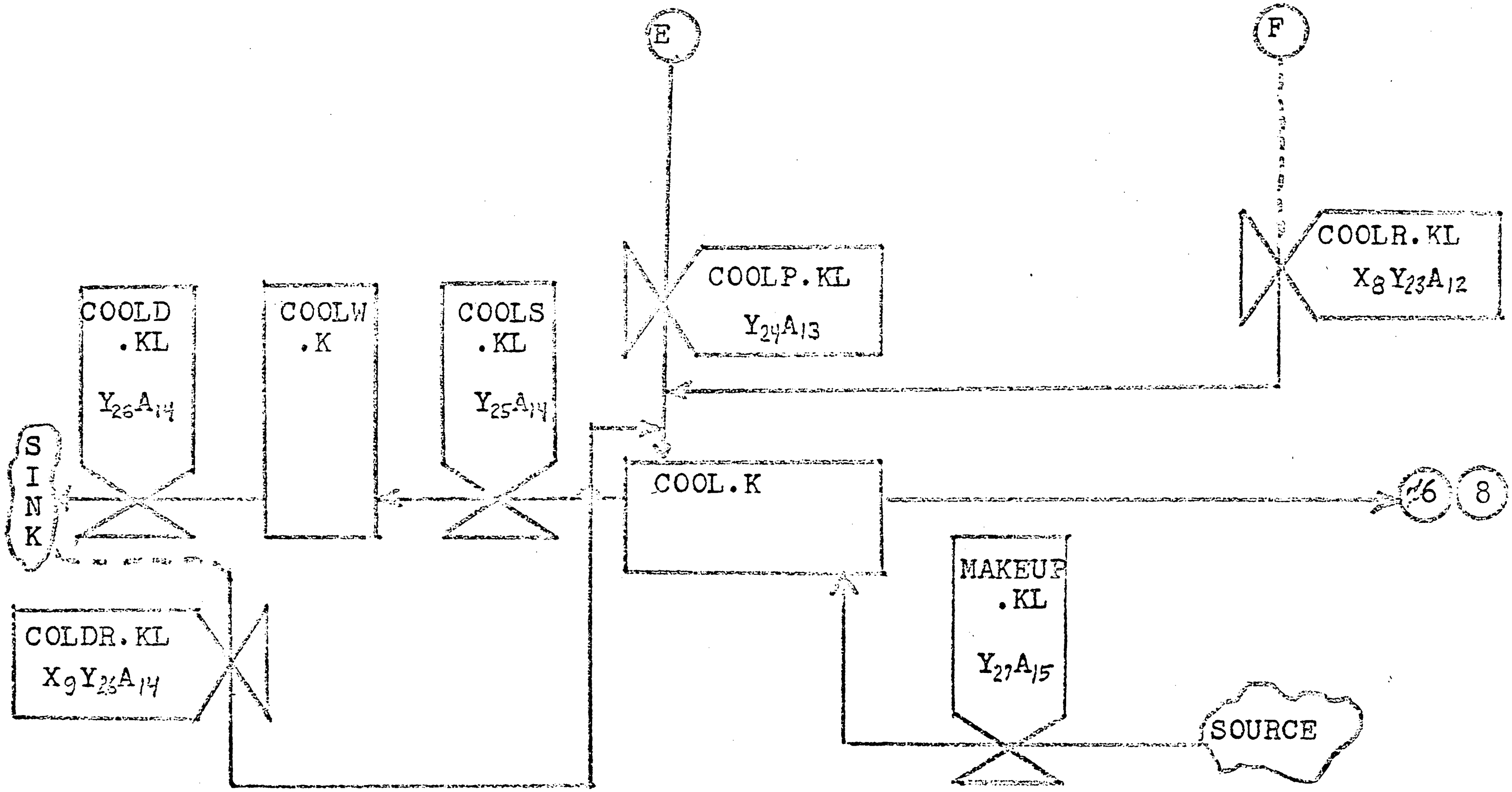


Figure 18. cont.

LEGEND

ELECIN.KL = electrical energy input to laser system
LASER.K = laser system power level
LASOUT.KL = laser ignition energy for fusion reactor

LCOOL.KL = laser system coolant (cold side)
LHEAT.KL = " " " hot "
LCOND.K = " " condenser thermal capacity level
LCONDC.KL = " condenser coolant (cold side)
LCONDH.KL = " " " hot "

DTFUEL.KL = deuterium-tritium fuel supply for fusion reactor
FCOOL.KL = reactor coolant (cold side)
FUSION.K = reactor power level
THERM.KL = reactor coolant (hot side)

NEUT.KL = neutron/X-ray production rate
NEUTRN.K = " " energy level
NEUTD.KL = " " demand from external users

PLASMA.KL = plasma exhaust rate from fusion reactor
DCOOL.KL = direct conversion system coolant (cold side)
DIRECT.K = " " " energy level

DELEC.KL = plasma supply to MHD device
DMCOOL.KL = MHD device coolant (cold side)
MHD.K = " " power level
DELECD.KL = MHD electricity demand from external users
MCOOL.KL = MHD device coolant (hot side)

REFUSE.KL = refuse supply from external sources
REFUSE.K = " " level
RFEED.KL = refuse feed rate to Fusion Torch

FTORCH.KL = plasma supply to Fusion Torch
DTCOOL.KL = Fusion Torch coolant (cold side)
FUSTOR.K = Fusion Torch energy level
TCOOL.KL = " " coolant (hot side)

MATPRD.KL = production of re-processed materials from Fusion Torch
PROMAT.K = Fusion Torch re-processed materials supply level
MATDMD.KL = external demand for re-processed materials

DHEAT.KL = direct conversion system coolant (hot side)

Figure 18. (cont.)

WASTES.KL = external supply of wastes to incinerator
INCIN.K = incinerator energy level
INCINH.KL = incinerator heat supply to steam generator

SGCOOL.KL = steam generator coolant (cold side)
STEAM.K = " " energy level
STEAMS.KL = steam supply to turbine system
TURBIN.K = turbine system power level

SELEC.KL = mechanical energy supplied to electrical dynamo
EPOWER.K = electrical dynamo power level
ELECD.KL = electricity demand from external users
ELECA.KL = electrical demand from internal auxiliaries

STPROC.KL = process steam supply rate
PSTEAM.K = " " " level
STEAMD.KL = " " demand from external users

STEXH.KL = low quality steam exhausted to condenser
CONDCW = condenser cooling water (cold side)
COND.K = condenser thermal capacity level
HOTWR.KL = condenser cooling water (hot side)

PSTCR.KL = process steam condensate return
HOT.K = hot water reservoir thermal capacity level

HOTS.KL = hot water supply rate
HOTSUP.K = " " " capability
HOTD.KL = " " demand from external users

WARMR.KL = warm water return from hot water users
WARMP.KL = " " production from thermal degradation in hot water reservoir
WARM.K = warm water reservoir thermal capacity level

WARMS.KL = warm water supply rate
WARMW.K = " " " capability
WARMD.KL = " " demand from external users

COOLR.KL = cool water return from warm water users
COOLP.KL = " " production from thermal degradation in warm water reservoir
COLD.KL = cold water return from cool water users
MAKEUP.KL = cold water makeup from external sources
COOL.K = cool water reservoir thermal capacity level

COOLS.KL = cool water supply rate
COOLW.K = " " " capability
COOLD.KL = " " demand from external users

Figure 18. (cont.)

$Q_1 = Y_2A_2 - Y_3A_2$ = excess heat recovered from laser system

$Q_2 = Y_1A_1 + Y_3A_2 - Y_4A_3 - Y_6A_4$ = " " " " fusion reactor

$Q_3 = Q_6 + Q_7$ = excess heat recovered from direct conversion

$Q_4 = Y_7A_9 + Q_2 + Q_3$ = " " " " steam generator

$Q_5 = (X_5 - 1)\ W_6 + X_5Q_4$ = " " " " condenser

$Q_6 = (1 - Y_7)X_1Y_6A_4$ = excess heat recovered from MHD device

$Q_7 = (1 - Y_{11})(X_2Y_6A_4 + Y_{10}A_5)$ = " " " " Fusion Torch

X_1 = proportion of fusion plasma energy directed to MHD

X_2 = " " " " " " Fusion Torch

X_3 = proportion of steam-turbine energy directed to dynamo

X_4 = " " " " " " process steam

X_5 = " " " " " " condenser

X_6 = proportion of process steam demand returned to HOT.K

X_7 = " " hot water " " " WARM.K

X_8 = " " warm " " " " COOL.K

X_9 = " " cool " " " " "

W_1 = coolant pump work

Y_1 = efficiency of utilization of thermodynamic potential

A_1 = optimum/ideal thermodynamic potential or availability

Figure 18. (cont.)

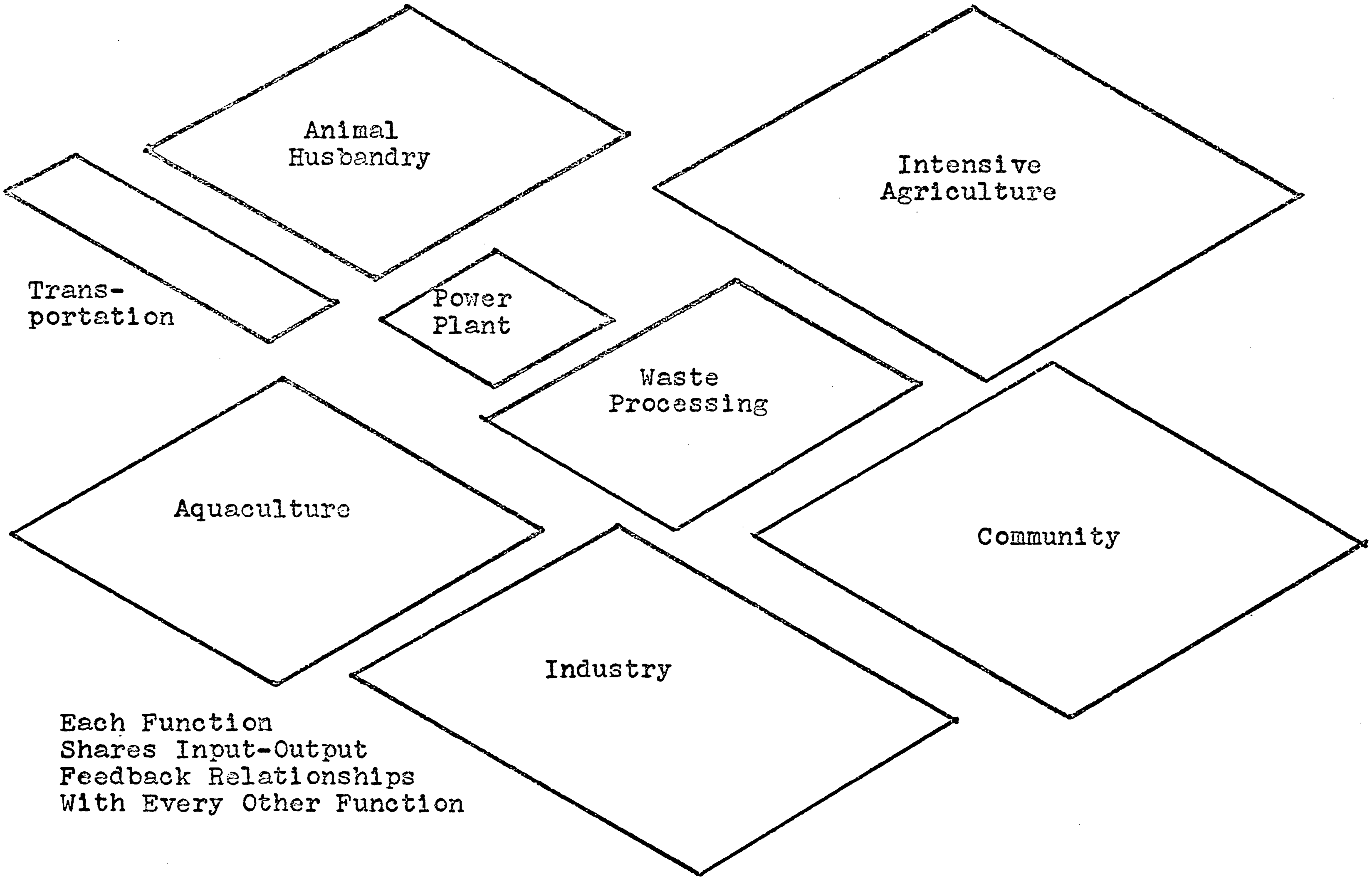


Figure 19. Total Energy System Functional Relationships

or indirectly via the central energy complex). Actual determination of a particular system design is a complex process dependent on such variables as: costs of material, labor and alternative energy sources; location, climate, site restrictions; user requirements; and interface with existing or planned facilities of a comparable nature. The following is a general procedure which allows systematic development of design data which can be tested in a Total Energy System simulation model (the laser-fusion model will be used for illustrative purposes):

1. Assess resource input sectors (in terms of 24 hour distributions for typical operating days of the year):

   a. determine fusion reactor fuel requirements.

   b. determine probable supply rate and quality distributions for solid refuse input to the Fusion Torch.

   c. determine probable supply rate and quality distributions for organic refuse input to the incinerator.

   d. determine potential makeup water rate distributions.

   e. determine other resource inputs (if any).

2. Assess user demand patterns (for 24 hour distributions for typical days):

   a. determine demand for neutron and X-ray energy.

   b. " " solid waste processing.

   c. " " organic " "

   d. " " electricity

e. determine demand for process steam.

f. " " " hot water

g. " " " warm "

h. " " " cool "

3. Assess qualitative energy requirements for user demand:

a. determine high quality requirements (in excess of 1000°C).

b. determine intermediate quality energy requirements (between 100°C and 1000°C).

c. determine low quality energy requirements (less than 100°C).

4. Assess preliminary Total Energy System design:

a. size prime quality components (fusion reactor, MHD device, Fusion Torch, lasersystem, and steam generator) to meet high quality energy demands.

b. arrange intermediate quality demand functions (process steam, hot water) so as to best utilize highest quality "cascade" potential.

c. if all intermediate quality demand cannot be satisfied, increase "prime" component capacities such that intermediate quality demand is just satisfied. Size intermediate components (hot water reservoir) according to this "cascade" relationship.

d. arrange low quality demands (warm water, cool water) so as to best utilize the "cascade" potential from the intermediate levels.

e. if low quality demands are not satisfied:

(1) use auxiliary low cost sources such as solar energy to meet excess needs.

(2) use makeup resources (such as cold water) if an equivalent amount of comparable resources can be returned to the external source (river, lake).

(3) require increase in prime and intermediate component capacities only when requirements cannot be met by (1) and (2).

f. size low quality component capacities (warm water and cool water reservoirs).

5. Use simulation model to test dynamic operation of the Total Energy System in terms of effective use of thermodynamic potential. Determine sensitivity of the system to:

a. canges in demand rates on hourly, diurnal, weekly, and seasonal bases.

b. changes in demand quality; i.e., is high quality demand of such magnitude that there is insufficient demand potential for effective utilization of the system's cascade potential?

c. spatial factors such as length of run or elevation (hydrostatic pressure).

d. alternative resource supply rates and types

e. stocastic events such as component breakdowns, adverse weather, etc.

f. "non-energy" constraints (legal, environmental, political, etc.).

6. Assess system economic feasibility:

a. determine capital costs of the Total Energy System.

b. " operating " " " " " "

c. " value of service provided to the demand sectors.

