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PLANNING FOR A PROGRAM DESIGN
FOR
ENERGY ENVIRONMENTAL ANALYSIS

FINAL REPORT

DRAFT

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ABSTRACT

The objective of the work reported here is to assist BER/ERDA in program planning with respect to a regional assessment study program for energy environmental analysis. The focus of the work was to examine the use of operational gaming for regional assessment studies. Specific concerns were gaming applications (1) in regional assessment or management and direction of regional assessments; (2) for achieving a higher level of public understanding of environmental, health, and safety problems of energy; (3) with respect to the supply of adequately trained manpower for energy; (4) with respect to computational requirements; and (5) with respect to current state-of-the-art in computer simulation. In order to investigate these concerns and examine the feasibility of using operational gaming in a regional assessment study program, a Regional Energy Environment Game (REEG) was designed and implemented on an IBM 370/168 digital computer employing APL (A Programming Language). The applicability of interactive operational gaming has been demonstrated by the REEG as applied to a region consisting of Delaware, Maryland, New Jersey, Pennsylvania, and the District of Columbia.

A new approach to energy policy analysis is developed by structuring the interactive dynamic processes in energy environment systems. The future of an energy environment system is influenced by the decisions of a number of policy makers with differing interests and objectives. Current energy system modeling efforts do not effectively account for multiple interests and the interaction of policy makers. However, this interactive process can be captured in a gaming environment. A methodology formalizing, within the framework of hierarchical systems, operational gaming for policy analysis is presented. The methodology has been applied to the design of REEG.

The REEG accomodates a variety of simultaneously interacting players, ranging from the very technical player to the policy executive and different types of players interact simultaneously as well. The successful demonstration of the REEG provides a new tool, with capabilities in: (1) carrying through a consistent set of regional assessment studies; (2) managing and directing a regional assessment study program; (3) achieving a higher level of public understanding with respect to environmental, health, and safety problems of nuclear energy in a consistent context of alternative energy systems; (4) revealing possibly serious needs for adequately trained manpower, both nuclear and non-nuclear; (5) implementing the interaction between public executives, technologists, and public interest groups; (6) providing public interest group input to the policy executive and technologist; and (7) assessing the economic and environmental consequences of the future evolution of energy systems. The capability of interactive operational gaming in accomplishing these objectives is discussed.

The implementation of interactive operational gaming for energy environment analysis on a large scale sets some special requirements with respect to computerized information systems, computerized data management systems and file management systems, computerized visual and graphics display systems, and particularly the communication between systems. These requirements are presented. Within the framework of interactive operational gaming, a regional assessment study program is discussed in terms of its scope, purposes, goals and objectives, and its initiation is considered.

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PLANNING FOR A PROGRAM DESIGN
FOR
ENERGY ENVIRONMENTAL ANALYSIS

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

The future of an energy environment system is influenced by a large number of decision makers. These decision makers adopt policies suitable for the pursuit of their goals and objectives. In the process they interact not only with the physical system but also with each other. Thus, the future of the system is the outcome of what the actors collectively do. This methodological study was designed to structure the dynamic interactive processes in energy environment systems.

Current comprehensive energy policy analysis models [49] usually take into account impacts of decisions by a single policy maker on the energy system. Before 1973 the preponderance of energy models [43], [12], [9] used for projection purposes employed extrapolation on trend analysis and did not account for the impact of price changes made by decision makers on the supply and demand for different sources of energy. After the Arab oil embargo, it became clear that economic forces are fundamental to energy system dynamics. Recently there has been a profusion of energy models which either impose or assume market clearing conditions [2d, [14], [24], [6], [16], [53]]. These models are normative in nature, with cost minimization (or profit maximization) as their sole objective. Some models also include explicit resource and technological constraints [14], [53], [24]. Environmental impacts are frequently derived from economic and energy activities and are treated as a secondary output [14], [22], [23], [32], [29].

By modeling the evolution of an energy system on the basis of one objective, other objectives vital to the energy future are overlooked. For example, the preservation of environmental quality, health and safety are important objectives which are often left out of the consideration. In the case of nuclear power, earlier projections have been overly optimistic [55], [17], about the nuclear generating capacity attainable

in the near future. The models used failed to include public concern regarding nuclear safety. Thus, in order to model the evolution of an energy system we need to incorporate multiple interests and objectives of each energy policy maker together with their interactions. Thus far, there have been scant efforts to model the problem in this rich context. For example, Mesarovic attempted a multi-objective approach to model the world energy systems as a goal seeking system [40]. Others [16] have constructed a dynamic simulation of the effects of alternative political, economic and technical policies for electrical generation on the sulfur-dioxide problem.

Operational gaming is an alternative approach to policy analysis particularly in severely stochastic situations involving a high degree of risk taking, or to prepare policies oriented to deal with crises. The form of current games varies from "free" to "rigid" [19], [20], [3], [50]. In "free-form" games new rules, relationships, and even completely new actors are admitted into the game as it proceeds. In "rigid-form" games such creations are restricted. The former have been employed in disciplines such as military strategic planning, political science, sociology, education and resources [19], [18], [36], [13] [35].

It is interesting to note that because of their fixed mathematical structure, the latter have been employed in disciplines such as economics, engineering and management [58], [44], [25], [37]. Today games have a "hybrid" form, combining features from both the "free" and the "rigid" forms.

Recent advances in interactive computing [7], and structuring of the policy making process [48], [34], [8] are important developments in the formalization of gaming for policy analysis. The purpose of policy analysis games is to assess the implications of decisions made by the important policy makers.

Hierarchical Structure

The context within which energy and environment problems arise in society forms a complex and interrelated policy making system. In such a system there is a wide variety of decisions which encompass economic, environmental, technological, social and energy factors. These factors are hierarchically interrelated. Energy policy makers differ in geographic scope (i.e., national, regional, local) and in objective (e.g., profit, preservation of environmental quality, safety, etc.). Their interactions are characterized by formal rules, regulations and procedures (e.g., rate hearings, power plant licensing hearings, interstate gas price regulations, etc.). Here we focus primarily on an energy policy making system at the regional level. Hence a regional energy environmental system is a complex system of interacting factors some of which exert greater influence and control over the system than others. It is desirable, through the study of interactions, to determine the relative importance of these factors and their impacts on the progress of the system.

A complex system may be characterized by a hierarchical structure in which the levels are the subsystems whether physical, economic, social, political or technological, classified according to their dominance or control. A hierarchy is an inductive or synthetic construct. It can be used to study the interactions among the parts of a system according to function and structure -- and also captures the overall results of these interactions. In this process, one arrives at priorities for these functions depending on the hierarchy level in which they fall and the priorities of dominating functions which fall in higher levels. Priorities are the indicators needed to exercise control over the system. By using the functional approach between hierarchy levels, one simplifies the analytical complexity of interaction between the parts, yet captures the overall effect of interactions between them.

The hierarchical approach to systems is based on the theory of pairwise comparisons between activities which derives a scale of priorities for these activities. This scale satisfies the requirements of a ratio scale and is invariant under positive similarity transformations. Thus the priorities belong to a cardinal ratio scale and are much stronger than ordinal rankings. Our approach involves the solution of an eigenvalue problem in the matrix of comparisons. The activities are grouped on different levels, forming a chain or hierarchy in which the lowest level elements can be compared with respect to elements of the next higher level, these in turn with respect to elements of the next level, etc. A process of weighting yields the overall priorities for the lowest level. These weights are then used in planning. Here we construct a set of contrasting scenarios. They are outcomes of influential individual or group actions which emphasize only the interests of these actors. All the scenarios share a common set of state variables. The values of these variables are fixed for each scenario. The object is to use the weighting process which produces different priorities for the scenarios to derive the state variables of a composite scenario which lies in the convex hull of the contrasting scenario. It is the likely outcome of the forces or actions by decision makers seeking to influence the development of the system through their individual objectives and interests.

For the energy environment system detailed analysis may produce refinements on the following seven level hierarchy (see Figure 1). The second level of this structure includes all the forces which affect the energy systems. These forces are economic, social, political, legal and technological. So far as this influence on energy is concerned, they have different priorities. The actors who occupy the third level of the hierarchy pursue their interests by shaping these forces. Thus their influence on the energy system is determined by their relative priorities. The

Figure 1 - The Structure of Hierarchical Analysis
 (Only a few interconnecting lines are shown in figure. Each box is connected with every other one on the upper and lower level.)

next level consists of the objectives of the actors. The same objective may be shared by more than one actor. The priorities of these objectives determine the importance of the members of the next level: the policies with which each actor seeks to change the total environment in order to fulfill his interests through strategy implementation. The state of the environment is represented by a set of scenarios reflecting actor conceptions of the various possible states of the energy systems. These are the elements of the next level of the hierarchy. The interactions of the actors give rise to economic, social, etc. forces which in the balance shape a composite scenario. Within the framework of hierarchical analysis such a composite scenario can be actually constructed. This scenario can be used to supply information on changes in decision making which produce desirable results from the standpoint of one or more actors as discussed previously in the introduction. The outcome is a result of the balance of forces attempting to shape the evolution of the energy environment system.

The Macro Approach

Elements of the methodology of gaming for policy analysis have been illustrated in the design of a Regional Energy Environment Game (REEG). A regional game requires that all game components be tailored for this regional context, including players, system variables, the process functions, and system constraints.

A system analysis, based on the work of Saaty [47], was first performed to identify the structural hierarchy of the regional energy policy making system[11]. This analysis provided a macro approach to gaming, without specifying the underlying fine structure. The results generate a set of crisis scenarios (environments) that can be used to construct the fine-structure models used in playing the game, the relevant policy makers together with their objectives, policies, and the important system variables. This analysis has indicated that economic considerations, particularly those of energy consumption in interindustry activities, are of prime importance in the modeling of energy policy making systems.

In an operational game, the priorities of the actors are used to weight the objectives of each actor and the results are then used to weight the factors of the scenarios in the corresponding category of each. The decision of actors to vary values of their control variables can be guided by the outcome of their individually preferred "ideal" outcome scenarios and how each relates to the composite scenarios through interactions with the remaining actors.