7. Iterate analysis procedure using the Principle of Minimization of Entropy until an acceptable solution is obtained. Options that do not allow effective utilization of thermodynamic potential (either directly or indirectly via cascading) should be carefully investigated for basic functional invalidity.

It is again emphasized that Total Energy System planning, design and operation inherently requires a highly cooperative behavior on the part of all participants. An increased cooperative attitude by all members of a socio-technical system, in turn, generates still more effective entropy minimizing practices. Thus a closed loop is formed which is capable of rapidly converging on optimal steady-state policies. (This closure phenomenon, interestingly, is also found in non-equilibrium thermodynamics as the "limit cycle").

In summarizing this chapter, it is recognized that many people are seriously questioning the roles of engineering, science and technology as major contributors to the

"Limits to Growth" crisis. The thrust of this study has been an attempt to understand the fundamental requirements of steady-state policy and to illustrate how the science of thermodynamics, the engineering concept of thermodynamic analysis, and the technological concept of the Total Energy System can contribute to the expeditious attainment of otimal steady-state conditions. The scientist-engineer-technologist (using minimization of entropy methods) shares equally with the social scientist-humanist (using methods emphasizing cooperative behavior) the fundamental responsibility for achievement of an optimal steady-state world system.

CHAPTER 4 FOOTNOTES

55. R. Stephen Berry. "Recycling, Thermodynamics, and Environmental Thrift." in R.S. Lewis and B.I. Spinrad (eds.) The Energy Crisis. Chicago: Education Foundation for Nuclear Science, 1972, p. 88.

56. The crux of thermodynamic analysis is recognition that pollution is nothing more than a misplaced resource which can, with proper planning, be matched with a function that will put it to useful purpose.

57. Derek Bryan. "Alternative Futures: China- A New Society in the Making." Futures, vo. 4, no. 4, Dec 1972. pps. 363-9.

58. Charles A. Berg. "A Technological Basis for Energy Conservation." Technology Review, Feb 1974, p. 18.

59. R.A. Gaggioli."The Concepts of Thermodynamic Friction, Thermal Available Energy, Chemical Available Energy and Thermal Energy." Chemical Engineering Science, vol. 17, 1962, pps. 523-530. Gaggioli has shown that the friction factor T_C/T_H applies universally to the triology of entropy production: mechanical, chemical, and thermal. Thus, with mathematical elaboration, the following (essentially thermal cycle) derivation can be extended to all physical phenomena.

60. D.O. Lee and W.H. McCulloch. "A New Parameter for Evaluating Energy Systems." Proceedings , 8th Intersociety Energy Conversion Conference, 1973. Washington, DC: American Chemical Society, p. 417.

61. ibid.

62. The relation $y = YA_Y = W_u + Q$ is a measure of the degree to which the ideal or optimum potential was actually used. The formulation of potential can take several forms, the most popular being those of Helmholtz and Gibbs; the formulation used in this study is that of Helmholtz:

Starting with the First Law: $dE = dQ + dW$
where E = the original or internal energy of the system
Q = heat transfer by the system (- if rejected, + if received)
W = work performance (- if done by the system on its environment; + if done on the system by the environment)

if the pressure of the system environment is constant:

$$dW = - pdV$$
$$dE = dQ + dW = dQ - pdV$$
$$\therefore dQ = dE + pdV$$

from: I. Prigogine and R. Defay. Chemical Thermodynamics. (trans. by D.H. Everett). London: Longman Green, 1954, p. 36: ...taking the Second Law:

$$dS = \frac{dQ}{T} + \frac{dQ'}{T}$$ where: $dQ' = 0$ for reversible process; $dQ' > 0$ " irreversible "

...combining the First and Second Laws:

$$dE = TdS - pdV - dQ'$$

It is the further utilization of the "wasted" potential dQ' that is of importance to alternative technology thermodynamic analysis.

63. In this hypothesis it is assumed that any cascaded use of dQ' (i.e., Q_H or Q_C) minimizes overall entropy production in the global system by precluding unnecessary duplication of original resource throughput by the functions that are able to use the cascaded resources.

64. Charles A. Berg. "A Technical Basis for Energy Conservation". Mechanical Engineering, May 1974, p.33.

65. Frank L Parker, Peter A. Krenkel. CRC Physical and Engineering Aspects of Thermal Pollution. Cleveland: CRC Press, 1970, p. 28. "...the waste heat from power generation would be more than sufficient to heat every home in America."

66. R.T. Jaske, "An Evaluation of Energy Growth and Use Trends as a Potential Upper Limit in Metropolitan Development." The Science of Total Environment, vol. 2, 1973, P. 53.

67. S.E. Beall. Total Energy Applications: Industrial, Urban, Agricultural. Oak Ridge, Tenn: ORNL, Jun 1973. A.J. Miller, et. al. Use of Steam Electric Power Plants to Provide Energy to Urban Areas. Oak Ridge, Tenn: Jan. 1971, p. 1: the authors note that such development will require new planning, funding, approval, construction and management machinery.

68. ibid.

69. The Soviets, however, have developed a concrete insulated single-pipe system that has proven capable of distributing 400°F water at distances of as much as 140 miles at costs roughly 2/3 the cost of comparable (conventional) two-pipe systems. R.M. Diamant. Total Energy. Pergamon Press, 1970, p. 334.

70. D.C. Leslie. "Connah's Quay: The Interaction of Nuclear Power and the Environment." Annals of Nuclear Science and Engineering, Jan 1974, pps. 10-19. Connah's Quay is a Welsh town near Liverpool, England, where three major functions (a New Town, nuclear power plant, and water storage reservoir) competed intensively for exclusive use of basically the same site... with the result that there has been an indefinite stalemate, with none of the functions being satisfied. While fission power plants are to be treated with extreme caution, careful planning and development using the Total Energy concept could have allowed satisfaction of all three functions; most likely at a considerable overall cost savings.

71. Nicolas Wade. "Windmills: The Resurrection of an Ancient Energy Technology." Science, 7 Jun 1974, p. 1056.

72. Wilson Clarke. "Interest in Wind is Picking Up as Fuels Dwindle." Smithsonian, 1974, p. 71.

73. Wade. op. cit.

74. G. W. Leonard. "Total Energy Community." The Military Engineer. Dec 434, Dec 1974, p. 354. The U.S.Navy's China Lake program for development of comprehensive Total Energy System criteria for both civil and military use is perhaps the most significant T.E.S. experiment presently being conducted in the U.S.

75. Fossil fuels may not be in as short a supply as it appears at the moment .. but even under the most optimistic of futures, their reserves are being unnecessarily depleted. Further, there is every reason to assume that these hydrocarbon resources will be in even greater demand than they are presently as chemical feed stocks. Nuclear fission is perhaps one of the greatest technolgoical threats to the future of mankind. Few, if any, energy needs warrant the enormous inefficiency, security, safety and long-term public health risks involved in the use of nuclear fission power.

76. The fusion research community is unusually conservative in their progress estimates; however, in spite of differences in terminology, basic scientific feasibility has been established in numerous experiments in recent years.

77. William C. Gough and Bernard J. Eastlund. "Fusion Torch: Closing the Circle from Use to Reuse. Germantown, MD: U.S. Atomic Energy Commission, 15 May 1969, p. v. Also, William C. Gough Why Fusion? Controlled Thermonuclear Research. Program. Germantown, MD: A.E.C., Jun 1970, p. 591.

78. Neutron bombardment of reactor walls will cause production of some short half-life materials that can be easily managed and are not of weapons grade character.

79. ibid.

80. John Nuckolls, John Emmett, and Lowell Wood. "Laser Induced Thermonuclear Fusion." Physics Today, Aug 1973, p. 53. "...fusion energy pulses, as extremely high-grade energy sources, apparently admit to several very different means of converting their energy into electricity ... three types of systems have been identified thus far: (1) ordinary thermal conversion; (2) MHD hot-gas generator conversion; (3) MHD plasma conversion .. the efficiency of MHD is limited by the efficiency with which X-ray energy may be converted to electrictiy ... the basic feasibility of such fireball-to-electricity energy conversion has already been demonstrated. Low capital cost, high efficiency (greater than 70%) electrical energy generation may thus be ultimately attainable ... estimates indicate that laser-fusion power plants will be economically feasible."

81. MHD is essentially an expansion engine which transforms the total heat (enthalpy) of the plasma into some other form of energy, such as electricity. As compared to the piston or turbine engine, it is extremely simple in design ... and as a consequence, it provides a significant increase in intrinsic power handling capacity and potential reliability, ... including the ability to handle the very high temperatures produced in fusion plasmas. A MHD plant has virtually unlimited single unit rating... it can reach very high overall plant efficiences when used for base demand loading (thus reducing thermal pollution); while for emergency or peaking power, MHD has an extremely short (1-5 sec) start-up and a rapid response (milliseconds) to load variations. Cost estimates indicate significant savings in construction and operating costs (approximately 50% less than the cost of a nuclear plant; about 25% less than the cost for a conventional fossil plant). Richard J. Rosa. "MHD Power Generation" IEEE Transactions on Plasma Science, May 1973, pps. 3-5.

82. editorial. "Laser Fusion" Energy Conversion, 1973, p. 140.

83, L.A. Booth. Central Station Power Generation. Los Alamos, NM: LASL Report LA - 4858 MS, vol. 1, Feb 1972, p. 1: " The ICTR (inertially confined thermonuclear reactor) consists of concentric spherical vessels (shells) in which the TN (thermonuclear) energy is derived from D-T (deuterium-tritium) burn within a "pellet" located at the center of the vessels and initiated by a laser pulse. The resulting alpha particle energy and a small fraction of neutron energy are deposited within the pellet... this pellet energy is eventually transformed into sensible heat of Lithium in a condenser outside the vessels. The remaining neutron energy is dissipated in a Lithium blanket, located within the concentric shells, where the fuel ingredient, tritium, is also produced. The heat content of the blanket and of the condenser lithium is eventually transferred to a conventional Rankine steam cycle plant."

84. When the term, laser-fusion, is used in this study it is intended to include other inertial confinment schemes such as electron beam systems, though the latter technology differs significantly from the laser approach. Magnetically confined systems are largely ruled out due not only their enormous engineering problems, but also because of their overly large plant sizes (in excess of 5000 MW) and great requirement for scarce construction materials ... which make it unlikely that such reactor systems could play an appropriate role in future energy technology.

85. Gough and Eastland. op. cit.

86. W.C. Wolkenhauer, B.R. Leonard Jr, B.F. Gore. "Transmutation of High Level Radioactive Waste With A Controlled Thermonuclear Reactor." Richland, WASH: Battelle Pacific Northwest Laboratories, July 1973, p. 87-88.

87. Gough, Why Fusion?, op. cit., p. 310. This closing of the resource circle via recycling is particularly attractive when Gough and Eastland note that, at 1965 rates, the U.S. will by the year 2000 generate roughly 10 billion tons of solid refuse; which, if compacted and buried to a depth of 20 feet, would require a land area the size of Rhode Island. Gough and Eastland. op. cit. Additionally, Heer and Hagerty point out that, at the U.S. solid waste production rate of 0.9 tons per person per year, the conservative fuel value of solid wastes is equivalent to 45 million tons of coal per year ... not even considering the energy required to mine and haul the coal or repair the damage done by strip mining. John E. Heer, Jr, and D. Joseph Hagerty. "Refuse Turns to Resource". IEEE Spectrum, Sep 1974, p. 83.

88. Zeinab A. Sabri. _A Study on the Feasibility of Fusion Torches_. unpublished PhD dissertation, Madison: University of Wisconsin, 1973, p. 5.

89. _ibid_.

90. _ibid_.

91. The DYNAMO computer program follows explicitly from Figures 17 and 18; however, it is simplified in order to present the basic procedure for constructing Total Energy System simulation models. The model is not intended to reflect actual system dynamics and the values used in the model have no particular significance except to allow the model to run in a computer using a DYNAMO compiler. In order to use the model in a practical fashion it is necessary to obtain realistic initial values, rate of flow values, probable supply and demand distributions, and (most importantly) characteristics for system feedback relationships. Effort should also be made to create stochastic features in Total Energy System models.

92. See Jay W. Forrester, _Principles of Systems_. Cambridge, Mass: Wright-Allen Press, 1968, for a detailed explanation of Systems Dynamics modeling; see Alexander L. Pugh III, _DYNAMO II Users Manual_. Cambridge, Mass: MIT Press, 1973, for a detailed explanation of DYNAMO simulation.

Total Energy Systems analysis should always use continuous system simulation languages such as DYNAMO or CMSP or a hybrid (discrete-continuous) language such as SMOOTH. If it can be assumed that the feedback relationships are essentially linear, then it may prove useful to use Goal programming to attempt a "satisfying" solution (as opposed to a global optimum). If Goal Programming is used, however, FORDYN must be used in place of DYNAMO.

CHAPTER 5

SUMMARY AND SUBJECT FOR FURTHER RESEARCH

A. Summary

The subjects of this study can be summarized by responding to Herman Daly's questions concerning steady-state policy criteria; specifically, Daly asked:[93]

1. At what levels should stocks of wealth and population be maintained constant?

2. What is the optimal level of maintenance throughput for a given level of stocks?

3. What is the optimal time horizon or accounting period over which population and wealth are required to be constant?

4. What is the optimal rate of transition from the growth economy to the steady-state economy?

5. What means are appropriate for attaining the the steady-state goals?

In considering responses to Daly's queries, it was neccessary to first identify mankind's ultimate cultural responsibilities:

1. Maximize the future horizon for humanity

2. Provide a satisfactory quality-of-life for all of humanity.

Using the First and Second Laws of Thermodynamics in conjunction with Einstein's relativistic mass-energy law, it was found that the maximization of the future requires strict adherence to resource policies that minimize entropy in the global system. Identifying a fundamental "reversible" relationship between the concept of thermodynamic equilibrium and the concept of the Golden Rule, it was found that provision of a satisfactory quality-of-life for all mankind requires adherence to cultural policies that minimize cultural "friction" or cultural entropy. This physical-cultural relationship involving minimization of "friction" or entropy suggested the existence of a common natural law foundation: The Goal of Maximum Stability (i.e., the perfectly efficient state characterized by the total absence of "friction" or entropy). It was recognized that the importance of this law (which is the most fundamental of all natural laws) is not simply its ideal, unachievable character, but rather its value as a perfect, unambiguous standard against which the consequences of any real activity can rationally be determined. It was, therefore, concluded that the optimal steady-state policy criteria Daly is seeking are:

1. The Principle of Minimization of Entropy (when involved with essentially physical phenomena in which the concept of thermodynamic equilibrium can be meaningfully used as the ideal standard for judging performance).

2. The Principle of Cooperative Behavior (when involved with essentially cultural phenomena in which the concept of the Golden Rule can be meaningfully used as the ideal standard for judging performance).

These policy criteria can be unambiguously applied both at the individual (micro or local) level or at group/society (macro or global) level; however, micro level compliance with steady-state criteria is a pre-condition to the successful achievement of macro level steady-state conditions. These criteria are presented as ecologically suitable alternatives to current decision criteria, such as the "Invisible Hand" or "Rational Selfishness".

The Principle of Minimization of Entropy was embedded in Forrester's World Dynamics simulation model and found to provide steady-state world system responses that project the potential for an infinitely distant future horizon for mankind as well as a satisfactory quality-of-life for all of mankind. The World Dynamics simulation method provides a powerful menas for providing more specific answers to Daly's first three questions concerning basic steady-state goals.

The latter part of the study was devoted to determining responses to Daly's last two questions concerning steady-state transition requirements. It was found that minimization of entropy was the defining condition for any steady-state system, including a world system; further, that macro or global steady-state stability can result only as the culmination of the achievement of steady-state conditions by subsystems starting from the local or individual level. Thus, in order to provide for global welfare priority must be given to first insuring satisfaction of local welfare;i.e., the privileged sectors of world society must immediately take steps to insure provision of a basic subsistence ability for all members of the world population. The practical means for this achievement are characterized as low entropy methods -- which are, in fact, readily accessible worldwide. These methods are "self-help" methods; their effective implementation, however, requires the initial aid of agencies skilled in the practice of steady-state technology, particularly biotechnology. Such implementation requires the full support of the world's currently privileged classes, who,(if they are unsympathetic to altruistic motives) must come to comprehend that their own long-term interests (if not their more immediate welfare) rests on providing the earliest possible global equity in terms of basic quality-of-life needs.

Lastly, it was recognized that appropriate technology must be identified and developed to support optimal transition to the steady-state world system. The concepts of thermodynamic potential and thermodynamic analysis were related to the Principle of Minimization of Entropy and together were used to develop:

1. A Decision Tree Analysis procedure for Biotechnic Energy Systems.

2. A computer simulation procedure for more complex Total Energy Systems analysis.

Such procedures provide practical means for determining optimal solutions to the technical problems that have tended to magnify the "Limits to Growth" crisis.

B. Subject for Further Research

In closing Limits to Growth, Meadows observed:[94]

> (Man) has all that is physically necessary to create a totally new form of human society - one that would be built to last for generations. The two missing ingredients are a realistic, long-term goal that can guide mankind to the equilibrium society and the human will to achieve that goal... with that goal and that commitment, mankind would be ready to begin a controlled, orderly transition from growth to global equilibrium.

This study has analytically demonstrated optimal criteria for achieving and maintaining the steady-state world system. Further, it has contributed technological concepts appropriate for transition to the steady-state. Yet, none of this work (or similar work by many others) guarantees that man will, in fact, subscribe to the steady-state goal; or commit himself to the rational, low entropy-type policies steady-state achievement requires. A common question today is: "Is mankind evolving or degenerating?" Observations of human experience could affirm either direction. This ambiguity is implied in Meadows' admonishment, as it has been implied throughout the development of man's fundamental understanding of the meaning of existence. It is perhaps most evident in the apparent paradox between the cosmic interpretation of the Second Law of Thermodynamics and the Theory of Evolution:[95,96]

> In thermodynamics the second law is formulated as the Carnot-Clausius principle. It appears essentially as the evolution law of continuous disorganization ... i.e., of disappearance of structure introduced by initial conditions.
>
> The extension of the thermodynamic concept of evolution to the world as a whole, leads to the idea that "structure" originated in some far distant "golden age". Since then, chaos is progressively taking over.
>
> In biology or in sociology, the idea of evolution is, on the contrary, closely associated with an increase of organization giving rise to the creation of more and more complex structures... (quoting) Bergson: "...duration means invention, creation of forms, continuous elaboration of what is absolutely new."

One aspect of the above paradox is that each position appears to totally exclude the other, causing a serious quandary, since these questions determine man's fundamental perception of the meaning of life. Resolution of this paradox is essential to understanding the motivational requirements for transition to a steady-state world system. (Einstein, for example, considered the Second Law as the most fundamental law of nature and the least likely to ever be invalidated.[97] Yet, the Second Law clearly has demoralizing undertones that seem incompatible with the positive outlook needed for commitment to the concept of a long-term, evolutionary future.)

Clues to solving this paradox may have been recognized a century ago by Herbert Spencer, who essentially integrated the Second Law interpretation (tendency towards uniformity) and the evolutionary interpretation (tendency towards elaboration) in a dual relationship:[98]

> ...growth consists of an increase in substance, while development consists of an increase in structure. Growth is usually manifested by a proliferation of structural elements already present, while development is marked by the rise of new structural elements. Growth, therefore, is essentially quantitative, while development is essentially qualitative. One can occur without the other, but ... evolution, in the full sense of the term, comprehends both.
>
> ... a duplex relation exists between growth and structure ... beyond a certain point there cannot be further growth without further organization ... the only way in which a society can accommodate continued growth is by periodically elaborating its structure...

Since the 1940's Ilya Prigogine (who first derived the Theorem of Minimum Entropy Production as the defining condition for a steady-state system) has followed a similar logic. In recent years, he and his associates have concentrated on a thermodynamic theory which, while recognizing the supreme position of the Second Law in the universe, allows evolutionary development or elaboration of structure "locally" (i.e., in any subspace/subsystem of the universe such as Earth).[99,100]

In a manner reminiscent of Boltzmann (whose cosmology defined all structure as the consequence of fluctuations)[101], Prigogine has extended Einstein's fluctuation formula such that it becomes a basic evolutionary mechanism. Of particular importance to the cultural implications of a steady-state world system are the following inferences in Prigogine's work:

1. The more stable the world system, the greater the probability of a qualitative or evolutionary development in human culture; i.e., the closer a system approaches equilibrium, the greater the number of degrees of freedom or opportunities for a successful or evolutionary fluctuation.[102]

2. Evolution is characterized by increasing emphasis on the ability of the evolving systems to manage information (i.e., regulation, storage, retrival and transmission) as a primary means of maintaining new and increasingly coherent regimes.[103]

3. All evolutionary development is strictly dependent on the character of a single microscopic fluctuation. As a consequence, a single small-scale example is fully sufficient to cause a macroscopic change in the entire cultural system to some new evolutionary level.[104] This phenomenon suggests a vitally important answer to those people who desire a steady-state world system, but who are presently intimidated by the overwhelming complexity of their lives. Where individual/local complacency or intimidation presently allows gross degradation of the natural management ability inherent in humanity, individuals and small groups subscribing to the principles of entropy minimization and cooperative

behavior can, in fact, set "self-help" examples (as opposed to relying on higher authorities) which will lead all of humanity into a low-entropy, non-materialistic steady-state world system which optimally supports cultural evolution.

4. Evolution is not a continuous process; thresholds appear to be involved which tend to "frustrate" continuous growth efforts. As a consequence, overall evolution appears as a cyclic process of (a) initial equilibrium, (b) evolutionary fluctuation, (c) equilibrium seeking, (d) evolutionary fluctuation, etc. This evolutionary "threshold" appears to be the basic mechanism involved in such modern physical phenomena as lasing, tunneling, and fusion plasmas. Erich Jantsch has advanced as equivalent interpretation for cultural phenomena.[105]

5. An evolutionary fluctuation is always a highly non-linear process characterized by some type of auto-catalytic effect.[106]

Prigiogine has identified the basic evolutionary fluctuation mechanism as the following catalytic or feedback function:[107]

$$\begin{array}{ccccccc} A & \rightleftharpoons & X & \rightleftharpoons & Y & \rightleftharpoons & B \\ & & & & \upharpoonleft\downharpoonright & & \\ & & & & M & & \end{array}$$

where: A = input activity
B = output "
X,Y = intermediate "
M = catalytic "

This problem is adaptable to the methods of Systems Dynamics since the latter can readily simulate complex non-linear feedback systems. In this manner it may be possible to study positive (anabolic) evolutionary dynamics caused by fluctuations as well as negative (catabolic) evolutionary dynamics manifested by the Second Law of Thermodynamics. Application of Systems Dynamics techniques to Prigogine's thermodynamic concepts will allow development of an "Evolutionary Dynamics" model that extends the analysis begun by Forrester's "World Dynamics" model. Such an extension will allow investigation of the basic forces shaping human perception of the future and thus the ability to be motivated towards the goals of a steady-state world system.

CHAPTER 5 FOOTNOTES

93. Daly, op. cit., p. 155.

94. D. H. Meadows, op. cit., p. 188.

95. P. Glansdorff and I. Prigogine. Thermodynamic Theory of Structure, Stability and Fluctuations. New York: John Wiley, 1971, p. 287.

96. With regard to the concept of "survival of the fittest" (which, interestingly, is essentially an inverted Golden Rule or "Invisible Hand"-type concept), it is likely that Darwin has been grossly misinterpreted or misrepresented. Ernst Mayr. "The Nature of the Darwinian Revolution." Science, vol. 176, 2 Jan 1972, p. 989: "... in all recent discussions of natural selection, the assumption is made that the concept traces back to Adam Smith, Malthus, and Ricardo, with emphasis on competition and progress. This interpretation overlooks the point that the elimination of "degradation of the type" ... does not lead to progress ... Darwin was the first to see clearly that a second factor was necessary, the production of a new variation ... Selection can be creative only when such new variation is abundantly available."

97. Benjamin Gal-Or (ed.) Modern Developments in Thermodynamics. New York: John Wiley, 1974. Appendix listing of similarly notable comments on the laws of thermodynamics.

98. Robert L. Carneiro. "The Measurement of Cultural Development in the Ancient Near East and Anglo-Saxon England." Transactions of the New York Academy of Science, 1969, pps. 1020-1.

99. Ilya Prigogine. Introduction to Thermodynamics of Irreversible Processes. New York: Wiley-Interscience, 1961, p. 83: "... in the stationary state all state variables are independent of time. Thus, a positive entropy production has to be compensated by a negative flow of entropy (negentropy) in such a way that the total time variations of entropy is zero:

$$\frac{dS}{dt} = \frac{d_eS}{dt} + \frac{d_iS}{dt} = 0$$

since, in accordance with the Second Law: $\frac{d_iS}{dt} \geqslant 0$, then

$\frac{d_eS}{dt} < 0$, or in terms of the derivation in this study: $\Delta S = -\Delta N$, i.e., a consumption of negentropy or natural resources leads to an equivalent increase in entropy (S), or (d_iS) in Priogine's terminology.

Prigogine moves from this point to state that the evolutionary state can be maintained indefinitely provided the system can reach a steady-state such that: $dS = 0$, or equivalently: $-d_eS = d_\lambda S > 0$

"... in principle, at least, if we supply a system with a sufficient amount of negative entropy flow we can maintain the system in an ordered state." This principle is the basis for all life. In addition, the biosphere as a whole is subject to a similar negentropy gradient from the sun. It is this solar gradient (when referenced to the cold sink in space) that allows the biosphere to do the work of life. Thus, evolution is possible in the biosphere as long as negentropy is supplied by the sun and entropy is dissipated into space -- where the Second Law of Thermodynamics is making its ultimate accounting of the "cost" of evolution of life on Earth. (Tryon has carried this argument to the limits of the universe. See Edward P. Tryon, "Is the Universe a Vacuum Fluctuation?", _Nature_, Dec. 14, 1973, pps. 396-7.)

100. I. Prigogine, _et. al_. "Nonequilibrium Problems in Biological Phenomena." _Annals of the New York Academy of Sciences_, Vol. 231, 1974, p. 104. In the question period Jay Portnow (Woods Hole Observatory) made a useful observation concerning potential misinterpretation about what Prigogine means by a "dissipative" or evolutionary structure: "The point that has not been fully appreciated ... is that dissipative structures are structures that require a minimum level of (entropy) dissipation. The important point is the requirement of a minimum, finite level of dissipation ... of course, biological systems are open, but the notion of dissipative structure goes further; it requires a minimum, finite flow of entropy through the system." The significance of this observation is the inference that evolution is a qualitative development involving entropy minimizing mechanisms which can actually reduce the entropy associated with the evolving structures or systems.

101. Ilya Prigogine. "Time, Structure and Entropy." in Jiří Zeman (ed.) _Time in Science and Philosophy_. New York: Elsevier, 1971, p. 91.

102. Ilya Prigogine. (panel discussion) in E.B. Stuart, B. Gal-Or, A.J. Brainard (eds.) _A Critical Review of Thermodynamics_. Baltimaore: Mono Book Co., 1970, p. 295.

103. I. Prigogine _et. al._, _op. cit._, p. 99.

104. P. Glansdorff and I. Prigogine. _op. cit._, p. 105.

105. Erich Jantsch. "Organizing the Human World: An Evolutionary Outlook." Futures, Vol. 1, no. 1, Feb. 1974, pps. 4-7.

106. Glansdorff and Prigogine, *op. cit.*, p. 82. By autocatalytic Prigogine means that the "same compound has to fulfill at least two different functions in the same reaction scheme." This concept, interestingly, is popular in science and philosophy as a basic mechanism for describing the unity of existence; examples include: the Bootstrap theory of modern physics (hadrons); Buddhist philosophy (pearls of Indra's necklace); Leibniz's monodology (monods); and General Systems Theory (holons). Richard Bellman's dynamic programming (invariance) is a pragmatic example of the concept.

107. Prigogine (in Zeman), *op. cit.*, p. 97.

108. Glansdorff and Prigogine, *op. cit.*, p. xxii: "We must study 'molecular ecology', analyse the order in terms of population dynamics and compare it with the order in equilibrium systems."

109. Erich Jantsch (*op. cit.*) has made an initial effort at interpreting Prigogine's concepts at the level of human cultural development. See also Erich Jantsch, *Design for Evolution*. Amsterdam: Elsevier, 1974.

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APPENDIX A

THE GOLDEN RULE

As Marcus Singer has observed:[110]

> There is probably no principle which has been so widely accepted and remained so controversial. Nonetheless, the Golden Rule has been the subject of comparatively little philosophical discussion.
>
> The Golden Rule has been widely accepted, in word if not in deed, by vast numbers of greatly differing peoples; it is a basic device for moral education; and it can be found at the core of innumerable moral, religious, and social codes.
>
> The Golden Rule, in one version or another, has a prominent place in all the major religions;[111] it has been enunciated by pagan philosophers both before and after Christ... by Sophists (Isocrates) and anti-Sophists (Aristotle)...[112]
>
> There are no detectable historical traces which could explain this (universalism), and the historical diffusion theory is worthless as an explanation here. The nearly universal acceptance of the Golden Rule and its promulgation by persons of considerable intelligence, though otherwise of divergent outlooks, would therefore seem to provide some evidence for the claim that it is a fundamental ethical truth.

The position taken in the main body of this study is that the Golden Rule is something more than a fundamental ethical truth. It is, in reality, the cultural manifestation of (and as such, helps identify) the most fundamental of natural laws: The Goal of Perfect Stability. In the physical realm the Golden Rule is paralleled by the concept of thermodynamic equilibrium (which is the ultimate goal of the Second Law of Thermodynamics). A similar interpretation is found in Thomas Hobbes' conclusion:[113]

> The Golden Rule is the sum ... of all the Laws of Nature

It was further shown that the Golden Rule could be formally related to the concept of thermodynamic equilbrium by their common dependency on the defining mechanism of "reversibility" (i.e., perfect stability, perfect efficiency, freedom from dynamic friction or entropy, or reciprocity). Minimization of "friction" or entropy was then determined to be the policy criterion that best complied with the dictates of nature's fundamental, stabilty seeking law. This finding was used to develop practical decision criteria for achievement of optimal stability on Earth (specifically, the Principle of Minimization of Entropy, using thermodynamic equilibrium as an ideal standard, for essentially physical problems; and the Principle of Cooperative Behavior, using the Golden Rule as an ideal standard, for essentially cultural phenomena).