In REEG the following 10 policy makers (actors) were included:

1. Electric Utilities
2. Individual Consumers
3. Residential Consumers
4. Environmental Regulators
5. Crude Oil and Gas and Refined Petroleum Suppliers
6. Coal Suppliers
7. Nuclear Suppliers
8. Financiers and Investors
9. Labor Union
10. Executive Government

The decision or crisis environment determines the choice of active policy makers to be included in the game.

The Micro Approach

The micro approach is designed to model the relations between a large set of state and decision variables giving rise to a framework analogous to that of the composite scenario. For the relation between the macro and micro approaches see Figure 4.

Three major subsystems are identified in the energy game, i.e. economic, energy, and environmental, each of which has a corresponding model. The coordination of these

models forms the basis for analyzing policy decisions in the game.

The economic subsystem is the core of the overall model and is composed of three parts. The first is a macro-economic growth model based on the results of the Data Resources energy model [26]. In this sub-model dynamic growth and change of the decision environment are handled. In particular growth rates are applied to system variables and discontinuities such as availability of new technologies are introduced. The second sub-model is a microeconomic equilibrium model. This model is based on an interindustry model due to Hudson and Jorgenson [26]. This interindustry model receives as input from the macro-economic growth model prices, availability of capital and labor, and total levels of final expenditure. The distinctive feature of the interindustry model is that the production technology determined for each industry is economically efficient (i.e. optimized) in terms of the current prices. Hence, this model serves as a decision analysis model for industry players, by guiding them to substitute within the bounds of given technical parameters, the relatively less expensive for relatively more expensive inputs. At the same time, the model also supplies the players with prices for their production output determined on the basis of price alone. The players make final decisions after they take into consideration other non-economic and environmental factors. Eleven industries are included: agriculture, manufacturing, transportation, trade and services, coal mining, crude petroleum and natural gas, petroleum refining, electric utilities, gas utilities, nuclear fuel mining and processing, and pollution abatement equipment manufacturing. The principal outputs of this sub-model are a table of technical input-output coefficients, the current equilibrium prices of industry output, and projected levels of final demand.

These final demands of goods and services are determined by individual consumers and by the government. Finally the third economic sub-model is an input-output impact analysis model, (Leontief [32]) used to compute the total output of each industry and the interindustry transactions required to support the final demands.

The energy and economic subsystems are linked by a model developed by Herendeen [23]. In the Herendeen Model interindustry energy consumption is directly related to interindustry economic activity. Total energy consumption is found by adding the energy used in interindustry activity to that used in final consumption.

The environmental and economic subsystems are linked by a relationship between economic activity and industry output. (Toscas [54]). Coefficients relating pollution to industry output are applied to the results of the input-output analysis to yield total pollution levels for each industry. These coefficients are affected by the level of investment in pollution abatement equipment. We see that the economic, energy, and environmental subsystems are connected in a generalized interindustry framework (see Figure 2).

The system variables are grouped in the following five categories:

A. Economic Factors

Total industrial outputs, final demands (net exports, government expenditure, private investment), energy prices, output prices, labor and capital service prices, cost of pollution abatement equipment.

B. Environmental Factors

Levels of air pollution (SO_2 , NO_x , HC, CO)

C. Energy Consumption Factors

Total energy consumption, energy consumption by industry.

Energy Environment Game Components

Figure 2

D. Employment Factors

Total employment, employment by industry.

E. Technological Factors

Production technology, available alternatives, energy efficiency, pollution abatement technology.

The decision environment is determined by the values of these system variables. The macroeconomic growth and the microeconomic equilibrium models make the variables dynamic. Players control decision variables in response to this dynamic decision environment. The impact of their decisions are then computed by the input-output, energy and environmental models. Finally closing the loop, the results are incorporated into the decision environment for the next time period. A policy then guides a player's decisions for a number of iterations. Interacting policies of a number of players form the game.

Computer Implementation

REEG has been implemented in the interactive computer language APLSV[7], which provides a sophisticated communication network allowing non-computer oriented players to communicate easily with decision analysis models and other players.

A player influences the state of the energy policy making system by the following hierarchy of decision choices:

POLICY - STRATEGY - ACTION

Associated with each general policy is a number of specific strategies available to the players, each consistent with their overall policy.

As the game proceeds, the computer prompts a player for a particular policy choice and then presents him with a number of strategy alternatives. The strategy choice

determines what decision variables the player will control in order to effect that strategy. Finally, in executing the strategy (action) the player is reminded of previous values (trends) of the state variable and is prompted for new values. This kind of "limited strategy" allows each player to control only a few of the decision variables. For the less technically oriented, a number of "executive strategies" are available that do not prompt the player for values of state variables but simply ask for direction of change of a present trend in action. This is particularly important for policy oriented players who are not interested in actual numerical but only in general order of magnitude results. For more technical players "comprehensive strategies" allow a player to control all his assigned decision variables. When a strategy is finally executed, whether it is executive, limited, or comprehensive, the actions are sent to the game operating system.

Figure 2 illustrates how a "limited" strategy is used by a policy maker. In this case the electric utility has four policy options: i) altering industrial electric rates, ii) altering residential rates, iii) altering generation technology, and iv) installing pollution abatement equipment. Under each policy option there is a set of strategy options that a player can pursue. Also Figure 10 shows that the player has a discrete set of action choices, e.g., he may increase electric prices from 0% to 18%.

Policy Options: Electric Utility
Figure 2

Policy Options:

Policy 1- Alter Industrial Rates

- Strategies: 1. Increase Rates
2. Decrease Rates

Policy 2- Alter Residential and Commercial Rates

- Strategies: 1. Increase Rates
2. Decrease Rates

Policy 3-Install Pollution Abatement Equipment

- Strategies: 1. Add SO₂ Abatement Equipment
2. Add Particulate Abatement Equipment

Policy 4-Alter Generation Technology

- Strategies: 1. Increase/decrease Coal-Fired Generation
2. Increase/decrease Oil-Fired Generation
3. Increase/decrease Nuclear Generation

Computer Sequence:

POLICY 1: CHANGES IN ELECTRIC RATES

STRATEGIES: 1

S1: PROPOSED PRICE: 1.47 NEW PRICE OPTION: 1 2 3 4 5 :2

POLICY 2: CHANGES IN GENERATION TECHNOLOGY

STRATEGIES: 2

S2: PROPOSED COEFFICIENT : .01031 NEW OPTION: 1 2 3 4 5 :3

POLICY 3: CHANGES IN POLLUTION ABATEMENT TECHNOLOGY

STRATEGIES: 1

S1: OLD COEFFICIENT : .01350.. NEW OPTION: 1 2 3 4 5:4

Design Considerations for Large Scale Games

There are several important considerations in the design of large-scale computerized games. Perhaps the most important is the interface between policy makers and computers. Policy makers are not normally comfortable with computers and models. Hence there is a need for a decision input mechanism that is computer language independent, simple, and efficient. The policy-strategy-action hierarchy defined earlier is particularly helpful. Computer output from models should be relevant and simple to understand. In this respect we find that tailoring the output to the individual policy maker is useful. In addition to the above design considerations, information retrieval procedures should be hierarchically organized and responsive to the level of aggregation desired by the policy makers. Questions concerning what information should be made available to each player must also be addressed in the initial game design. At the end of a game step, it is also important to record the results. They should include a complete description of the decision environment, player actions, and game results. This complete record would be useful for post-game analysis.

A national game should be designed from the analysis of different energy policy problems. Policy makers would be chosen on the basis of whether or not their actions or decisions have significant impact on the future of the national energy picture. The levels of aggregation of a subsystem, however, are dependent on a particular policy issue. For instance, in the study of the deregulation of natural gas, one should not treat the gas industry as a single policy maker, since interactions among gas industry drillers, pipeline distributors, wholesalers and retailers are also important and must be represented by several players.

In the natural gas problem, only a handful of states produce the majority of gas requirements of all other states. Hence, there is a need for regional decision makers in a national game. The set of energy policy makers can be grouped into three categories: (i) industry (which produce goods and services), (ii) public interest groups (which are made of citizens representing a special interest, e.g. environmentalists), and (iii) government (which has regulatory and conflict resolution functions). We may include regional policy makers in each category. For example, we may include both a national regulatory agency (e.g. Nuclear Regulatory Commission), a regional regulatory agency (e.g. Delaware Valley River Basin Commission), or local industry (e.g. Philadelphia Electric Company).

Another key consideration is the design of models used in a large-scale national game. We do not find it desirable to design new models from the start for individual subsystems. Many sectoral models are already in existence. For instance, we have models for refined petroleum [1] production, for the capacity expansion of electric utilities [2] , gas models [37] , nuclear fuel cycle models [56] , coal models [52] , and crude oil models [14] . Similarly, we have models for non-energy industries [41] , [30] .

And finally we have environmental models as well [21],[45], [42]. We find recent development of social indicator models potentially useful in social modeling[31][57]. However, for a truly national game, these models must include regional considerations.

There remains the task of interfacing these subsystems models for a faithful representation of the overall system. The interfacing requirement between sectoral models would be less severe than interfacing two global models of the overall system, which would require enforcing consistency on overlapping variables.

The design of computerized energy models could profitably avoid collection of large volumes of survey data, and use the existing data collection mechanism. To use gaming for policy analysis, the data base must be updated periodically. Hence a formalized data processing procedure must be included as a part of the initial design. At present there is no need to collect extra data for a large-scale energy game. However, a new data structure and organization design for a national energy game would differ from that used in REEG, because of its size and complexity.

Existing computer hardware is sufficient for the implementation of large-scale energy games. On the other hand, a different design for a communication network (than that used in REEG) would be needed. In a fully computerized game, communication links should be established among policy makers and the game operating system. Using the computer, policy makers should be able to record decisions, retrieve information about current and previous states of the system, communicate with each other, and test policies with their own models. In REEG, this was accomplished through use of APL (A Programming Language) shared variable features. For the national energy game we propose a disk file communication approach to distribute the game across a network of

computers, such as the well-known ARPA network. This would solve problems of handling large data files, interfacing models written in different computer languages and restrictions on players' decision analysis capabilities. With this new approach, the extra cost in the increased input-output and in using such a network would be marginal.

We have demonstrated here the feasibility of an energy game by structuring the gaming approach to capture the interactive dynamic decision making process for policy making purposes. The macro approach provides an effective tool to define and structure the hierarchy of subsystems whose detailed interactions are developed through the micro approach. The successful demonstration of the REEG provides a new tool, with capability in: (1) carrying through a consistent set of regional assessment studies; (2) managing and directing a regional assessment study program; (3) achieving a higher level of public understanding with respect to environmental, health, and safety problems of nuclear energy in a consistent context of alternative energy systems; (4) revealing possibly serious needs for adequately trained manpower, both nuclear and non-nuclear; (5) implementing the interaction between public executives, technologists, and public interest groups; (6) providing public interest group input to the policy executive and technologist; and (7) assessing the economic and environmental consequences of the future evolution of energy systems. The capability of interactive operational gaming in accomplishing these objectives is documented by the REEG.

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PART 1

INTRODUCTION

The interaction between energy and environmental concerns has intensified in recent years. The economic impacts of each has led to severe conflicts between energy policy executives (governmental and industrial) and the environmental movement. In the middle of these conflicts often stand the technologists who may inadequately understand and appreciate the policy viewpoints as well as the environmental viewpoints. Clearly, there is a great and pressing need to reconcile these three conflicting groups, yet each speaks a somewhat different language (even though the words may be the same). The rich diversity of the different regions of the Nation appears to prohibit the resolution of these conflicts on a national scale, and thus it seems fruitful to approach the problem on a smaller scale through regional assessment studies. It is hoped that the knowledge gained through regional studies will illuminate the path toward solution of the national problem. If this hope is to be fulfilled, the regional assessments must be done in a self-consistent framework of analysis; otherwise, the knowledge gained in one region will not be transferrable to other regions, even in part, with any confidence.

There are many techniques for executing regional assessment studies. The task involves the collection of information, analysis of data, organization of results, and presentation of results in a useful format. Often the problem looks deceptively simple, although tedious, and the effort is expended with the implicit assumption that once the "facts" are known all conflicting views will be automatically resolved. Unfortunately, history indicates that the assumption is entirely false when applied to the energy-economic-environment trilogy. The reason appears to be that, in this arena, "facts" are different when viewed from the different vantage points of energy policy, environmental concerns, economic well-being, and technology. The result is a continuing conflict which the traditional regional assessment study techniques do not resolve. Thus a new technique is required, one which must address the problem

of conflict resolution while accepting the full spectra of energy policy options, environmental concerns, economic considerations, and technological capabilities. The only technique which appears to address the fullness of the problem in the context of conflict resolution is computerized interactive operational gaming. This approach cannot be gaming in any traditional sense, often gaming for gamers. Instead it must be operational in serving the needs of players who have little or no knowledge of gaming theory as well as little or no knowledge of computers. In other words, it must be very applied. Although the non-reproducibility of strictly free-form games is undesirable, some freedom of expression must be allowed the players. The complete specificity of the rigid-form game, with its roots in classical mathematical game theory is also undesirable, yet the technology of energy, once selected, is specific. Thus a hybrid gaming approach between these two forms is sought, retaining the necessary features of each while dispensing with those that are unacceptable.

It is a truism that the computer cannot provide anything other than what is programmed into it or provided as input. It is also true that the knowledge is not available to program the computer so that it can, unassisted, resolve the conflicts that are evident. Thus it becomes necessary to place man in interaction with the computer through the operational gaming structure. In this way, an entirely new capability can be created by joining together the computer with the players. This coupling of man with computer generates a great tool for analyzing the results of interactions, with each element working at its best. Here the computer must play two roles. It must provide the communication structure between players and, given the information supplied by each player, it must carry out computations of the evolution of energy systems which are to be presented to the players. Each player must operate in his own domain in providing policy, strategy, and

action inputs to the computer with these inputs being provided by the computer to the other players. Thus the player differences will become apparent as well as the impacts on the evolution of energy systems. The result is that a viable basis is established for reconciliation of player differences through inter-player negotiation within the communication structure provided by the computer. It cannot be emphasized too strongly that the computer is not to be used to provide reconciliation of conflicts. It only offers the framework for reconciliation and a forecast of the future evolution of energy systems based upon the different proposed compromises. The result is a self-consistent feedback to each player of the forecasted results attendant upon each of his options. The assumption is implicit that either all players will reconcile their differences to gain a desirable future state or the game director will be provided sufficient insight to chart a course of actions which will minimize the remaining conflicts.

The individual player is expected to have little or no knowledge of gaming or of computers. Thus the computer must be able to accept inputs that are natural for the player and provide outputs which are readily understood by the player in his own role. This requirement imposes a multiplicity of levels of aggregation of information before it is presented to the players. Similarly, the inputs from players must be disaggregated before they are presented to the computer models. This is part of the general task of interfacing a variety of roles with a computerized energy system model.

The possible uses of the game are quite varied, involving from one to many simultaneous players. Thus the game must be constructed with internalized roles which can be used to simulate the behavior of absent players. The internalized roles can only reflect a continuation of the present policies, strategies, and actions of each role. Even though this approach does not lend itself to reconciliation of differences between roles, it does allow an individual player, or a limited set of players,

to explore the nature of the differences that they will encounter when they interact with the actual players. This capability would be most useful in achieving a higher level of understanding of alternative energy futures for all of the interested parties, the public, the energy policy executive, the technologist, the environmentalist, the business executive, the economist, etc. It would be particularly valuable in planning national programs for the development and implementation of alternative energy systems.

The work reported herein is directed toward planning for a program design for regional energy environmental analysis. The emphasis is on the usefulness of operational gaming in regional assessment studies, either within a study program or in the management and direction of one. Assuming that a successful game is available, it is clear that it could play a key and central, even unique, role in both. Thus the basic questions are: (1) What constitutes a successful game? and (2) Is it feasible to construct such a game? The latter question has three parts: (a) Is it feasible to construct and manage the extensive data base that is required? (b) Is it feasible to provide and interface computer models of regional energy, systems and their evolution under different conditions? and (c) Is it feasible to organize the interaction between a group of simultaneous players and interface the players, in a meaningful manner, with the computer models? The remainder of this report demonstrates that the answer to all these questions is in the affirmative. The demonstration does not require the construction of a complete and valid game. It requires carrying each question far enough to demonstrate that it is feasible to undertake construction of a complete and valid game.

In Part 2 planning and development of a regional assessment study program are examined and the unique role of operational gaming in such a program is discussed. In Part 3 the problem is first structured on a macro scale by defining the forces controlling the situation, the actors and their ob-

jectives, and the scenarios describing the decision environment. The result of this approach is the construction of a composite scenario with a characterization of its state variables and an account of the influence of the actors to bring about this scenario. Guided by this broad understanding, the second thrust of the approach is to restructure the problem on a micro level in order to study the dynamics and sensitivity of a finer set of state variables selected for testing actor decisions. In Part 4 the regional energy environmental system is modeled on a micro level as three subsystems with corresponding models. They are: 1) economic, with an inter-industry model consisting of three parts - (a) a macroeconomic growth model, (b) a microeconomic equilibrium model and (c) an economic input-output model; 2) energy, with a model of energy consumption; and 3) environmental, with a pollution estimation model. It will be shown that these models are combined in a generalized input-output model which forms the basis for testing the impact of policy decisions in the game. The operational version of REEG is illustrated with an actual example. In Part 5, design considerations for implementation of a full-scale energy environment game is discussed.

PART 2

PLANNING AND DEVELOPMENT

OF

REGIONAL ASSESSMENT STUDY PROGRAM

Regional Approach

There are several facets to the planning and development of a regional assessment study program suitable for BER/ERDA. First of all, since ERDA must be concerned with the country as a whole, the question as to whether one should address the assessment problem regionally or nationally must be faced. The answer is available in the diversity of the Nation with respect to its potential energy sources, its environmental characteristics, its resources, and its energy demand centers.

The potential energy sources of the future are many and varied--oil, natural gas, coal, hydroelectric, nuclear fission, nuclear fusion, solar geothermal, wind, bio-energy, and ocean thermal gradients, tides, and currents. With respect to the fossil and nuclear sources, the U.S. has established transport systems to bring energy source forms to energy demand centers. The cost of the transportation is not exorbitant because the energy density of the fuels is so high. With respect to the other energy source forms, they must be used where they are available unless an intermediate form of high energy density, such as hydrogen, is employed in transport. Barring high energy density transport, it is clear that energy derived from solar insolation is most useful in the southern and southwestern regions of the country, geothermal sources are most useful in the west and southwest, wind energy is most useful in the great plains, hydroelectricity is most useful in mountainous terrain, and energy from the oceans is most useful in coastal areas. Thus the diversity of potential sources is persuasive for a regional approach. Nevertheless, considering the possibility of high energy density transport, it is not compelling.

The environmental characteristics of the different regions of the country are quite diverse ranging from the deserts of the southwest to the high rainfall areas of the southeast and from the cold northern regions to the hot southern regions. The key question with respect to the environment is its capacity

to accept the residuals attendant upon energy operations without irreversible damage to the quality of the environment. It is clear that the capacity is quite low in those regions where the life forms are in delicate balance with respect to the existing environment. Such regions are usually characterized by extremes such as low water availability in the deserts and much of the western mountains or temperature as in the northern great plains. These diversities in environmental characteristics are both convincing and compelling for a regional approach if the quality of the environment is not to decrease steadily with expanding production.

There are great differences in energy-related resource availability as well as the other natural resources for industrial production from region to region of the country. In the main, such resources are transported a short or long distance depending on the relative economics of transporting the raw materials or the finished products. The transportation system has been developed and, although it needs improvement, there seems to be no compelling need for a regional approach as far as resources are concerned.