Paul Weiss has made an observation which has enormous importance with respect to the problem of determining exactly what type, and in what manner, aid sould be given in order to assist the world's present underprivileged peoples in achieving the local stability that is required as a first step towards achievement of global steady-state conditions. He suggests a corollary to the Golden Rule which he calls:

> The Maxim of Dynamic Tolerance: Do to others that which enables them to do what they can (for themselves).[114]

> ...men require not merely the object of their desires but the satisfaction which ensues when they obtain the object through their own efforts.[115]

> The Golden Rule is not a medium for reducing all men to the level of those whose lives are harmonious because they are relatively empty, but for lifting them to the highest level man can reach.[116]

The above reasoning supports the position in the main body of this study that aid given to the world's underprivileged must be designed and offered as "self-help" methods. Self-help methods not only satisfy the ethical requirements identified by Weiss, they are also inherently the most expedient, most physically effective and least costly --- they are, fundamentally, the methods of the alternative/ appropriate technology required for establishment of an optimal steady-state world system.

The Golden Rule, however, has a potential complication that is directly related to the problem of whether mankind can actually be relied upon to act morally --- or even in his personal best interest. Singer describes this paradox as the need to distinguish between a specific (biased or local) interpretation of the Golden Rule and a general (unbiased or global) interpretation. This problem is inherent in such difficult social issues as punishment (especially capital punishment), abortion, mercy deaths, and behavioral modification.[117] Currently dominant "Invisible Hand"-type ethical codes essentially avoid this issue of micro versus macro welfare by relying on a "survival-of-the-fittest" policy that has impoverished much of humanity. Present world conditions are such as to inhibit awareness by much of the world's population that readily accessible alternatives exist which offer rapid and conclusive relief from present modes of marginal survival and degrading life-styles. In order to make the first steps towards a steady-state system capable of supporting the evolution of human culture, it is necessary to come immediately to grips with these issues.

Following the argument of the main body of this study, the paradox concerning specific versus general interpretation of the Golden Rule can be resolved by recognizing that the Golden Rule is an ideal standard, not a condition that has to be obtained (or even very closely approximated) in order to be useful. As in thermodynamics, all cultural activities must generate some "friction" or entropic expenditure. The inestimable value of the Golden Rule is that it provides a clear, comprehensible (it is known by virtually all men, and is practiced in some degree by many), essentially non-arbitrary standard for judgment of all cultural behavior. The practical decision criterion mankind seeks is the Principle of Cooperative Behavior, which uses the Golden Rule as a perfect standard against which to measure the appropriateness of actual behavior.

As in the case of applying the Principle of Minimization of Entropy with respect to physical problems, it is necessary to approach an apparent conflict of interest between an individual and society as an indicator of the existence of a more basic problem -- which must be tracked to its source, since problems are seldom, if ever, solved by dealing with their symptoms alone. There is no denying that, due to the inherent imperfection of existence -- including man, judgments will be in some degree probabilistic;[118] however, the spirit of cooperation and willingness to seek true understanding of problems can prevail by reducing the "friction" creating mechanisms in society.

As in the physical steady-state case, optimum cultural welfare requires a global stability that in turn must result as the culmination of "friction" minimizing stability at the individual level. Consequently, the best interest of the individual and society should not conflict; if they appear to, one or both parties have mis-defined their interests.

In closing, as Paul Weiss observes:[119]

> The Golden Rule is thus a principle which asks men to see one another as they are needed and used. Because it is a principle which concerns actions that are self-returning (reversible), it not only assures proper treatment to others but assures proper treatment for ourselves. He who truly serves others perfects himself.

APPENDIX A FOOTNOTES

110. Marcus G. Singer. "Golden Rule" in Paul Edwards (ed.) _Encyclopedia of Philosophy_, vol. 3, New York: Macmillan, 1967, p. 365.

111. Paul Weiss. "The Golden Rule" in _Man's Freedom_. New Haven, Conn: Yale University Press, 1950, p. 459. Various formulations of the apothegm include:

a. Confucius (500 B.C.): "What you do not like when done to yourself do not do to others." Singer, _op. cit_. This negative formulation is believed to be the first recorded statement of the Golden Rule. Spooner, however, notes that Confucius also expressed a positive form shaped as "reciprocity" or "heart to heart" which he gave a Chinese character symbol. W. A. Spooner. "Golden Rule" in James Hastings (ed.) _Encyclopaedia of Religion and Ethics_. vol. 6, New York: Charles Scribner Sons, 1962, p. 311.

b. Christ (Matthew 6-12): "All things whatsoever ye would that men should do unto you, do ye even so to them, for this is the law and the prophets." also (Luke 6-31): "And as would that men should do unto you, do ye also to them likewise." Spooner, _op. cit_.

c. Buddha: "Hurt not others with that which pains yourself." Forbes, _op. cit_.

d. Islam: "No one of you is a believer until he loves for his brother what he loves for himself." _ibid_.

e. Judaism: "What is hurtful to yourself do not to your fellowmen. That is the whole of the Torah. The remaining is but commentary." _ibid_.

f. Hinduism: "Do naught to others which, if done to thee would cause thee pain." Weiss, _op. cit_., p. 138.

g. Taoist: "To those who are good to me I am good, and to those who are not good to me I am also good. And thus all get to be good." _ibid_.

h. Zoroastrian: "That nature only is good which shall not do unto another whatever is not good for its own self." _ibid_.

i. Brahman: "One should act toward others as one would have them act towards oneself." _Ibid_.

112. example formulations include:

a. Isocrates: "Do not do to others what you would not wish to suffer yourself." Weiss, op. cit., or "Do not do to others that at which you would be angry if you suffered it from others." Spooner, op. cit., p. 311.

b. Aristotle (when asked how we should behave to our friends): "Exactly as we would they should behave to us." Aristides, Plato, and Epictetus stated similar formulations. ibid.; also Tobias and Diogenes. Weiss, op. cit.

c. Rabbi Hillel: "Whatever thou wouldest that men should not do unto thee, do not do that to them." ibid.

d. The Dooms of King Alfred: "...and that which ye will that other men should not do unto you, do ye not that to other men." Also: "Let him remember that he adjudge to no man that which he would not that he adjudge to him, if he sought judgement agaist him." Spooner, op. cit.

e. more recent supporters of the Golden Rule include Thomas Hobbes, Thomas Aquinas, John Stuart Mill, and Emmanuel Kant. Weiss, op. cit.

113. Marcus G. Singer. "The Golden Rule". Journal of Philosophy, vol. 38, no. 146, Oct 1963, p. 294. (from Hobbes' Leviathan):

a. "For the Lawes of Nature (as Justice, Equity, Modesty, Mercy, and (in summe) doing to others, as wee would be done to..."

b. Hobbes, who used the relatively rare positive form of the Golden Rule, states his Second Law of Nature as follows: "This is that Law of the Gospell: Whatsoever yo quire that others should do to you, that do ye to them."

114. Weiss, op. cit., p. 142-3: "All men use one another... usually, however, we do too much or too little. The Golden Rule offers a scale enabling us to balance the two. It is a principle of justice designed to make one give neither too much or too little; it is a guide to mercy, for it helps one to see what others truly deserve... the Golden Rule adds the element of consideration for the individuality of the other, spicing justice with mercy." In this manner, then, the Golden Rule differs from its inversions, such as the "Invisible Hand", in the sense of its mercy.

115. *ibid.*, pps. 142-4: "... men do not desire or deserve what others provide, but desire and deserve in ways and with emphases which reflect their individual nature. No man desires or deserves unremitting help. He desires and deserves only as much help and consideration as he is able and willing to use in the best possible way. And what he at once desires and deserves is good for him to have." This final point is intrinsic in Kant's interpretation of the Golden Rule: "I ought never to act except in such a way that I can also will that my maxim should become a universal law." R.M. Hare. *Freedom and Reason*. London: Oxford University Press, 1963, p. 34. This reasoning is essentially identical to that which founds the Principle of Cooperative Behavior as the policy criterion which optimally satisfies the quality-of-life needs for all of mankind.

116. There is a striking similarity between Weiss's ethical observation and similar observations made in thermodynamics by Ilya Prigogine and in biology by Herbert Spencer i.e., "the instability of the homogeneous.". Glansdorff and Prigogine, *op. cit.*, p. 287.

This hypothesis is related to the issues of evolution and steady-state stability via Einstein's fluctuation theory: "... the existence of many degrees of freedom in a (homogeneous) molecular system implies automatically the existence of fluctuations; therefore, we are really concerned with the response of the system to its spontaneous fluctuations." I. Prigogine in panel discussion following "Dynamic Foundations of Thermodynamics and Statistical Mechanics" in E.B. Stuart, *op. cit.*, p. 295. "(experiments in 1969) confirmed validity of Einstein's (fluctuation) formula for non-equilibrium patterns, at least when well defined conditions on the relaxation times are satisfied. These conditions refer to the separation of the time scales between the fluctuating system and the outside world. The time scales associated with the fluctuating system have to be much shorter than the time scales associated with the outside world, so that the state of the outside world may be considered as independent of the instantaneous state of the fluctuating system (where given boundary conditions maintain the non-equilibrium state of the fluctuating system)."Glansdorff and Prigogine, *op. cit.*, p. 97.

The interpretation that is drawn here, is that steady-state stability is essential in order to provide the opportunity for further evolution of the world system; i.e., qualitative development of new structure or thermodynamic potential ... as opposed to quantitative growth of existing structure. Conversely, failure to achieve steady-state stability allows support of only quantitative growth ... which is merely the degradation of former quality or thermodynamic potential. This is the crux of the "Limits to Growth" controversy. The second reference is of further importance in demonstrating that Earth and all of its activity is essentially the result of a macroscopic fluctuation in the universe...the latter's space being the entropic sink required in accordance with the second law: while the sun is the source of negentropy that maintains Earth as a high quality structure. For these reasons it should be clear that man must take no actions which effect the functioning of this fundamental thermodynamic relationship.

117. For example: Is life-time imprisonment, commitment to a life-time of indifference and highly probable misery, or extended, intense suffering humane or inhumane treatment? Medically-induced behavioral modification is on particularly treacherous ground because it seems so unavoidable in present cultural conditions. Are such practices sometimes a necessary entropic expenditure in the support of continuing evolution of life? These questions apply equally to man's policies and practices with respect to all other forms of life, especially animal life.

118. Prigogine has developed his theory of evolutionary thermodynamics in large part on Einstein's fluctuation theory and as a consequence concludes that life must be essentially a stochastic process. I. Priogine, et. al."Thermodynamics of Evolution". Physics Today, Dec 1972, p. 40. In a comparable interpretation of ethical evolution, John Dewey observed: "... but supposing that the principle (of the Golden Rule) were accepted in good faith by everybody; it would not at once tell everybody just what to do in all the complexities of his relations with others. When individuals are still uncertain what their real good may be, it does not finally decide matters to tell them to regard the good of others as they would their own." Singer, op. cit., p. 313.

It is in this regard that the interrelation of physical laws and cultural laws becomes useful, since uncertainty can often be reduced by recognizing needed information in another form. For example; minimization of physical entropy production supports cooperative behavior which reduces cultural "friction", and vice versa.

119. Weiss, op. cit., p. 149.

APPENDIX B

WORLD DYNAMICS MINIMIZATION

OF ENTROPY MODEL

AND

POLICY TABLES

```
*       WORLD DYNAMICS MINIMUM ENTROPY OPTIMIZATION
NOTE
NOTE
NOTE    POPULATION SECTOR
NOTE
L       P.K=P.J+(DT)(BR.JK-DR.JK)
N       P=PI
C       PI=1.65E9
NOTE
NOTE    LAND USE DENSITY
NOTE
A       CR.K=(P.K)/(LA*PDN)
C       LA=135E6
C       PDN=26.5
NOTE
NOTE    BIRTH RATE
NOTE
R       BR.KL=(P.K)(CLIP(BRNI,BRN.K,SWT1,TIME.K))(BRFM.K)(BRMM.K)(BRCM.K)(
X       BRPM.K)
C       BRNI=.04
A       BRN.K=(BRNQ.K+BRND.K)/2
A       BRNQ.K=TABHL(BRNQT,QS.K,0,3,.5)
T       BRNQT=.05/.036/.028/.024/.022/.021/.02
A         BRND.K=TABHL(BRNDT,DNR.K,-.15,.15,.05)
T       BRNDT=.0245/.025/.026/.028/.029/.0297/.03
C       SWT1=1975
A       BRMM.K=TABHL(BRMMT,MSL.K,0,5,1)
T       BRMMT=1.2/1/.85/.75/.7/.7
A       BRCM.K=TABHL(BRCMT,CR.K,0,5,1)
T       BRCMT=1.05/1/.9/.7/.6/.55
A       BRFM.K=TABHL(BRFMT,FR.K,0,4,.5)
T       BRFMT=0/.5/1/1.3/1.6/1.75/1.9/1.95/2
```

```
A       BRPM.K=TABHL(BRPMT,POLR.K,0,60,10)
T       BRPMT=1.02/.9/.7/.4/.25/.15/.1
NOTE
NOTE    DEATH RATE
NOTE
R       DR.KL=(P.K)(CLIP(DRN,DRN1,SWT3,TIME.K))(DRMM.K)(DRPM.K)(DRFM.K)(DR
X       CM.K)
C       DRN=.028
C       DRN1=.028
C       SWT3=1970
A       DRMM.K=TABHL(DRMMT,MSL.K,0,5,.5)
T       DRMMT=3/1.8/1/.8/.7/.6/.53/.5/.5/.5/.5
A       DRPM.K=TABHL(DRPMT,POLR.K,0,60,10)
T       DRPMT=.92/1.3/2/3.2/4.8/6.8/9.2
A       DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
T       DRFMT=30/3/2/1.4/1/.7/.6/.5/.5
A       DRCM.K=TABHL(DRCMT,CR.K,0,5,1)
T       DRCMT=.9/1/1.2/1.5/1.9/3
NOTE
NOTE    CAPITAL INVESTMENT SECTOR
NOTE
L       CI.K=CI.J+(DT)(CIG.JK-CID.JK)
N       CI=CII
C       CII=.4E9
A       CIM.K=TABHL(CIMT,MSL.K,0,5,.5)
T       CIMT=.1/.5/1/1.4/1.8/2.1/2.4/2.6/2.8/2.9/3
NOTE
NOTE    CAPITAL INVESTMENT GENERATION RATE
NOTE
R       CIG.KL=(P.K)(CIM.K)(CLIP(CIGN1,CIGN.K,SWT4,TIME.K))
C       CIGN1=.05
A       CIGN.K=(CIGNG.K+CIGND.K)/2
```

```
A       CIGNQ.K=TABHL(CIGNQT,QS.K,0,3,.5)
T       CIGNQT=.04/.033/.03/.028/.027/.0265/.026
A       CIGND.K=TABHL(CIGNDT,DNR.K,-.15,.15,.05)
T       CIGNDT=.025/.026/.028/.03/.035/.037/.038
C       SWT4=1975
NOTE
NOTE    CAPITAL INVESTMENT DISCARD RATE
NOTE
R       CID.KL=(CI.K)(CLIP(CIDNI,CIDN.K,SWT5,TIME.K))
C       CIDNI=.025
A       CIDN.K=(CIDNQ.K+CIDND.K)/2
A       CIDNQ.K=TABHL(CIDNQT,QS.K,0,3,.5)
T       CIDNQT=.032/.027/.025/.023/.022/.0215/.021
A       CIDND.K=TABHL(CIDNDT,DNR.K,-.15,.15,.05)
T       CIDNDT=.02/.0205/.022/.025/.028/.0295/.03
C       SWT5=1975
NOTE
NOTE    CAPITAL INVESTMENT IN FOOD
NOTE
A       CIRA.K=(CIR.K)(CIAF.K)/CIAFN
C       CIAFN=.3
A       CIR.K=CI.K/P.K
L       CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J*CIQR.J-CIAF.J)
N       CIAF=CIAFI
C       CIAFI=.2
C       CIAFT=15
A       CFIFR.K=TABHL(CFIFRT,FR.K,0,2,.5)
T       CFIFRT=1/.6/.3/.15/.1
NOTE
NOTE   FOOD PRODUCTION
NOTE
A       FR.K=(FPCI.K)(FCM.K)(FPM.K)(CLIP(FCI,FC.K,SWT7,TIME.K))/FN
```