The energy demand centers of the country are, of course, located in its population centers. To date, electrical generating plants have been located as close to the demand centers as feasible. With the present state of development one finds that the capacity of the environment to accept the residuals of increased energy production is marginal in many areas, such as the northeast and middle Atlantic states, even though the basic capacity of the environment is much larger than in other regions, such as the southwestern deserts. Thus there are persuasive factors toward regionalization as a result of the distribution of the energy demand center of the country. The factors are not mandatory because, by increasing transmission distances and tolerating the increased losses, it is possible to locate energy production facilities at greater

distances from the load centers. Such a strategy addresses only a portion of the problem. The end-point use of energy in the demand centers creates climatological changes, such as heat islands, which are unalterably connected to the demand centers.

In summary, if the environment is to be protected and energy production is to be increased (both being necessary), there are compelling reasons for adopting a regional approach to the assessment problem. In addition, there are persuasive reasons with respect to the potential energy sources, resources, and energy demand centers.

Scope of Regional Assessment

A regional assessment study involves two fundamental parts, an assessment of the existing state of affairs in the region and a forecast assessment of outcomes following a postulated action. Decisions with respect to implementation of a postulated action emerge from a comparison of the forecasted and existing states of affairs in the light of the goals which have been adopted. In order to set up the comparison, a specific geographical region must be selected for study, one which encompasses a sufficiently diverse set of characteristics such that the methodology employed in the assessments is generalisable to other regions yet one whose characteristics are sufficiently circumscribed that the available methodology is adequate for the assessment. The desirable set of characteristics encompasses energy supply and demand, environmental factors, economics, and resources. It is difficult to accommodate all of these characteristics if each is allowed to cover its entire spectrum of variation simultaneously with the others. The variations can be limited by using a scenario approach in which certain variations are not allowed. By employing a series of scenarios one can return to the entire spectrum of variation of each characteristic.

The data problem is a large one and affects the definition of an acceptable region. The required data encompasses energy supply and demand, environmental characteristics, economics, industrial and social institutions, and governmental organizations. The organization of the data is important and requires a consistent framework for its analysis.

The appropriate scope for a regional assessment study within a preselected region is to assess both the existing state of conditions in the region and the forecasted state of affairs following a postulated energy-related action. It must be kept in mind that an energy related action will generally invade the entire economy and the society and, as a result of the adjustment process of national productivity to changes in energy systems, the influence on the environment can be extremely widespread and not restricted to the region under study.

Purposes of Regional Assessment

The general purposes of regional assessment are to evaluate the probable state of the region attendant upon postulated energy-related actions and to derive strategies, tactics, and actions designed to minimize undesirable impacts in the context of the total needs of the society. One cannot afford the luxury of focussing solely upon environmental impacts, nor energy impacts, nor economic impacts, nor any other single type of impact. They must all be considered as a totality. Given an adequate consideration of the totality of impacts and the derivative judgments with respect to the "best" avenue of development, actions may be required to achieve a higher level of understanding of the public, and responsible individuals, with regard to environmental, health, and safety problems of nuclear, fossil, solar, geothermal, and other forms of energy supply systems. A good mechanism for improving the level of understanding is operational gaming. In this approach, a dynamic evolution of the region from its present state as a result of postulated actions is witnessed by the players who improve their understanding with

respect to the probable course of events which follow a set of energy-related policies.

Thus the purposes of regional assessment are:

1. To assess the present condition of the region.
2. To postulate a set of energy-related actions.
3. To forecast the evolution of the conditions in the region under the individual postulated energy-related actions.
4. To assess the relative benefits or disbenefits of the different postulated courses of action.
5. To derive strategies, tactics, and actions designed to minimize the undesirable regional impacts.
6. To insure that responsible individuals and the public understand both the preferred actions and the alternatives particularly with respect to environment, health, and safety; but also with respect to energy supply, economic impacts, and social impacts.

Goals for Regional Assessment

The overall goal of regional assessment is to provide the information base that will facilitate the proper choice of energy supply evolution path to maintain environmental, health, and safety standards for the region without unnecessarily restricting the spectrum of future energy supply options or economic development of the region. The application of operational gaming allows the players to forecast environmental, health, and safety as well as economic impacts resulting from postulated developments of future energy supply systems. The implementation of operational gaming requires the organization of a complex information base in a way which brings out all of the pertinent information for each option played in the game. This facilitates a higher level of understanding of each of the postulated actions in terms of high quality data and the most highly developed models.

Objectives of Regional Assessment

There are a great multiplicity of objectives that may be targeted for regional assessment programs within the discussion above. Operational gaming is a tool which has been designed to coordinate three primary elements of the problem:

(1) the important players, (2) the best computerized models, and (3) a large data base. The purpose of the interaction, which is carried out under computer controlled communication systems, is to show the players the best information with respect to evolution of the region under different energy-related options for development. Within this approach then there are several objectives which must be met as prerequisites to adequate regional assessment studies. These are:

1. Assemble and organize existing data.
2. Determine new data as required to provide a viable data base for operational gaming.
3. Identify the important players for each type of evolution scenario.
4. Identify the state parameters which each player can influence and the degree of his influence.
5. Incorporate existing models into the game.
6. Develop and incorporate new models for the game as required to improve the gaming capability.
7. Employ the gaming capability to enhance understanding of environmental, health, and safety problems of both nuclear and non-nuclear systems.
8. Forecast the nature, timing, and severity of problems that will be encountered in the evolution of the region (labor, capital, social, environmental, etc.) under different mixes of energy options.
9. Recommend programs designed to solve the developing problems in a timely manner.

Operational Gaming in Regional Assessment: A Summary

Operational gaming is the most powerful tool available today for forecasting the future evolution of a region under different evolutionary paths. It combines the unparalleled power of multiple human brains (the players) with the most advanced models of system behavior that have been (or can be) developed and with a data base of unprecedented completeness organized for serving both the models and the players. This capability provides a clear predictive capability to regional assessment studies and therefore is an ideal tool for the management and direction of a regional assessment program in

addition to organizing the studies to approach the problem in a rationally holistic manner.

PART 3

CONSIDERATIONS FOR A REGIONAL ENERGY ENVIRONMENT GAME*

* Contributions to this section were made by S. Ojalvo, F. Rahbar and G. Shimamoto, all graduate students in Energy Management and Policy at the University of Pennsylvania. This section also appeared as Report No. COO-2547-4 (June 30, 1975).

SECTION I

INTRODUCTION

This section reviews the considerations in the development and application of a methodology for a regional energy environment game as a part of a regional assessment study program. A scenario approach has been adopted to describe the context within which the game will be played. An actual small-scale game will be built on the scenario approach. It is clear that the small-scale game will be very limited in its capability, but it will serve the purpose of allowing the investigators to explore the various ramifications associated with the interacting elements of game structure, policy options, objectives set, number of players, and conflict resolution. The scenario approach is developed in a manner which serves to limit the game so that it fits the scope of a regional assessment study program.

In general, the major goals of the small-scale game are to explore the applicability of interactive operational gaming to:

1. Educate the game players in the complex mechanisms governing the evolution of a regional energy environment system.
2. Serve as a potential policy selection tool that brings into account the conflicting interests of the important actors in a regional energy environment system.
3. Scope, and set purposes, goals, and objectives for a regional assessment study program.

The methodology development is being approached in two phases of study. The first phase might be characterized as a "first generation" approach in that one attempts to encompass, in a highly aggregated sense, the essential elements of a regional energy environment system and its evolution while retaining the ability to enrich the elements in a subsequent generation. This phase serves as a tool to assist in the development of more meaningful games.

A fundamental weakness in previous operational gaming efforts has been the lack of a systematic method for determining a set of components (i.e., actors, relationships among those actors, and the factors involved in these relationships), all of which collectively determine the environment in which the game is to be played. The first phase of the two phase approach employed in this study is an attempt to solve this problem. It is clear that the operational small-scale game developed in Phase II requires careful characterization of the various elements of the game in order to insure realistic and useful results. Phase I offers a procedure by which we can choose a limited set of relevant components of the energy environment system which is being investigated (see Progress Report COO-2547-2) and tested, in a qualitative sense, to see if they properly describe the mechanisms involved in the energy environment system.

The Phase I or "first generation" approach employs the scenario scheme. A reference scenario is described (Section III). This scenario is the definition of the present state of the energy environment system under study. It is identified by a set of factors or state variables that determine the state of the system. A portion of these factors are decision state variables which are controlled by actors (players) in the energy environment game. An initial distribution of decision state variables constitutes a decision scenario. Various decision scenarios (section III) specify states of systems that require action or actions on the part of a set of identified actors who are playing the game. The Phase II approach to the game will take one of these defined decision scenarios as the context within which an interactive operational game will be constructed. The Phase I approach studies a set of possible future scenarios to which the reference scenario might evolve in the course of player interaction in the decision scenario. These future scenarios (Appendix D) describe a variety of futures that vary considerably in technology employed, policies emphasized, and values of the factors or state variables mentioned earlier.

Of particular importance in the Phase I approach is the identification of actors, their relationships with other actors, and the variety of policies each of these actors might pursue. It is clear that this identification and characterization

depends very much on the decision environment that is being considered which, of course, describes the context within which these actors are forced to make decisions. A weighting methodology (section IV) based upon the Eigenvalue Prioritization Model (Appendix B) is used to weigh the factors of (1) an actor's objectives, (2) an actor's relative influence on the state variables of the regional energy environment system, and (3) the relative effect each state variable has in realizing a possible future scenario. The final relative weights of the future scenarios describe the composite scenario, or resulting state of the regional energy environment system, as a consequence of the interactions between actors in pursuing their objectives.

Application of the weighting methodology allows one to determine the sensitivity of the choices of system components to the definition of the decision environment. A dominant actor in one decision scenario may be unimportant in another. This information is most important in determining which actors will become active participants or players in the Phase II interactive operational game. Section V will discuss the application of the weighting methodology to the modeling of the system components defined in the preceding sections. Section V also discusses the sensitivity of results to changes in various system components. For instance, a change in a particular actor's objectives could change the outcome of the weighting or the composite scenario. If a particular component (e.g. decision variable) is insensitive to change it is likely not to be considered for use on the Phase II interactive game.

The second phase, or "second generation" approach, to the game is an attempt to quantify the mechanisms identified in the "first generation" approach. The three key activities in the transition from first to second generation are to set limits on the mechanisms, to quantify them, and to particularize the mechanisms to the region under study in order to construct an adequate operational game within the time frame of the study and which is consistent with the goals of a regional assessment study program. The scheme for operationalizing the decision scenarios, actor policies, and impact models are under investigation as the Phase II study proceeds.

Fig. 3-1 shows the context within which the Phase I and II studies are coordinated. Note that an indication of consistency and/or success of the Phase II interactive game is how well the composite scenario describes the resultant state of the Phase II interactive game. In this sense Phase I is an approximation of the result we might expect in Phase II.

The target region selected for investigation encompasses Pennsylvania, Maryland, New Jersey, Delaware, and the District of Columbia. The region boundaries coincide with state boundaries because (1) all regional definitions presently in use in the U.S. have boundaries that coincide with county boundaries and (2) the states collect economic data for counties. Thus state boundaries form a convenient aggregation of counties. The basic regional definition is in terms of counties and therefore the definition is easily changed to vary from state boundaries. The number of states included were selected to cover a variety of environmental situations: the Delaware River Valley and Delaware Bay as well as the Chesapeake Bay. In addition, the region includes coastal and mountain regions as well as the transitional terrain. Thus the region selected exhibits a rich variety of environments. The loading on these environments also provides a wealth of variation ranging from the highly populated urban and industrial centers through the agricultural lands to mining and forest lands. Energy supply systems draw on nuclear and fossil systems including coal mining and petroleum production.

The data used to describe the target region are combined from a variety of sources. A summary of these data and their sources is included in Appendix A - Target Region Summary.

FIGURE 3
Structure of the Energy Environment Game

PHASE I

PHASE II

Section II

Identification of Actors, Relationships and Objectives

This section discusses a set of actors, whose interests, decisions and actions largely determine the state of the regional energy environment system. It is clear that, of the components developed in this Phase I effort that are to be employed in Phase II, the characterization of the principal actors is the least well developed. However, for the purposes of Phase I, only definition of the relevant actors and their principal objectives are required. Considerable refinement of the characterizations of these actors is a major task in Phase II. In particular, the time horizon considerations in an actor's decisions must be included. Some actors will have short term or even day to-day influence over the factors within the energy environment system. Others may only have long term influence.

Hence for Phase I a basic set of actors has been defined. The set of actors is divided into two subsets, government and non-government. The role of the former is that of setting rules, supervising and regulating the energy environment system while the latter is involved in production, transmission, distribution and consumption of energy in the system.

Governmental actors include the legislative, the executive, and the judicial branches, at both the Federal and state levels. The executive group includes the President of the United States, 50 state governors, and more than 40 federal and state agencies, bureaus, and commissions.

Non-governmental actors include energy suppliers, electric utilities, energy equipment manufacturers, heavy construction industry, individual consumers, industrial consumers, environmentalists, labor leaders, and financiers. Energy suppliers include the coal, oil, gas, and nuclear sectors.

Table 3-1 summarizes the classification of these actors in the Energy-Environment system. As mentioned in the Introduction, the characterization of actors and their objectives is a major step towards determining what roles will be included as players in the interactive Phase II game. The remainder of this section is devoted to a discussion of the roles and objectives of these actors.

Table 3

Classification of Actors in Energy
Environment Systems

Government	*Legislative	•Federal •State
	*Executive	•President •Governors •Federal Agencies: EPA, NRC, ERDA, FPC, FEA, etc. •State Agencies: DER, PUC
	*Judiciary	•Federal •State
Non-Government	*Energy Supplier	•coal •oil •gas •nuclear •Alternative Sources: LNG SNG Shale Solar
	*Electric Utility	
	*Equipment Manufacturers	
	*Heavy Construction	
	*Individual Consumer Industrial Consumer	
	*Environmentalism	
	*Labor Leader	
	*Financier	

Government Actors

There are three distinct types of government actors: legislative, executive, and judiciary. Each of these will be discussed briefly below.

The role of the legislative branch is to enact legislation to establish the rules under which the country operates. In addition, it maintains a continuing overview of the entire country. The general goals of legislators are to enact legislation which protects the interests of individual consumers; protects the interests of industries; maintains the welfare, health and safety of the nation; and safeguards the national security of the country.

The political parties to which legislators belong also have important influence over the actions of the legislators. Therefore, both Federal and state legislators may be divided into Democrats and Republicans. The general goals are the same but the relative emphasis is different, as is the approach to attaining the goals.

The executive branch of government needs to be divided into two groups: the policy group composed of the executive officials of the Federal and state governments (President, governors, agency heads, etc.) and the energy related agencies. The members of the policy group of executive officials make policy decisions and implement policies in matters which are authorized by the legislative branch. Its general goals are coincident with those of the legislative branch, i.e., it protects the interests of individuals and industries while maintaining health, welfare and safety, and protecting the national security of the country.

There are more than 40 Federal agencies, bureaus and commissions which have a role in the energy environment system. Ten of the major Federal agencies are: Energy Research and Development Administration, Environmental Protection Agency, Federal Energy Administration, Federal Power Commission, Interstate Commerce Commission, Nuclear Regulatory Commission, Mining Enforcement and Safety Administration, U.S. Geological Survey, U.S. Corps of Engineers, and Bureau of Land Management.

The objectives of both groups are directed towards: ensuring adequate and economical energy supplies; employing sound resource management to assure wise and efficient use of the nation's mineral and energy resources; protecting public health and safety; and protecting and enhancing environmental quality. For the different members of each group the relative emphasis is different, depending upon type of activity (policy vs. non-policy) and agency responsibility.

The energy agencies are created by the legislative and/or the executive branch to promulgate rules, regulations and standards, to issue licenses, permits, leases, to monitor and enforce compliance and to initiate energy research, development, and demonstration programs.

Besides the Federal energy agencies, each state has its own agencies involved in energy and environmental systems. The concern, as well as the power, of these agencies is limited to the boundary of the state in which they operate.

The relationships of the energy agencies with each other and with other actors in the energy environment system may best be derived from a statement of the responsibilities of each of the major agencies. This statement is available in many forms, but a concise form is presented in "Federal Energy Regulation: An Organizational Study". Excerpts are attached as Appendix C.

The judicial branch of the government has the responsibility of determining facts, interpreting laws, passing judgment and resolving conflicts between actors, in cases involving alleged violations of the laws and/or the constitution.

Non-government Actors

Energy suppliers extract, process, convert, transport and distribute coal, oil, natural gas and uranium, which are consumed by other actors in the energy environment system. Energy suppliers have a very important role in utilizing energy; therefore, different suppliers will be described separately.

Generally, these actors, like any other business operators, are interested in obtaining a fair profit, in serving their customers, and in obtaining less stringent regulation of their operations. Since relatively large amounts of investments are

necessary in these sectors, the actors desire governmental policy which assures a stable, long term market for their commodities. To understand more about each of these energy suppliers, a brief review of the industry structure and its constraints is presented below.

Coal Suppliers. There are several thousand companies involved in the coal industry. They range in size from small one-man operations to large organizations with labor forces totaling more than a thousand workers. In 1972 the top four coal producers provided 30% of coal production, and the top 20 producers provided 56% of coal production. The ranking of the top 15 coal producers in 1972 is shown in Table 2.

Oil Suppliers. Five major integrated international producers, twelve major integrated domestic producers and three major crude oil producers control the largest portion of the nation's oil industry. In 1972 they produced more than 60% of the total U.S. oil production, processing, and distribution in the U.S. The largest firms in the industry are fully integrated throughout all stages of production. In 1970, the top 20 crude oil producers provided 69% of crude oil production, 87% of refinery runs, and 76.3% of gasoline sales. In 1962, twenty large firms accounted for 79.9% of pipeline mileage.¹

In addition to increasing concentration of oil production in a few large companies, the major oil companies have expanded significantly into other fuel and energy producing industries. By 1971 the major oil companies accounted for approximately 84% of refining capacity, 72% of natural gas production, 30% of the domestic coal reserves, and 25% of uranium milling capacity.

The production, prices, and financing of the domestic oil industry are regulated at both state and Federal levels.

Natural Gas Supplier. The gas industry consists of three sectors: production, transmission, and distribution which are interconnected by pipeline networks throughout the country. There are several thousand producers, most of whom sell in interstate commerce. However, about 50% of sales are in the hands of the top 10 companies.¹

Table 3-2

Ranking of the Top 15 Coal Producers - 1972*

Rank	Name	Share of Market
1	Peabody Group	12.3%
2	Consolidation Group	11.1%
3	Island Greek Group	3.7%
4	Piltson Group	3.5%
5	Amax	2.8%
6	U. S. Steel	2.8%
7	Bethlehem Mines	2.3%
8	Eastern Associated	2.1%
9	North American	2.1%
10	Old Ben Group	1.9%
11	General Dynamics Group	1.7%
12	Westmoreland	1.5%
13	Pittsburgh & Midway	1.3%
14	Utah International	1.3%
15	American Electric Power	1.1%
Total		52%

* Draft Report to the FEA Project Independence, "Historical Perspective on U.S. Energy Consumption and Supply", August 1974.

There are some 1600 distribution companies, each a locally franchised monopoly in its own market area. Also there are 120 interstate pipeline companies certified by the FPC plus about 45 intrastate pipelines regulated by state laws.

The pipeline companies purchase gas in the field or from intermediate pipelines and resell the gas to other pipelines, distribution utilities, electrical utilities, and direct industrial customers. In 1971, the top 20 pipeline companies accounted for over 90% of all gas sold to interstate pipelines.

Pipeline companies and distribution utilities are heavily regulated by FPC and state law. A gas company producing and gathering gas and selling it to pipeline companies is also subject to regulation by the FPC.