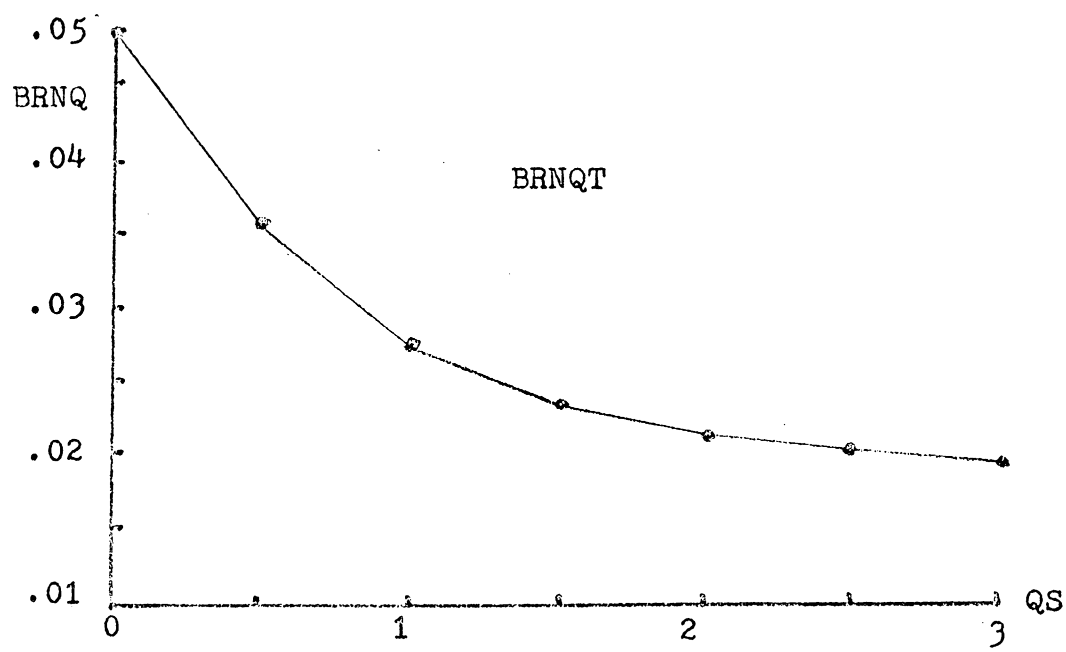
```
C       FCI=1
A       FC.K=(FCQ.K+FCD.K)/2
A       FCQ.K=TABHL(FCQT,QS.K,0,3,.5)
T       FCQT=1.3/1/.8/.7/.6/.55/.5
A       FCD.K=TABHL(FCDT,DNR.K,-.15,.15,.05)
T       FCDT=.6/.65/.7/.8/1/1.2/1.3
C       FN=1
C       SWT7=1975
A       FCM.K=TABHL(FCMT,CR.K,0,5,1)
T       FCMT=2.4/1/.6/.4/.3/.2
A       FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)
T       FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
A       FPM.K=TABHL(FPMT,POLR.K,0,60,10)
T       FPMT=1.02/.9/.65/.35/.2/.1/.05
NOTE
NOTE    MATERIAL STANDARD OF LIVING
NOTE
A       MSL.K=ECIR.K/(ECIRN)
C       ECIRN=1
A       ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)/(1-CIAFN)
NOTE
NOTE    NATURAL RESOURCES SECTOR
NOTE
L       NR.K=NR.J+(DT)(NRGR.JK-NRUR.JK)
N       NR=NRI
C       NRI=900E9
A       NREM.K=TABHL(NREMT,NRFR.K,0,1,.25)
T       NREMT=0/.15/.5/.85/1
A       NRFR.K=NR.K/NRI
A       NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)
T       NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4
A       DNR.K=((NRFR.K-NRFRJ.K)/NRFRJ.K)
```

```
N       DNR=DNRI
C       DNRI=0
L       NRFRJ.K=NRFR.J
N       NRFRJ=NRFRJI
C       NRFRJI=1
NOTE
NOTE    NATURAL RESOURCES GENERATION
NOTE
R       NRGR.KL=(POL.K)(ECIR.K)(CLIP(NRGRNI,NRGRN.K,SWT8,TIME.K))
C       NRGRNI=0
A       NRGRN.K=(NRGQ.K+NRGD.K)/2
A       NRGQ.K=TABHL(NRGQT,QS.K,0,3,.5)
T       NRGQT=.0007/.0008/.001/.0012/.0014/.0018/.002
A       NRGD.K=TABHL(NRGDT,DNR.K,-.15,.15,.05)
T       NRGDT=.0016/.0015/.0013/.001/.0008/.00075/.0007
C       SWT8=1975
NOTE
NOTE    NATURAL RESOURCES USAGE
NOTE
R       NRUR.KL=(P.K)(CLIP(NRUNI,NRUN.K,SWT2,TIME.K))(NRMM.K)
C       NRUNI=1
A       NRUN.K=(NRUNQ.K+NRUND.K)/2
A       NRUNQ.K=TABHL(NRUNQT,QS.K,0,3,.5)
T       NRUNQT=.04/.03/.025/.023/.021/.019/.018
A       NRUND.K=TABHL(NRUNDT,DNR.K,-.15,.15,.05)
T       NRUNDT=.019/.02/.022/.025/.03/.033/.034
C       SWT2=1975
NOTE
NOTE    POLLUTION SECTOR
NOTE
A       POLR.K=POL.K/POLS
C       POLS=3.6E9
```

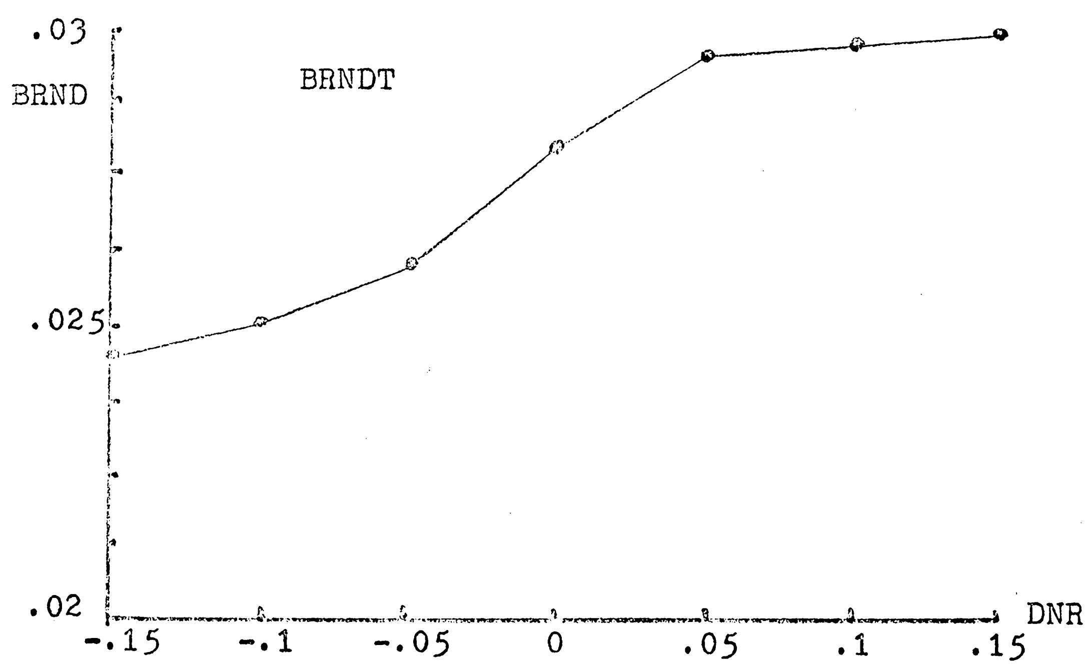
```
L       POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
N       POL=POLI
C       POLI=.2E9
A       POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)
T       POLCMT=.05/1/3/5.4/7.4/8
NOTE
NOTE    POLLUTION GENERATION
NOTE
R       POLG.KL=(P.K)(CLIP(POLNI,POLN.K,SWT6,TIME.K))(POLCM.K)
C       POLNI=1
A       POLN.K=(POLNQ.K+POLND.K)/2
A       POLNQ.K=TABHL(POLNQT,QS.K,0,3,.5)
T       POLNQT=.6/.53/.5/.48/.47/.465/.46
A       POLND.K=TABHL(POLNDT,DNR.K,-.15,.15,.05)
T       POLNDT=.45/.46/.5/.52/.54/.545/.55
C       SWT6=1975
NOTE
NOTE    POLLUTION ABSORPTION
NOTE
R       POLA.KL=POL.K/POLAT.K
A       POLAT.K=TABHL(POLATT,POLR.K,0,60,10)
T       POLATT=.6/2.5/5/8/11.5/15.5/20
NOTE
NOTE    QUALITY-OF-LIFE SECTOR
NOTE
A       QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
NOTE
L       QS.K=QL.J
N       QS=QSI
C       QSI=.62
C       QLS=1
A       QLM.K=TABHL(QLMT,MSL.K,0,5,1)
```

```
T       QLMT=.2/1/1.7/2.3/2.7/2.9
A       QLC.K=TABHL(QLCT,CR.K,0,5,.5)
T       QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
A       QLF.K=TABHL(QLFT,FR.K,0,4,1)
T       QLFT=0/1/1.8/2.4/2.7
A       QLP.K=TABHL(QLPT,POLR.K,0,60,10)
T       QLPT=1.04/.85/.6/.3/.15/.05/.02
A       CIQR.K=TABHL(CIQRT,QLM.K/QLF.K,0,2,.5)
T       CIQRT=.7/.8/1/1.5/2
NOTE
NOTE
NOTE    CONTROL CARDS
NOTE
C       DT=.2
C       LENGTH=3000
N       TIME=1900
A       PRTPER.K=CLIP(PRTP1,PRTP2,PRSWT,TIME.K)
C       PRTP1=25
C       PRTP2=100
C       PRSWT=2000
PRINT   P,BR,BRN,BRNC,BRND,BRFM,BRMM,BRCM,BRPM,*,CR
PRINT   2)DR/6)DRFM/7)DRMM/8)DRCM/9)DRPM
PRINT   1)CI/2)CIG/3)CIGN/4)CIGNQ/5)CIGND/7)MSL/8)CIR/9)ECIR/10)CIM
PRINT   2)CID/3)CIDN/4)CIDNQ/5)CIDND
PRINT   2)FR/3)FC/4)FCQ/5)FCD/7)FCM/8)FPCI/9)FPM/10)CIRA/11)CFIFR
PRINT   1)NR/2)NRGR/3)NRGRN/4)NRGQ/5)NRGD/7)DNR/8)NREM/9)NRMM/10)NRFR/11)
X       NRFRJ
PRINT   2)NRUR/3)NRUN/4)NRUNQ/5)NRUND
PRINT   1)POL/2)POLG/3)POLN/4)POLNQ/5)POLND
PRINT   2)POLA/4)POLR/5)POLAT/6)POLCM
PRINT   1)QL/2)QS/6)QLF/7)QLM/8)QLC/9)QLP/10)CIQR
A       PLTPER.K=CLIP(PLTP1,PLTP2,PLSWT,TIME.K)
```

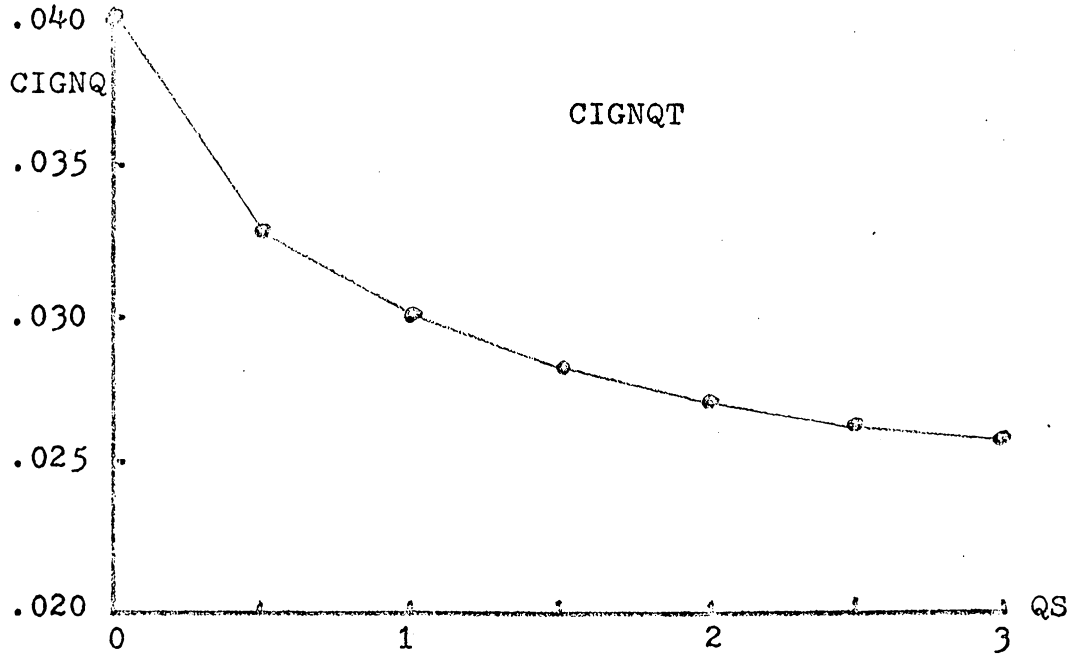
```
C       PLTP1=4
C       PLTP2=10
C       PLSWT=2100
PLOT    P=P(0,8E9)/PCL=L,CI=C(0,2039)/QL=Q(0,2)/NR=N(0,1000E9)
NOTE
RUN     ORIG
```