Nuclear Supplier. Supplying nuclear fuel is very different from supplying fossil fuels such as coal and oil. While the volume of natural resource material is much smaller for nuclear fuel, it must be concentrated in a milling process, changed to a gaseous state in a conversion plant, upgraded in an enrichment plant, converted back to solid oxide and fabricated into metal-clad fuel elements before it is used in the nuclear power plant. After it is used in a nuclear power plant, the spent fuel must be reprocessed and the radioactive wastes must be safely stored.

There are a large number of companies engaged in the exploration and mining of uranium, but the output is dominated by large companies. Of the ten companies with the largest uranium reserves, four are oil companies.

Milling of uranium ore involves fewer participants than mining, but there are a substantial number of mills. Oil companies control four of the sixteen mills now operating.

There are only three participants in the conversion process. Enrichment of uranium is exclusively in the hands of the Federal government. Conversion to uranium dioxide and fabrication of fuel are done by reactor manufacturers and some oil companies. Storage and management of processed radioactive waste is the responsibility of the Federal government.

Electric Utilities. These actors generate electrical power primarily in steam power plants using coal, oil, natural gas, or uranium as a fuel. To a smaller extent they generate power from other sources of energy such as geothermal and hydroelectric installations.

The goals of this actor, which is regulated heavily by both Federal and state agencies, are to meet the demand for electrical power, to have a reliable system of power generating capability, to minimize the cost of supplying electrical energy while maintaining a fair return on investment, and to have less stringent environmental and safety regulation (while maintaining a good safety record).

There are 3500 electric utilities, some owned by private companies (investor-owned utilities), some owned by the Federal government, and some owned by electric cooperatives. In 1970 the investor-owned segment accounted for 77%; Federally and publicly owned segments accounted for 28%; and electric cooperatives accounted for less than 2% of the nation's generating capacity.

Nearly all of the approximately 200 major investor-owned utilities operate integrated generation, transmission and distribution systems. Electric utilities are heavily regulated by different state and Federal agencies. The scope of authority of state commissions to regulate electric utility systems varies considerably among the states. Many state commissions have rather broad powers including the regulation of rates, accounting procedures, security issues, safety and adequacy of service, certification of major property addition, initiation and abandonment of service, and allocation of territory. At the Federal level, several agencies have important responsibilities for regulating specific activities of electric power systems.

Energy Equipment Manufacturers. This actor provides the component equipment which is used in the extraction, conversion, transportation, and distribution of energy. The energy equipment manufacturers include a wide variety of companies such as the nuclear reactor, turbine, boiler, heat exchanger, and mining equipment manufacturers.

As in any business venture, this actor is concerned with making a reasonable profit. Because of the long lead times required to deliver much of this equipment, he is also interested in a stable national energy policy which will assure him of a long term steady market for his product.

Heavy Construction Industry. The heavy construction industry necessarily is involved in nearly all energy construction projects - power plants, refineries, coal mining, oil drilling, etc. Consequently the input from this sector in terms of labor and material availability and cost is important to energy development. The pace and cost of energy development are therefore determined by the limitations of the construction industry. The heavy construction industry is made up of many independent operators, varying in size from the largest steel firms in the U.S. to local operators of bulldozing equipment. Their decisions are based mostly upon market and general economic conditions.

Consumer (Individual and Industrial). A consumer is an actor who buys goods and services (including coal, oil, natural gas and electricity). Consumers may be divided into two categories based on their behavior and goals in the energy environment system: individual consumers and industrial consumers.

An individual consumer is a "pure consumer" in the sense that he is involved only in the consumption of goods and services. An industrial consumer is involved in consumption for the purpose of producing goods and services. He is more "producer oriented" in his interest than the individual consumer.

The goals of the individual consumer are: to have lower prices for fossil fuels and electricity, to have lower prices for non-energy goods and services, to have a reliable source for all goods and services, and to have a safe and healthy environment.

The goals of the industrial consumer are: to have lower prices for fossil fuels and electricity, to have a reliable source of primary and intermediate goods and services, to return an adequate profit on investment, to have less government regulation, and to maintain a good public image.

Environmentalist. An environmentalist has a primary interest in human health and safety and preservation of the natural environment and wild life. This actor does not have a direct influence over other non-government actors to achieve his goals, but instead influences the energy environment system through government actors, e.g., legislative, judicial, and executive actors.

The environmentalist's objectives are to reduce environmental pollution to a minimum, and to enhance public health and safety.

Investors. At historical rates of expansion, the energy industry will require increasing amounts of capital investment. Large banks and investment firms, along with the Federal government, have control over large blocks of capital. The ultimate source of capital is the aggregate personal savings derived from the GNP. The relationship between savings and income has been one of America's most stable economic relationships. The availability of capital can thus be affected by an increase in the proportion of savings (unlikely), an increase in GNP (likely), and an increase in the proportion of total capital devoted to the energy industry (historically about 23%, with peaks at about 30% which would be feasible and necessary for rapid energy expansion).

Even if the investors possess the capital, they are not likely to expand investment in energy industries unless there are signs of stable, long term growth possibilities. The financial status of the energy companies thus depends on their rates of return in relation to other industries, and may be greatly influenced by government actions (PUC rate decisions, Federal subsidies, etc.). Energy is such a basic commodity to all enterprise that an expanding economy should provide an excellent outlook for the energy industries in particular.

Labor Leaders. Labor interests in the energy environment system will be represented through a labor leader. His principal goals are to maximize wages and other benefits to workers in the region. Aggregated state variables of interest to the leaders are the wage rate, total wage type income generated within the region, and the rate of unemployment.

Section III

Decision Environment

Introduction

The decision environment is composed of a reference scenario of the energy environment system under investigation and a set of possible decision scenarios which serve as possible conditions of the system that require action or actions of various actors whose roles are represented in the regional energy environment system. In general the decision scenarios under study depict shortfalls of one or more energy sources within the study region. Each scenario sets the stage for the players' interactions that would be required to cope with the shortfall.

The identification of the most important actors and state variables in such a decision scenario, as mentioned earlier, defines the players and state variables that would need to be included in an interactive operational game tailored to that decision scenario. Before the reference and decision scenarios are discussed, a description and justification of the factors or relevant elements that describe each of these scenarios is presented. This is prerequisite to establishing a comparative framework that can be employed in the weighting methodology to be discussed in a subsequent section.

A. Identification of Actors

Seventy factors, or state variables, are identified for the energy-environment game. A factor and its level of aggregation is determined on the basis of three criteria: (1) whether it is an important input that would affect the energy-environment system through the decisions of some actors (identified in Section II) involved in the regional game; (2) whether it can be adequately and succinctly described in the reference and the chosen future scenarios; and (3) whether the level of aggregation is sufficiently detailed to be of meaningful use to the actors (players) in the game.

Three groups of factors are identified, each is related to the others: energy factors, environmental factors, and economic factors.

The energy factors are characterized by consumption of energy and type of fuel usage. Energy consumption is allocated to residential and commercial, transportation, industrial, and electric utility sectors. The electric utility sector is disaggregated from the industrial sector because of its important role in the regional energy environment game. Sources of coal used in the study region are identified as either produced within the region or imported from outside the region. Oil consumed by the region is either produced domestically or imported from other countries. Clearly, a minor modification would enable the game to simulate oil produced within the region. Natural gas is presumed to be imported from outside the region.

Environmental factors are divided into two categories. They are air, water, land-use quality indicators and environmental regulatory control indicators. There are many factors that can be used to assess air quality; however, only particulate and sulfur oxide emissions are selected for the Phase I study. More air quality factors may be included in Phase II. For water quality assessment, the utility water consumption rate and water effluent quality are included. The indicators for land use are coal mining land use rate and nuclear waste generation rate since strip mining

and storage of nuclear waste are important considerations in both the reference and future scenarios. The environmental regulatory control levels are included to indicate the extent each energy industry is regulated by environmental regulatory agencies. The status quo designations indicate regulatory control levels at the reference scenario level.

The set of economic factors includes gross regional product which indicates the financial health of the region, gross national product per capita to show the standard of living, and unemployment rate. It also includes certain price indicators, such as the consumer price index, the wholesale price index, and four energy price indices. Since development of energy sources requires substantial capital investments in new plants and equipment, cumulative and annual regional capital investments for all industries, coal mining, petroleum and gas extraction and refining, non-nuclear electric generation, nuclear electric generation, and nuclear fuel processing are included. Two important factors are not included in this Phase I set of factors but will be added to the list in the Phase II gaming effort. These are the level of regional capital formation which will describe the source of capital for energy investments, and a regional labor earnings index to supplement the information provided by the GRP per capita figure in reflecting labor and standard of living interests.

This list of factors serves the important function of unifying all the reference and future scenarios on a common basis. It provides a framework of consideration that should be addressed in all scenarios. The list of factors which collectively comprises a quantitative summary of a scenario is outlined in Table 3-3.

B. Reference Scenario

The reference scenario is described by two sets of factors, one of which reflects the current (1975) factors in the study region's energy environment situation and another which reflects the historical rate of changes in these factors. This historical rate of change is presented as a listing of the same factors five years from now - 1980 - the year for which the decision scenario is designed.

The values of the factors in the reference scenario are obtained from various sources, which will be enumerated as they are quoted. They are not meant to be sufficiently accurate to reflect exactly what is happening in the region. Instead, they are estimates to indicate the magnitude of the values of the factors and are to be used primarily for comparison purposes.

The data for energy consumption by type of user and forms of energy, shown in Quantitative Summary R-1 for the study region, are obtained from "Fuel and Energy Data - U.S. by States and Regions, 1972", published by the Bureau of Mines (IC8647).¹ These data are adjusted to obtain their values for 1975, using energy consumption growth rates projected by Hudson and Jorgenson in the paper "U.S. Energy Policy and Economic Growth, 1975 - 2000".²

The energy consumption for the study region is over 8 quadrillion BTU. Of this, 27% is consumed by the residential and commercial sector, 21% by the transportation sector, 32% by the industrial sector, and 20% by utilities. The region's fuel use is comprised of 6% extra-regional coal (mostly for low sulphur coal burning electric utilities), 16% intra-regional coal, 19% foreign oil, 34% domestic oil, 18% natural gas, and 7% electricity. The region imported 40% of its total oil consumption from foreign countries.