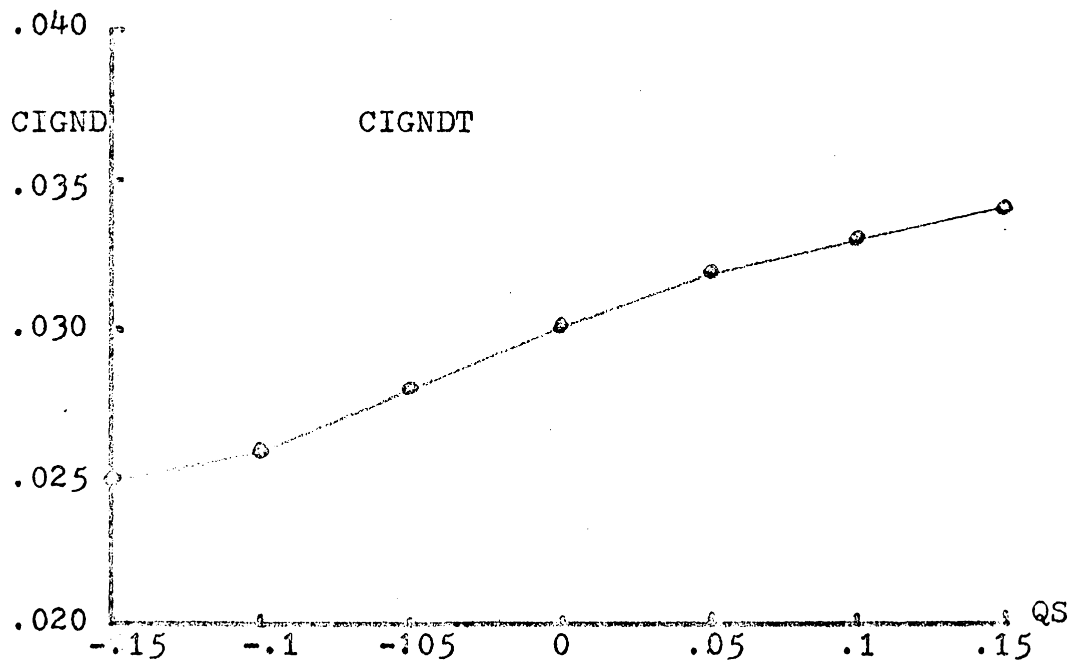
Birth rate from Quality-of-Life multiplier table



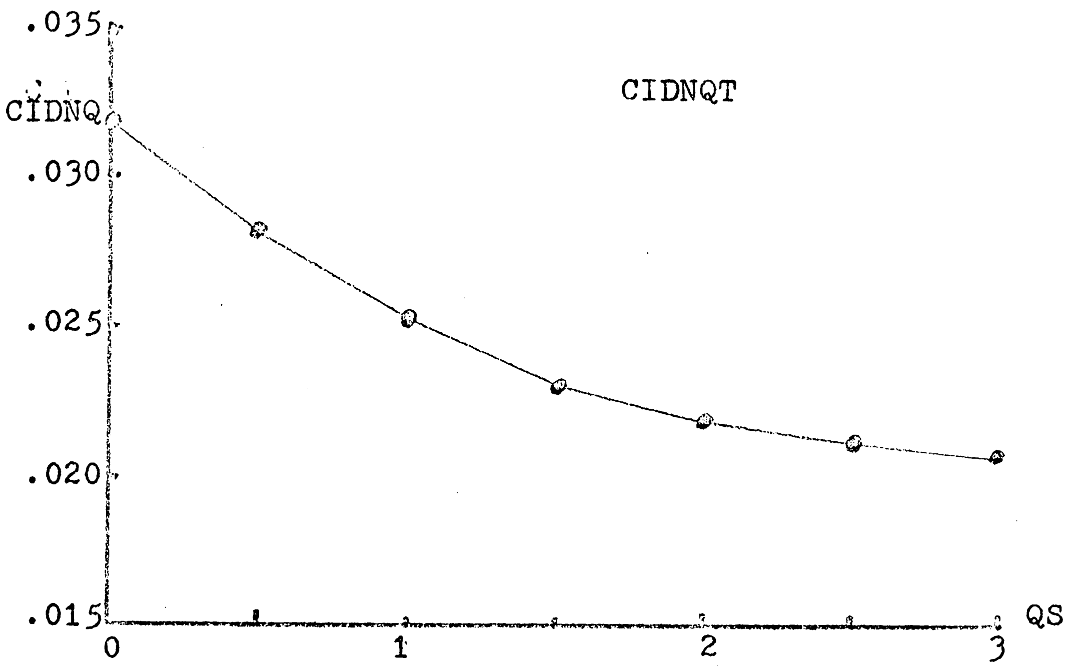
Entropy Minimizing Birth Rate Policy Table



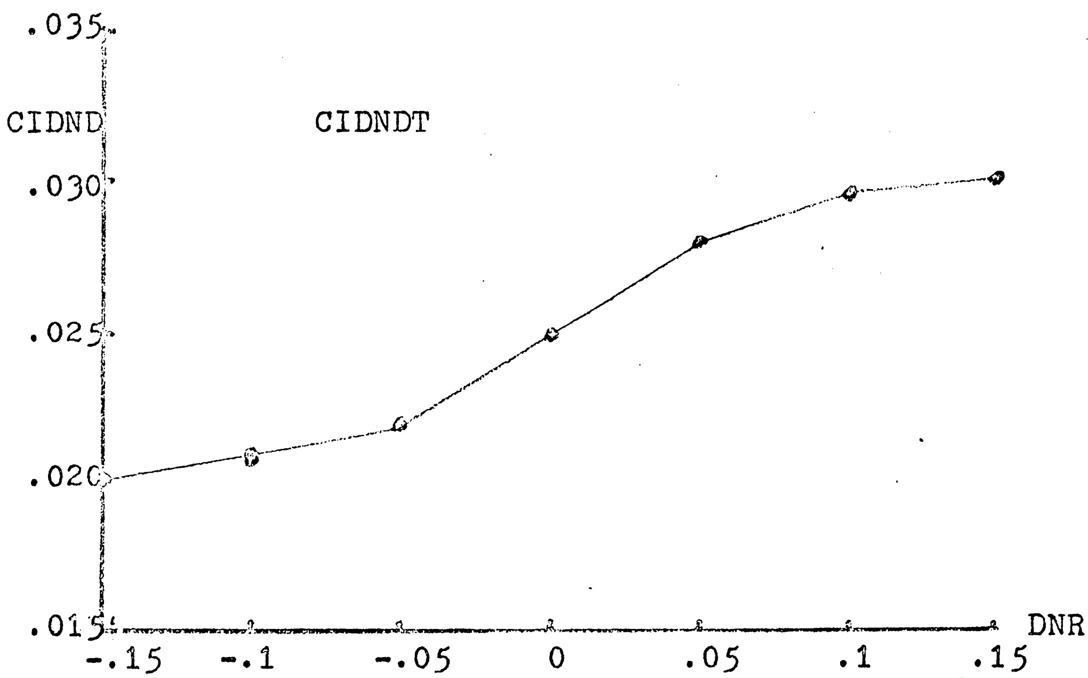
Capital Investment from Quality-of-Life Multiplier Table



Entropy Minimizing Capital Investment Policy Table



Capital Investment Discard from Quality-of-Life Multiplier Table



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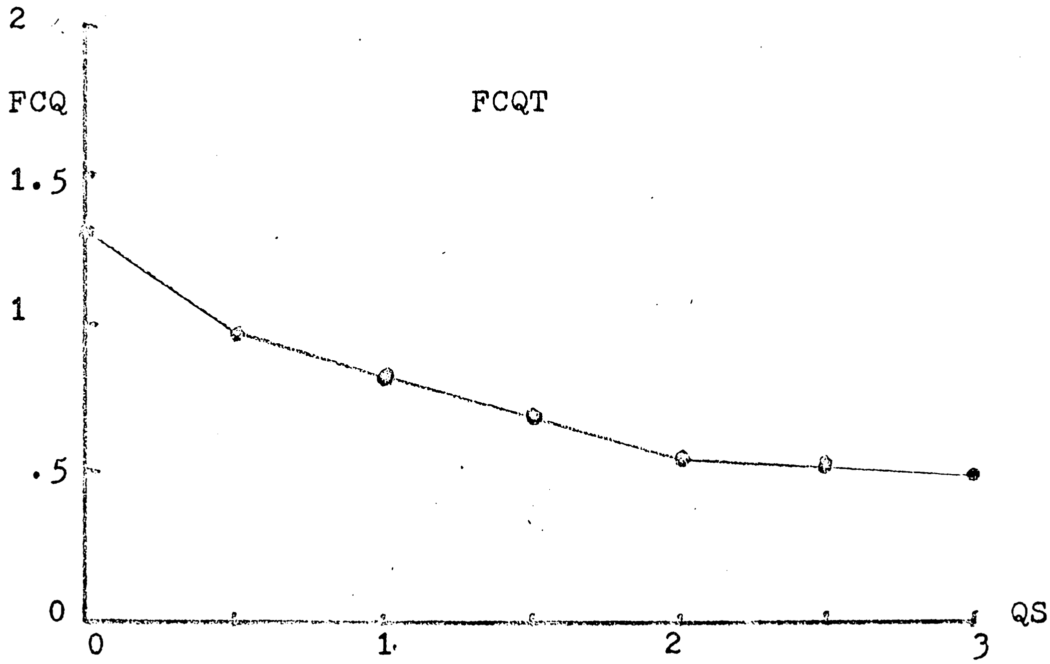
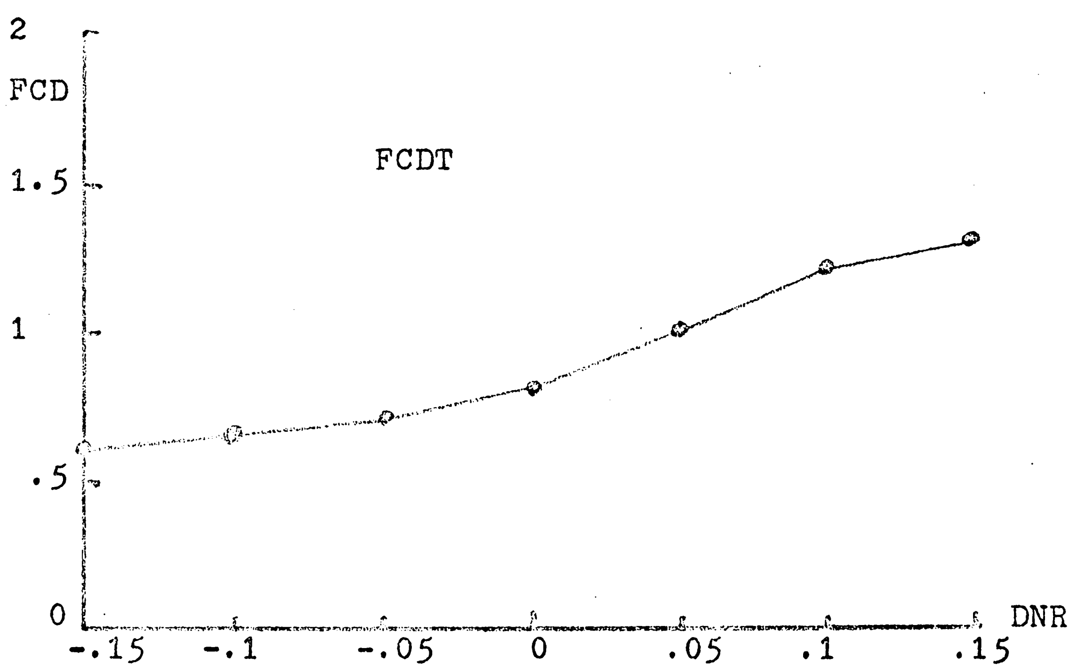
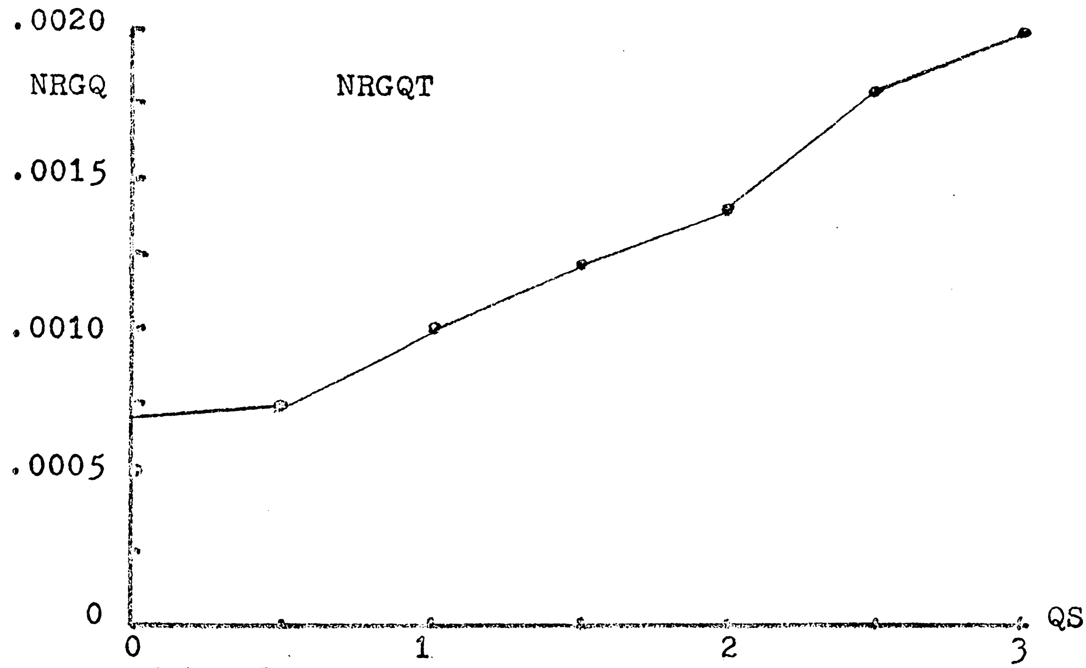


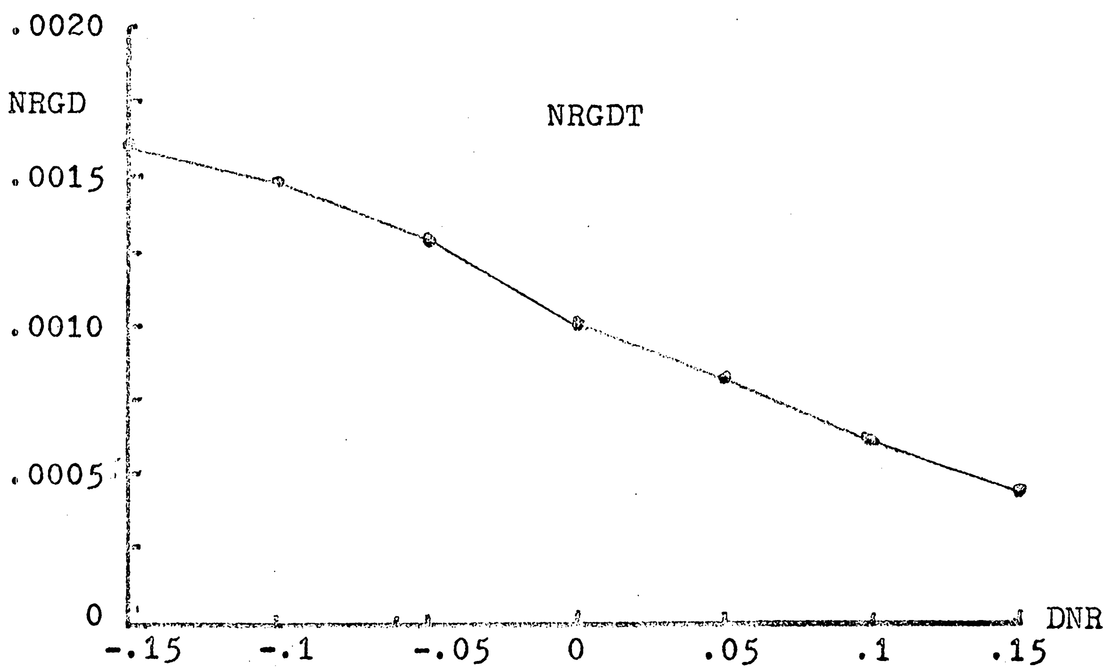
Food Production from Quality-of-Life Multiplier Table



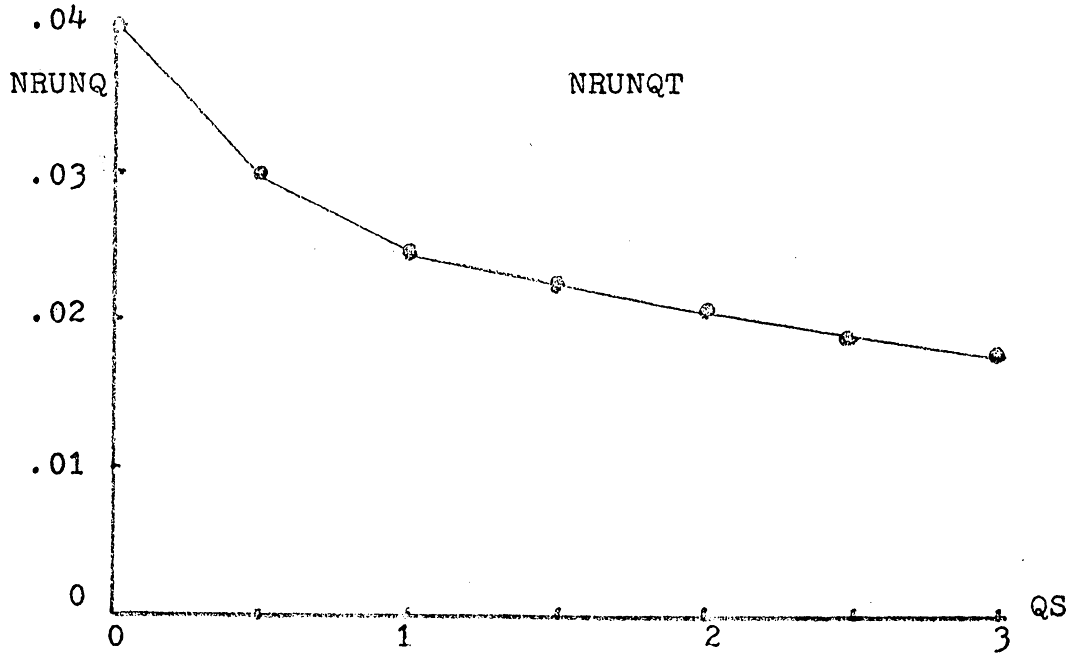
Entropy Minimizing Food Production Policy Table



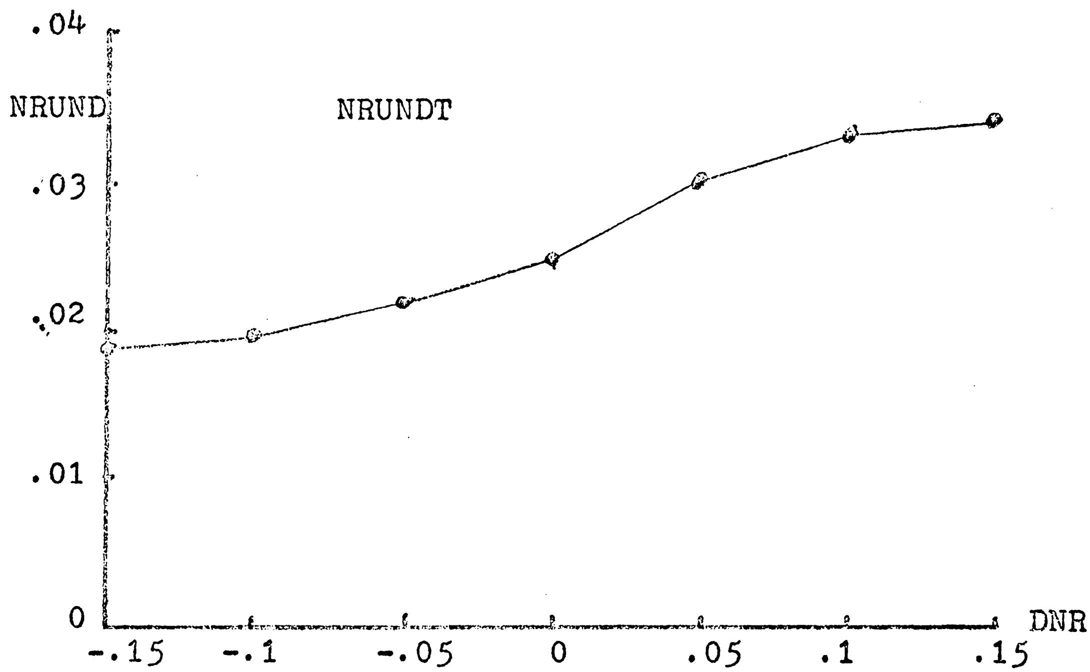
Natural Resource Generation from Qulaity-of-Life Multiplier Table



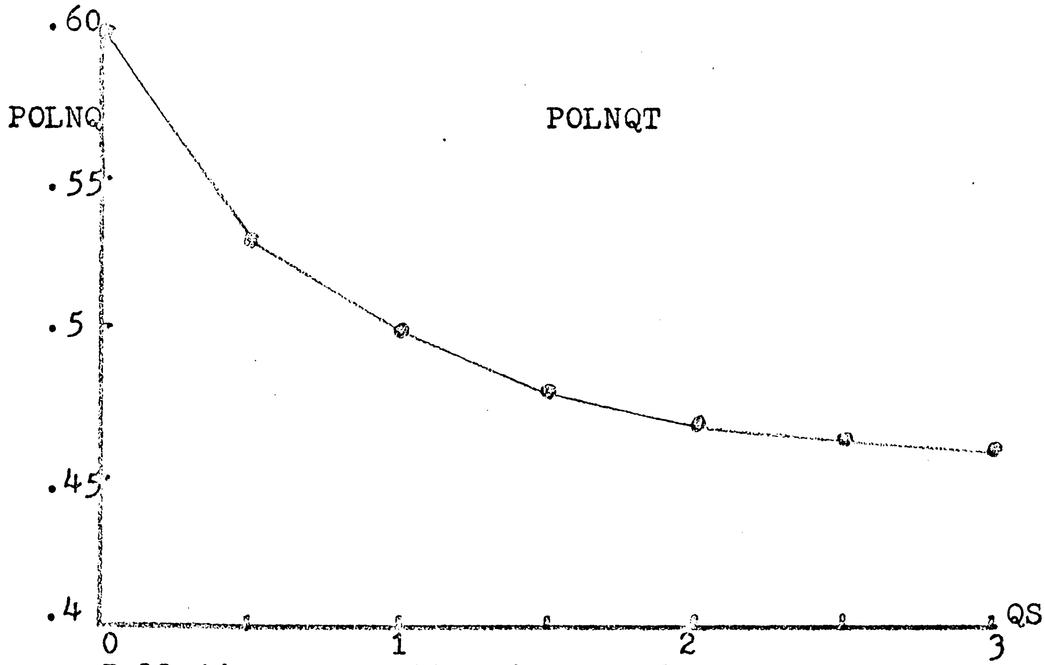
Entropy Minimizing Natural Resource Generation Policy Table



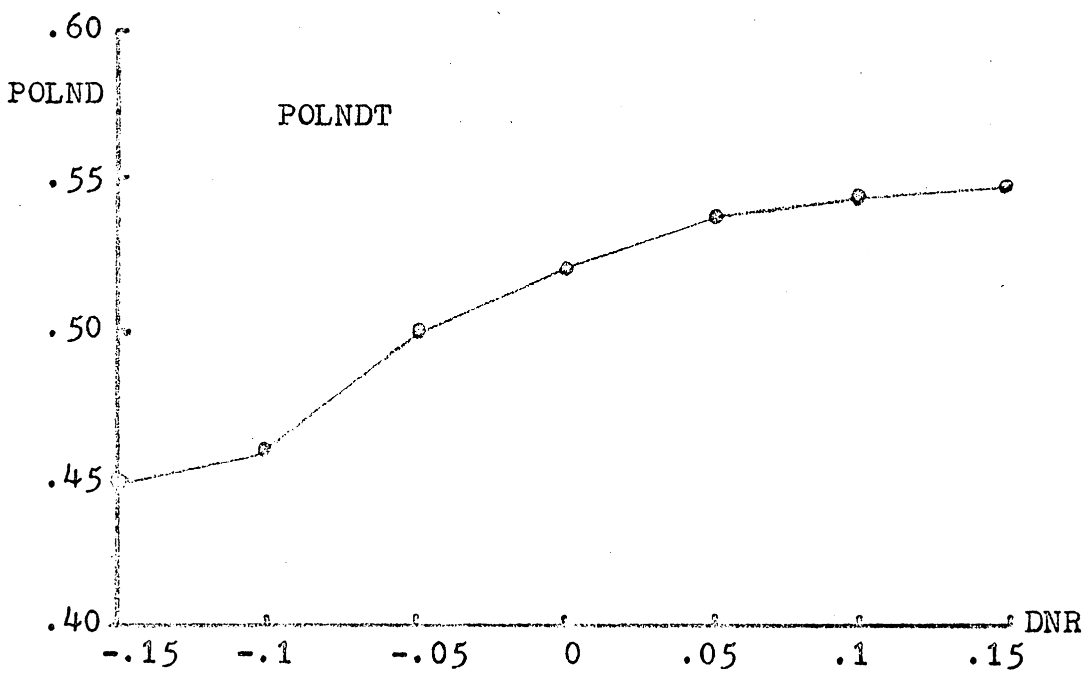
Natural Resource Usage from Quality-of-Life
Multiplier Table