The rates of increase of energy consumption projected by type from 1975 to 1980 are as follows: 0.52% for coal, 2.62% for oil, 4.96% for electricity, and 2.34% for natural gas.

The energy mix for electrical generation in the study region consists of fossil (78% of total generating capacity), some nuclear (7%, which is somewhat higher than

the average national figure) and other types of generation such as hydro and pumped storage. The overall generating capacity is about 42,000 MW. These data are adjusted from the figures of the 1970 National Power Survey.³ The electric generating capacity expansion rate is taken at 7% per year, which may be high in the time period under study.

The environmental quality indices for air, land, and water are obtained from a number of sources, and are scaled down to the regional level from National figures. These sources include "Air Quality and Stationary Source Emission Control" prepared for the Committee on Public Works, U.S. Senate, August 1973⁴, "Land Utilization and Reclamation in the Mining Industry, 1930 - 71", by the Bureau of Mines (IC-8642),⁵ "Assessment of Impacts of New Technologies by Generalized Input-Output Model", by James Just, 1973.⁶

In 1975, the region's pollution output included 5 million tons of particulates, 9.03 million tons of sulphur oxides, 6.88 trillion gallons of heated water by utilities, 5,710 acres of strip mined land, and 8.55 cubic meters of nuclear waste. These figures for 1975 are treated as base figures and are all given values of 100 as an index reference.

In 1980, the particulate emission index is estimated to rise slightly to 108 (on the index scale) due to more coal being burned in power plants as well as by the industrial sector. Sulphur oxides are expected to decline as a result of tighter regulations. Water consumption by the utility sector is expected to increase significantly to an index of 160 at a rate of 9.4% per year since the trend away from once-through cooling systems will increase consumptive use of water. Thermal effluent quality would remain constant. Rate of land use for strip mining is assumed to be the same as that of 1975 because the deep mining to stripping ratio is expected to remain 50:50 with little growth in the coal industry. But nuclear waste generated will rise drastically to 560 due to the drastic growth rate predicted in the 1970 National Power Survey from relatively low levels at present. Environmental regulation control level will remain the same except for fossil electric generation since more stringent standards will be enforced. (See Table 3-4.)

In 1975, total gross regional product stands at \$138 million, for a population of 26 million people, or \$5308 per capita. Gross regional product is estimated to grow at an annual rate of 3.4% to \$164 million in 1980, for a population of 27.2 million (increasing at a rate of .9% per year) or \$6015 per capita, a net rise in the standard of living in 1975 dollars. Unemployment rate is expected to drop from the present 9% to 5% in 1980.

Consumer and wholesale price indices will rise from the base figure (100 on the index scale) in 1975 to 135 and 122 respectively, at a growth rate of 4%. Observed energy prices in 1975 are obtained from "FPC News, March 1975" at 118.3¢/Mbtu for coal, 219¢/Mbtu for oil, 67.6¢/Mbtu for natural gas. The current price for electricity from Philadelphia Electric Company was calculated to be 450¢/Mbtu to the residential customer.

Total capital investments for new plants and equipment for all industries is \$1,231 million, growing at a rate of 8% annually. In the energy sectors capital investment is \$50 million for coal mining; \$100 million for petroleum and gas extraction and refining; \$100 million for non-nuclear generation equipment; \$209 million for nuclear generation equipment and nuclear fuel processing. The nuclear figure appears low because of the relatively small amount of construction going on in this year. However, capital investments for nuclear generation and fuel processing plants will be increased drastically at a rate of 35% per year. These figures are obtained from scaling down of the national data published by McGraw-Hill Inc.⁷ The PJM region contains approximately 9.4% of the U.S. population and 11.2% of its manufacturing capacity. Consequently, 11% of the national investment data were assumed to be applied to this region. Economic regulatory control levels for 1980 are taken to be the same as those of 1975.

Scenario: Reference Scenario (1975)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com	Transport	Industry	Utilities
Extraregional coal				
Intraregional coal	3.7	-	244.6	252.7
Foreign oil	10.1	-	661.3	683.4
Domestic oil	450.8	673.8	145.4	283.7
Natural Gas	676.3	1010.8	218.1	425.5
Electricity	791.4	32.9	595.5	41.2
	332.3	4.0	220.3	-

Electrical generation mix: 78 % fossil, 7 % nuclear, 15 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions 5.0×10^6 tons/yr SO_x emissions 9.03×10^6 tons/yr

Water quality:

Utility consumption rate 6.88×10^{12} gals/yrEffluent quality 100 index

Land use:

Coal mining land use rate 5710 acres/yrNuclear waste generation rate 8.55 m^3 /yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal		X	
Oil		X	
Natural gas		X	
Fossil electricity			
Nuclear electricity		X	

Economic indicators

Gross regional product: (3.4% growth)	<u>138 x 10⁹</u>	\$
Gross regional product per capita:	<u>5308</u>	\$/person
Unemployment rate:	<u>9%</u>	%
Consumer price index:	<u>100</u>	index
Wholesale price index:	<u>100</u>	index
Energy price indices:		
Coal	<u>118.3</u>	index
Oil	<u>219.1</u>	"
Natural gas	<u>100</u>	"
Electricity	<u>100</u>	"

Capital investments:

	Cumulative	Current year
All non-energy industry	<u>\$</u>	<u>1231 x 10⁶</u> \$
Coal mining	<u>\$</u>	<u>50 x 10⁶</u> \$
Petroleum extraction & refining	<u>\$</u>	<u>100 x 10⁶</u> \$
Non-nuclear generation	<u>\$</u>	<u>100 x 10⁶</u> \$
Nuclear generation	<u>\$</u>	<u>204 x 10⁶</u> \$
Nuclear fuel processing	<u>\$</u>	<u>9 x 10⁶</u> \$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal		X	
Intraregional coal		X	
Domestic oil		X	
Foreign oil		X	
Natural gas		X	
Fossil electricity		X	
Nuclear electricity		X	

Reference 1975

Scenario: Status Quo 1980

Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com	Transport	Industry	Utilities
Extraregional coal	3.8	-	230.5	259.4
Intraregional coal	10.4	-	678.7	701.4
Foreign oil				
Domestic oil	556.3	875.6	188.9	368.8
Natural Gas	834.5	1313.5	233.4	553.2
Electricity	1000.0	41.6	752.5	52.0
	545.7	6.6	361.8	-

Electrical generation mix: 57 % fossil, 30 % nuclear, 13 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions	5.4×10^6	tons/yr
SO _x emissions	9.0×10^6	tons/yr

Water quality:

Utility consumption rate	8.45×10^{12}	gals/yr
Effluent quality	100	index

Land use:

Coal mining land use rate	5710	acres/yr
Nuclear waste generation rate	47.9	m ³ /yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal		X	
Oil		X	
Natural gas		X	
Fossil electricity		X	
Nuclear electricity		X	

Economic indicators

Gross regional product:	<u>163.6 x 10⁹</u>	\$
Gross regional product per capita:	<u>6015</u>	\$/person
Unemployment rate:	<u>5.0</u>	%
Consumer price index:	<u>135</u>	index
Wholesale price index:	<u>122</u>	index
Energy price indices:		
Coal	<u>237</u>	index
Oil	<u>495</u>	"
Natural gas	<u>161</u>	"
Electricity	<u>175</u>	"
Capital investments:		

	Cumulative		Current year	
All non-energy industry	<u>7591 x 10⁶</u>	\$	<u>2030 x 10⁶</u>	\$
Coal mining	<u>275 x 10⁶</u>	\$	<u>642 x 10⁶</u>	\$
Petroleum extraction & refining	<u>500 x 10⁶</u>	\$	<u>100 x 10⁶</u>	\$
Non-nuclear generation	<u>500 x 10⁶</u>	\$	<u>100 x 10⁶</u>	\$
Nuclear generation	<u>2366 x 10⁶</u>	\$	<u>2016 x 10⁶</u>	\$
Nuclear fuel processing	<u>102 x 10⁶</u>	\$	<u>52 x 10⁶</u>	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal		X	
Intraregional coal		X	
Domestic oil		X	
Foreign oil		X	
Natural gas		X	
Fossil electricity		X	
Nuclear electricity		X	

Status Quo 1980

DECISION SCENARIOS

A. DECISION SCENARIO I - NATURAL GAS SHORTAGE

In the Pennsylvania, New Jersey, Delaware, and Maryland region, the requirements for natural gas in 1975 totaled 1,925,383 mcf; measured against the total deliveries of 1,796,382 mcf, the result is a 6.7% shortfall. This shortage was handled without major economic disruption, mainly by the exercise of interruptability clauses in some large industry contracts. Some area steel and petrochemical plants suffered sporadic losses, but no residential, commercial, or institutional customers were refused precommitted supplies, although utilities in the area had been following a policy of "no new customers" since 1972.

The source of the gas used in the four-state region was the basins of the Gulf Coast, piped north through the pipelines of Texas Eastern Transmission Co. and Transco. Production in these fields had been progressively falling behind demand during the early 1970's. The ratio of reserves to annual production had been eroding since the 1960's. The reserve to production ratio basically indicates the number of years of gas production left at a given amount of reserves and a constant production level. In 1975 the reserve to production ratio was slipping dangerously close to ten, which by industry standards is near-calamitous.

The reasons for falling production in domestic gas fields were claimed by the industry to lie mainly in the policies of the Federal government. Since 1954 the Federal Power Commission has exercised direct control over the wellhead price of natural gas to be sold in interstate commerce. Such gas amounted to about two thirds of the total U.S. gas consumption in the early 1970's. The producers complained that FPC prices were too low to allow a rate of return on capital high enough to spur new gas discoveries at a rate sufficient to keep up with demand. They claimed that the artificially low prices both overstimulated demand in the Industrial Northeast and restricted development of new supplies. The producers pointed to the difference between unregulated gas (sold inside producing states) and FPC-regulated gas. Prices in Texas were as high as \$1.75/mcf in the early 1970's, whereas by 1974 the FPC

ceiling price had risen to just under \$.50/mcf. Producers claimed that by thus holding prices below market equilibrium, supply and demand were becoming artificially imbalanced and a shortage of catastrophic proportions was being created.