Entropy Minimizing Natural Resource Usage
Policy Table



Pollution Generation from Quality-of-Life Multiplier Table



Entropy Minimizing Pollution Generation Policy Table

APPENDIX C

LASER - FUSION

TOTAL ENERGY SYSTEM

DYNAMO SIMULATION MODEL

```
*       LASER-FUSION TOTAL ENERGY SYSTEM SIMULATION
NOTE
NOTE    THE CONCEPT OF THERMODYNAMIC AVAILABILITY IS USED TO ACHIEVE
NOTE    MAXIMUM UTILIZATION OF ENERGY RESOURCES AND MINIMUM ENTROPY
NOTE    PRODUCTION AS AN APPROACH TO TOTAL ENERGY SYSTEMS OPTIMIZATION
NOTE
NOTE    UTILIZATION RATE=  UTILITY FUNCTION * THERMODYNAMIC AVAILABILITY
NOTE    UTILIZATION RATE=  Y * A = W + Q = USEFUL WORK + ABSORBED HEAT
NOTE    ALL VALUES X AND Y ARE DIMENSIONLESS. ALL OTHER VALUES ARE IN
NOTE    TERMS OF AN ARBITRARY UNIT OF ENERGY DESIGNATED AS "Q". ALL RATE
NOTE    EQUATIONS ARE IN TERMS OF "Q" PER UNIT TIME.
NOTE
NOTE    OPTIMIZATION POLICY: MAX Y = SUM(UTILIZATION)/SUM(AVAILABILITY)
NOTE
NOTE
NOTE    LASER SYSTEM
NOTE
L       LASER.K=LASER.J+(DT)(ELECIN.JK-LASOUT.JK+LCOOL.JK-LHEAT.JK)
N       LASER=LASERI
C       LASERI=20
NOTE
R       ELECIN.KL=(Y2.K)(A2.K)
A       Y2.K=Y_2
C       Y_2=1
A       A2.K=A_2
C       A_2=10
NOTE
R       LASOUT.KL=(Y3.K)(A2.K)
A       Y3.K=Y_3
C       Y_3=.1
NOTE
R       LCOOL.KL=W1.K
```

```
A       W1.K=W_1
C       W_1=10
NOTE
R       LHEAT.KL=W1.K+Q1.K
A       Q1.K=(Y2.K-Y3.K)(A2.K)
NOTE
L       LCOND.K=LCOND.J+(DT)(LHEAT.JK-LCOOL.JK+LCONDC.JK-LCONDH.JK)
N       LCOND=LCONDI
C       LCONDI=29
NOTE
R       LCONDC.KL=W2.K
A       W2.K=W_2
C       W_2=10
NOTE
R       LCONDH.KL=W2.K+Q1.K
NOTE
NOTE    FUSION REACTOR
NOTE
L       FUSION.K=FUSION.J+(DT)(DTFUEL.JK+LASOUT.JK+FCOOL.JK-PLASMA.JK-
X       THERM.JK-NEUT.JK)
N       FUSION=FUSI
C       FUSI=111
NOTE
R       DTFUEL.KL=(Y1.K)(A1.K)
A       Y1.K=Y_1
C       Y_1=0.1
A       A1.K=A_1
C       A_1=1000
NOTE
R       FCOOL.KL=W3.K
A       W3.K=W_3
C       W_3=10
```

```
NOTE
NOTE   NEUTRON AND XRAY PRODUCTION
NOTE
R      NEUT.KL=(Y4.K)(A3.K)
A      Y4.K=Y_4
C      Y_4=1
A      A3.K=A_3
C      A_3=1
NOTE
L      NEUTRN.K=NEUTRN.J+(DT)(NEUT.JK-NEUTD.JK)
N      NEUTRN=NEUTI
C      NEUTI=1
NOTE
R      NEUTD.KL=(Y5.K)(A3.K)
A      Y5.K=Y_5
C      Y_5=1
NOTE
NOTE   DIRECT ENERGY CONVERSION
NOTE
R      PLASMA.KL=(Y6.K)(A4.K)
NOTE
L      DIRECT.K=DIRECT.J+(DT)(PLASMA.JK+DCOOL.JK-DELEC.JK-FTORCH.JK-
X      DMCCOL.JK-DTCOOL.JK)
N      DIRECT=DIRI
C      DIRI=30
NOTE
R      DCOOL.KL=W4.K
A      W4.K=W_4
C      W_4=10
NOTE
R      DELEC.KL=(X1.K)(Y6.K)(A4.K)
A      X1.K=X_1
```

```
C       X_1=0.5
A       Y6.K=Y_6
C       Y_6=1
A       A4.K=A_4
C       A_4=20
NOTE
NOTE    MAGNETO-HYDRO-DYNAMIC (MHD) CONVERSION TO ELECTRICITY
NOTE
L       MHD.K=MHD.J+(DT)(DELEC.JK+DMCOOL.JK-DELECD.JK-MCOOL.JK)
N       MHD=MHDI
C       MHDI=15
R       DMCOOL.KL=(X1.K)(W4.K)
R       MCOOL.KL=(X1.K)(W4.K)+Q6.K
A       Q6.K=(1-Y7.K)((X1.K)(Y6.K)(A4.K))
NOTE
R       DELECD.KL=(Y7.K)(X1.K)(Y6.K)(A4.K)
A       Y7.K=Y_7
C       Y_7=1
NOTE
NOTE    FUSION TORCH
NOTE
R       FTORCH.KL=(X2.K)(Y6.K)(A4.K)
A       X2.K=X_2
C       X_2=0.5
NOTE
L       FUSTOR.K=FUSTOR.J+(DT)(FTORCH.JK+RFEED.JK+DTCOOL.JK-MATPRD.JK-
X       TCOOL.JK)
N       FUSTOR=FTORI
C       FTORI=15
R       DTCOOL.KL=(X2.K)(W4.K)
R       TCOOL.KL=(X2.K)(W4.K)+Q7.K
A       Q7.K=(1-Y11.K)((X2.K)(Y6.K)(A4.K)+(Y10.K)(A5.K))
```

```
NOTE
R       MATPRD.KL=(Y11.K)((X2.K)(Y6.K)(A4.K)+(Y10.K)(A5.K))
A       Y11.K=Y_11
C       Y_11=0.5
NOTE
R       RFEED.KL=(Y10.K)(A5.K)
A       Y10.K=Y_10
C       Y_10=1
A       A5.K=A_5
C       A_5=5
NOTE
NOTE    REFUSE SUPPLY TO FUSION TORCH
NOTE
L       REFUSE.K=REFUSE.J+(DT)(REFSUP.JK-RFEED.JK)
N       REFUSE=REFI
C       REFI=5
NOTE
R       REFSUP.KL=(Y9.K)(A5.K)
A       Y9.K=Y_9
C       Y_9=1
NOTE
NOTE    PROCESSED MATERIAL FROM FUSION TORCH
NOTE
L       PROMAT.K=PROMAT.J+(DT)(MATPRD.JK-MATDMD.JK)
N       PROMAT=PMATI
C       PMATI=7.5
NOTE
R       MATDMD.KL=(Y12.K)((Y11.K)((X2.K)(Y6.K)(A4.K)+(Y10.K)(A5.K)))
A       Y12.K=Y_12
C       Y_12=1
NOTE
R       DHEAT.KL=W4.K+Q3.K
```

```
A       Q3.K=Q6.K+Q7.K
NOTE
R       THERM.KL=W3.K+Q2.K
A       Q2.K=(Y1.K)(A1.K)+(Y3.K)(A2.K)-(Y4.K)(A3.K)-(Y6.K)(A4.K)
NOTE
NOTE    STEAM GENERATOR
NOTE
L       STEAM.K=STEAM.J+(DT)((THERM.JK+DHEAT.JK+SGCOOL.JK+INCINH.JK-
X       DCOOL.JK-STEAMS.JK-FCOOL.JK-DCOOL.JK))
N       STEAM=STEAMI
C       STEAMI=119.5
NOTE
R       SGCOOL.KL=W6.K
A       W6.K=W_6
C       W_6=10
NOTE
R       STEAMS.KL=W6.K+Q4.K
A       Q4.K=(Y17.K)(A9.K)+Q2.K+Q3.K
NOTE
NOTE    STEAM TURBINE              (COMPOSITE REPRESENTATION)
NOTE
L       TURBIN.K=TURBIN.J+(DT)(STEAMS.JK-STELEC.JK-STPROC.JK-STEXH.JK)
N       TURBIN=TURBI
C       TURBI=99.5
NOTE
R       STELEC.KL=(X3.K)(W6.K+Q4.K)
A       X3.K=X_3
C       X_3=0.5
NOTE
R       STPROC.KL=(X4.K)(W6.K+Q4.K)
A       X4.K=X_4
C       X_4=0.2
```

```
NOTE
R       STEXH.KL=(X5.K)(W6.K+Q4.K)
A       X5.K=X_5
C       X_5=0.3
NOTE
NOTE    INCINERATOR HEAT SUPPLY TO STEAM GENERATOR   (ORGANIC REFUSE FUEL)
NOTE
L       INCIN.K=INCIN.J+(DT)(WASTES.JK-INCINH.JK)
N       INCIN=INCINI
C       INCINI=2
NOTE
R       INCINH.KL=(Y17.K)(A9.K)
A       Y17.K=Y_17
C       Y_17=0.4
A       A9.K=A_9
C       A_9=5
NOTE
R       WASTES.KL=(Y16.K)(A9.K)
A       Y16.K=Y_16
C       Y_16=0.4
NOTE
NOTE    ELECTRICAL POWER GENERATION
NOTE
L       EPOWER.K=EPOWER.J+(DT)(STELEC.JK-ELECD.JK-ELECA.JK-ELECIN.JK)
N       EPOWER=EPOWI
C       EPOWI=50
NOTE
R       ELECD.KL=(Y13.K)(A6.K)
A       Y13.K=Y_13
C       Y_13=1
A       A6.K=A_6
C       A_6=30
```

```
NOTE
R       ELECA.KL=(Y14.K)(A7.K)
A       Y14.K=Y_14
C       Y_14=1
A       A7.K=A_7
C       A_7=10
NOTE
NOTE    PROCESS STEAM SUPPLY      (COMPOSITE REPRESENTATION)
NOTE
L       PSTEAM.K=PSTEAM.J+(DT)(STPROC.JK-STEAMD.JK)
N       PSTEAM=PSI
C       PSI=19.5
NOTE
R       STEAMD.KL=(Y15.K)(A8.K)
A       Y15.K=Y_15
C       Y_15=1
A       A8.K=A_8
C       A_8=19.5
NOTE
R       PSTCR.KL=(X6.K)(STEAMD.JK)
A       X6.K=X_6
C       X_6=0.51
NOTE
NOTE    STEAM CONDENSER
NOTE
L       COND.K=COND.J+(DT)(STEXH.JK+CONDCW.JK-HOTWR.JK-SGCOOL.JK)
N       COND=CONDI
C       CONDI=40
NOTE
R       CONDCW.KL=W7.K
A       W7.K=W_7
C       W_7=10
```

```
NOTE
R       HOTWR.KL=W7.K+Q5.K
A       Q5.K=((X5.K-1)(W6.K)+(X5.K)(Q4.K))
NOTE
NOTE    HOT WATER RESERVOIR          (COMPOSITE REPRESENTATION)
NOTE
L       HOT.K=HOT.J+(DT)(HOTWR.JK+LCONDH.JK-HOTS.JK-WARMP.JK+PSTCR.JK)
N       HOT=HOTI
C       HOTI=58.9
NOTE
R       HOTS.KL=(Y19.K)(A10.K)
A       Y19.K=Y_19
C       Y_19=1
A       A10.K=A_10
C       A_10=28.9
NOTE
R       WARMP.KL=(Y21.K)(A11.K)
A       Y21.K=Y_21
C       Y_21=1
A       A11.K=A_11
C       A_11=30
NOTE
NOTE    HOT WATER SUPPLY             (COMPOSITE REPRESENTATION)
NOTE
L       HOTSUP.K=HOTSUP.J+(DT)(HOTS.JK-HOTD.JK)
N       HOTSUP=HOTSI
C       HOTSI=28.9
NOTE
R       HOTD.KL=(Y20.K)(A10.K)
A       Y20.K=Y_20
C       Y_20=1
NOTE
```

```
R       WARMR.KL=(X7.K)(HOTD.JK)
A       X7.K=X_7
C       X_7=0.4
NOTE
NOTE    WARM WATER RESERVOIR      (COMPOSITE REPRESENTATION)
NOTE
L       WARM.K=WARM.J+(DT)(WARMP.JK-WARMS.JK-COOLP.JK+WARMR.JK)
N       WARM=WARMI
C       WARMI=41.5
NOTE
R       WARMS.KL=(Y22.K)(A12.K)
A       Y22.K=Y_22
C       Y_22=1
A       A12.K=A_12
C       A_12=11.5
NOTE
R       COOLP.KL=(Y24.K)(A13.K)
A       Y24.K=Y_24
C       Y_24=1
A       A13.K=A_13
C       A_13=30
NOTE
NOTE    WARM WATER SUPPLY         (COMPOSITE REPRESENTATION)
NOTE
L       WARMW.K=WARMW.J+(DT)(WARMS.JK-WARMD.JK)
N       WARMW=WARMWI
C       WARMWI=11.5
NOTE
R       WARMD.KL=(Y23.K)(A12.K)
A       Y23.K=Y_23
C       Y_23=1
NOTE
```

```
R       COOLR.KL=(X8.K)(WARMD.JK)
A       X8.K=X_8
C       X_8=0.4
NOTE
NOTE    COOL WATER RESERVOIR       (COMPOSITE REPRESENTATION)
NOTE
L       COOL.K=COOL.J+(DT)(COOLP.JK+MAKEUP.JK+COOLR.JK+COLDR.JK-CONDCW.JK-
X       LCONDC.JK-COOLS.JK)
N       COOL=COOLI
C       COOLI=50
NOTE
R       COOLS.KL=(Y25.K)(A14.K)
A       Y25.K=Y_25
C       Y_25=1
A       A14.K=A_14
C       A_14=30
NOTE
R       MAKEUP.KL=(Y27.K)(A15.K)
A       Y27.K=Y_27
C       Y_27=1
A       A15.K=A_15
C       A_15=3.4
NOTE
R       COLDR.KL=(X9.K)(COOLD.JK)
A       X9.K=X_9
C       X_9=0.4
NOTE
NOTE    COOL WATER SUPPLY          (COMPOSITE REPRESENTATION)
NOTE
L       COOLW.K=COOLW.J+(DT)(COOLS.JK-COOLD.JK)
N       COOLW=COOLWI
C       COOLWI=30
```

```
NOTE
R       COOLD.KL=(Y26.K)(A14.K)
A       Y26.K=Y_26
C       Y_26=1
NOTE
NOTE    OPTIMIZATION PARAMETER:Y_AVG=SUM(UTILIZATION)/SUM(AVAILABILITY)
NOTE
S       Y_AVG.K=UTIL.K/AVAIL.K
NOTE
A       UTIL.K=(DT)((NEUTD.JK)+(DELEC.JK)+(MATDMD.JK)+(ELECD.JK)+
X       (STEAMD.JK)+(HOTD.JK)+(WARMD.JK)+(COOLD.JK))
NOTE
A       AVAIL.K=(DT)((A1.K)+(A5.K)+(A9.K)+(A15.K))
NOTE
NOTE    CONTROL CARDS
NOTE
C       DT=.25
C       LENGTH=24
N       TIME=0
NOTE
A       PRTPER.K=CLIP(PRTP1,PRTP2,PRSWT,TIME.K)
C       PRTP1=6
C       PRTP2=6
C       PRSWT=0
PRINT LASER/LCOND/FUSION/DIRECT/MHD/FUSTCR/PROMAT/REFUSE/STEAM/TURBIN/
X       NEUTRN
PRINT 1)EPOWER/2)STEAMD/3)COND/4)HOT/5)HOTSUP/6)WARM/7)WARMW/8)COOL/
X       9)COOLW/10)INCIN
PRINT 1)ELECIN/2)LASOUT/3)LCOOL/4)LHEAT/5)LCONDC/6)LCONDH/7)DTFUEL/
X       8)FCOOL/9)THERM/10)NEUT
PRINT 1)NEUTD/2)DCOOL/3)DELEC/4)FTORCH/5)DELECD/6)DHEAT/7)MATPRD/
X       8)RFEED/9)REFSUP/10)MATDMD/11)SGCOOL
```

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PRINT 1)STEAMS/2)STELEC/3)STPROC/4)STEXH/5)INCINH/6)WASTES/7)ELECD/
X      8)ELECA/9)STEAMD/10)PSTCR/11)CONDCW
PRINT 1)HOTWR/2)HOTS/3)WARM/4)HOTD/5)WARMR/6)WARMS/7)COOLP/8)WARMD/
X      9)COOLR/10)COOLS/11)MAKEUP
PRINT 1)COLDR/2)COOLD/3)DDCOOL/4)DMCOOL/5)MCOOL/6)DTCOOL/7)TCOOL
X      9)Y_AVG/10)UTIL/11)AVAIL
NOTE
A      PLTPER.K=CLIP(PLTP1,PLTP2,PLSWT,TIME.K)
C      PLTP1=1
C      PLTP2=1
C      PLSWT=0
PLOT   LASER=L/FUSION=F/MHD=M/PROMAT=P/EPOWER=E/NEUTRN=N/PSTEAM=S/Y_AVG=Y
PLOT   LCOND=L/STEAM=S/TURBIN=T/COND=C/FUSTOR=F/DIRECT=D/REFUSE=R/INCIN=I
PLOT   HOT=H/WARM=W/COOL=C/HOTSUP=1/WARMW=2/COOLW=3
PLOT   Y_AVG=Y/UTIL=U/AVAIL=A
NOTE
RUN    BASIC MODEL
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APPLICATION OF THE PRINCIPLE OF MINIMIZATION OF ENTROPY IN THE ACHIEVEMENT OF STEADY-STATE SOLUTIONS FOR DYNAMIC SYSTEMS

by

Robert Ferrell Wells

(ABSTRACT)

The "Limits to Growth" controversy has identified attainment of a steady-state world system as an essential goal for human culture. This study investigates implications of steady-state systems using principles of thermodynamics in conjunction with Systems Dynamics simulation techniques.

Evaluation of Forrester's World Dynamics model shows it to degenerate in accordance with the dictates of the Second Law of Thermodynamics. Two fundamental policy criteria are established for world society:

1. Maximization of the future horizon for mankind.
2. Satisfaction of basic quality-of-life requirements for all of mankind.

Optimization principles for satisfaction of these criteria are derived from interrelationships found to exist between three physical laws (Einstein's relativistic mass-energy law and the First and Second Laws of Thermodynamics), non-equilibrium thermodynamics (Prigogine's Theorem of Minimum Entropy Production as the defining condition for a steady-state system) and a cultural law (the Golden Rule).

Policy based on the Principles of Minimization of Entropy and Cooperative Behavior are presented as the optimal means for defining, achieving and maintaining long-term steady-state systems both locally and globally.

It is shown that the "Golden Rule" shares with the thermodynamic concept of equilibrium the defining mechanism of "reversibility" (synonyms: reciprocity, self-returning, "frictionless", ideal efficiency, etc.). This common criterion allows both concepts to be used as unambiguous, perfect standards for determining the relative effectiveness of actual performance (one in terms of cultural behavior and the other in terms of physical behavior). Recognition of this relationship (which reflects the fundamental tendency of natural systems to seek optimal stability conditions in the most efficient manner) is advanced as a means for achieving optimal steady-state solutions for complex cultural- physical systems; specifically:

1. Use the Principle of Minimization of Entropy (with respect to the equilibrium standard) when making decisions that essentially involve physical behavior.

2. Use the Principle of Cooperative Behavior (with respect to the Golden Rule standard) when making decisions that essentially involve cultural behavior.

The effects of these policies are identical: the minimization of system "friction"; or, conversely, the maximization of system "welfare". These principles are embedded as policy tables in Forrester's World Dynamics model and used to demonstrate the conceptual feasibility of achieving truly long-term steady-state solutions satisfying desirable quality of-life goals.

In order to demonstrate the practical potential of such policies, the Principle of Minimization of Entropy is related to the engineering concept of Thermodynamic Analysis and advanced as a method for evaluating Total Energy Systems. Two application schemes are presented as examples which represent the range of both Total Energy System technology and analytical procedure:

1. A manually calculated Decision Tree Analysis for a Wind Source Total Energy System emphasizing simple technology that can be immediately utilized world-wide (using indigenous "self-help" labor and materials) to satisfy small scale "biotechnic" community needs.

2. A DYNAMO simulation model for a Laser-Fusion Total Energy System offering the ultimate range in resource management technology needed to support complex, large-scale communities.

The study is closed with a suggested subject for further research: development of an "Evolutionary Dynamics" model based on Prigogine's thermodynamic concepts for "open" systems.