From 1975 to 1980 the debate over gas prices intensified. Demand in the four-state region had increased to 2,325,390 mcf, but supplies had increased only to 2,092,844 mcf, thus widening the shortfall to 10%. The FPC had allowed further price increases up to a maximum of \$.75/mcf, but gas was bringing \$2.25 on unregulated markets (intra-state sales). Major industrial gas users had begun to announce relocations of major facilities from the four-state region to producing states in order to insure supplies. The regional construction industry was increasingly crippled by gas utilities' "no new customers" policies. Though no residential, commercial or institutional customers had yet been curtailed, the utilities had had to rely more and more on gas manufactured from naphtha feedstocks for peak-shaving purposes; hence customer prices for electrical energy had risen an average of 80% since 1975.

The demand for outer continental shelf gas and oil supplies had been soaring since 1975, but environmentalist opposition had delayed the beginning of exploration until 1978, and exploratory wells were still in progress in the Baltimore Canyon and Georges Bank. Oil and gas producers operating on the OCS predicted the first flows to east coast markets in 1981-82, and estimated that gas supplies from the OCS in 1985 could total 5 tcf (trillion cubic feet), barring unforeseen delays. This source was expected to partially offset the projected shortfall in the Northeast. A trans-Alaskan pipeline completed in 1979 was bringing 0.7 tcf into the lower 48 states, but little of this was reaching the Northeast.

LNG imports had increased at an unexpectedly high rate over the 1975-80 period, totaling 5.5 tcf in 1980. This LNG was imported mainly from Algeria, Venezuela, and the North Sea. However, nationalistic influences in Venezuela had forced planned cutbacks in exports of oil and gas, ending all shipments to the U.S. by 1985. Britain and Norway, concerned at the increasing volumes flowing across the Atlantic and dwindling reserves, announced a plan to reduce exports to all countries beginning

in 1981, culminating in 1990 at levels no higher than 50% of 1980 levels. One hopeful possibility on the horizon was a tentative agreement arrived at in 1979 between the U.S. and the Soviet Union to enter a joint full-scale development of Siberian natural gas fields, with provisions for liquifaction and export to the U.S. Officials estimated that by 1985 up to 5 tcf could be imported in this manner; however, delicate negotiations remained, and internal power struggles in the Politburo made the future of detente increasingly uncertain.

The most disappointing development in the 1975-80 period had been the development of coal gasification. Federal research budgets had given coal gasification research and development a low priority compared with nuclear and other energy sources. Most research had been carried out by oil companies or oil company-owned coal companies. Critics charged that the industry had been purposefully dragging its feet on SNG development so as to maximize profit on dwindling supplies of conventional fuels. The industry claimed that the state of the art in SNG technology was such that SNG was not competitive with existing fuels. They pointed to the FPC price policy as being the main bottleneck to SNG use; they claimed that the breakeven price for SNG from the Hygas process was \$1.20/mcf, and that the FPC ceiling of \$.80 was too low to permit economical use of SNG. They predicted that if FPC price ceilings were dropped immediately, SNG from coal could amount to as much as 1 tcf by 1985.

Things came to a head in Congressional hearings on the decontrol of all natural gas prices in May 1980. Governors from the Northeastern states testified as a group that their region was headed for catastrophic shortages by 1985 unless major changes in the gas supply system were made. The oil and gas producing industry pointed out that full decontrol would make a number of new fuel sources more profitable and hence more available, notably SNG from coal and conventional gas fields on the outer continental shelf. Environmentalists argued that OCS development could do severe environmental damage to the East Coast, and that the safety of LNG import facilities was still unproven. They pointed to explosions and fires

at two major sites on the East Coast as evidence that LNG imports were dangerous. Industries with heavy investments in the Northeastern states testified that they would be willing to pay the price of uncontrolled gas as long as it would insure adequate supply.

It was predicted at the hearings that unless major changes occurred, there would be up to a 33% shortfall in gas supplies in the Northeast in 1985, which would have devastating impacts on industry and residential consumers alike. The upshot of the hearings was that 1980 would be the watershed year for natural gas; decisions made in that year would clearly have a decisive effect on the nation's economic health for decades to come. So far as the industrial Northeast was concerned, the point of no return was at hand. Either conditions would be set which would provide sufficient natural gas or the dismantling of its industrial complex would accelerate and unemployment would sky-rocket. The quantitative summary is included in Appendix D.

Summary

Gas shortfall in the four-state region amounted to 6.7% in 1975, increased to 10% in 1980, and was predicted to increase to 33% by 1985. A number of factors contributed to the mounting shortage, most of them revolving around Federal regulation of natural gas field prices, dwindling domestic field reserves, and difficulties in developing alternate gas sources, including gas from the Outer Continental Shelf, from liquified imported gas, and from synthetic coal gas.

At congressional hearings in May 1980, it became clear that 1980 was to be the decisive year for the future of natural gas in the United States. The positions of the Federal government, state government, local utilities, consuming public, consuming industry, and environmental groups were brought out, dramatizing the complexity of the problem.

B. DECISION SCENARIO II: Overall National Shortage of Important Refined Oil Products with Severest Effects in the Pennsylvania, New Jersey, and Delaware Areas (commonly called PENJERDEL).

During the summer of 1979, the United States Government acted in unison with a number of other major industrialized countries to protest a large increase in the price of oil sold by the OPEC countries. The OPEC countries joint decision to raise prices was claimed to be in retaliation for recent increases in the price of exported food grains. The previous year's grain crop was the worst in six years and the subsequently intensive demand for grain by the grain importing nations had caused prices to increase rapidly.

The major industrialized countries' protest took the form of a "lockout" or boycott of OPEC crude and related oil products. This "lockout" was expected to bring the less affluent OPEC countries out of the recent price increase agreement. Important officials of the oil importing countries believed that the "lockout" would have successful results in less than six months. These same officials believed that the present domestic production of the industrialized nations, along with the oil already purchased and still in the delivery system from OPEC countries and the crude oil stored against such eventualities, would satisfy the needs of the industrialized nations until the price increase was broken.

Top advisors to the President advised him that this country could last the boycott with little harm to the national economy. They were against any type of allocation or rationing, stating that such systems would cause voter anguish and cause the President and his political party to lose large numbers of votes in the upcoming elections. They were most optimistic that through the "lockout" and through negotiations with certain OPEC countries, the price increase could be lowered in a matter of three months. These officials felt that the need for allocation and rationing controls would only cause panic buying among consumers.

By the end of 1979, the OPEC countries were still presenting a solid front in their increased price of oil. U.S. officials interpreted this strong showing of

solidarity as a facade. Rumors persisted that the less affluent oil exporting countries were about to back down on the price increase in order to obtain needed foreign exchange. These officials further persuaded the President and top members of Congress to forestall any plans for rationing and allocation lest it indicate to the OPEC nations a weakening of the U.S. position.

The supply of refined oil products in the U.S. was scarce throughout the nation, but was most apparent in the eastern part of the country. Western states, which had previously exported refined oil products to the eastern states, were now claiming that there was no exportable surplus due to shortages in their own regions. An eastern area suffering extreme shortages was the PENJERDEL region. The reason for this extreme case was the lack of crude production and refinery capacity for the region. In more normal times, the region's oil users would be able to purchase their needs from the western states or from overseas.

The effect of the PENJERDEL region's oil crisis was widespread. Industries, dependent on fuel oil to power their production processes, were unable to continue normal operations. Reduced workweeks and large scale layoffs were starting to become a serious economic and social problem. The region's vast petrochemical industry was among the most severely affected. This industry, employer of tens of thousands of regional inhabitants, was unable to obtain sufficient feedstock for its operations. The effects of the feedstock shortage filtered downstream to industries dependent on supplies of petrochemical materials for their production needs. Regional retail stores also felt the impact through the reduction of regional disposable income.

The shortage also brought long waiting lines at gasoline stations. Fear spread among car owners that the long lines would disappear, not because the shortage was over, but because the stations would close due to the lack of any gasoline. Homeowners who relied on oil for heating purposes were fearful that they would not be able to obtain sufficient fuel oil to see them through the winter.

Pressure was placed on area government officials to find solutions for the region's problems. The officials assigned to the problem saw no immediate short term solution other than petitioning Federal officials for additional supplies of national oil production. The officials felt a need for a long term solution to the region's dependency on outside energy sources. The majority considered that the solution was to undertake full scale development of the Atlantic Outer Continental Shelf. In the past, the problems associated with development of the Atlantic OCS prevented any substantial production from this source of regional fuel. The stage was now set for the debate as to whether the problems of OCS development were worth resolving or whether the region's dependence on outside petroleum sources should be continued. The advocates of OCS development proposed that the fuel needs for the interim years between 1980 and full scale development of the OCS should be met by substituting regional coal supplies for non-regional fuels wherever it was technologically feasible. This plan was met with opposition from the same environmentalists who were opposing rapid development of the OCS.

In order to better evaluate the region's oil crisis and understand the factors leading to the present situation, a regional organization called CONCERNED (Committee on National Control of Energy Resources Needed for Efficient Development) published their findings regarding the cause of the regional crisis. The following document was given extensive exposure in regional media.

Overall Problem: Oil product shortage in Nation with extreme hardship
to PENJERDEL region

Factors leading to above problem:

1. OPEC oil "lockout"
2. Regional refinery shortage, due to:
  - a. environmental opposition
  - b. capital funds shortage
  - c. insufficient profit incentive for refiners
  - d. state and local government "red tape" and tax burdens
3. Decreasing U.S. production/exploration, due to:
  - a. environmental opposition
  - b. capital funds shortage

- c. insufficient profit incentive for producers
- d. delays in OCS development due to:
  - (1) environmental opposition
  - (2) capital funds shortage
  - (3) insufficient profit incentive for OCS producers
- e. delay in bringing forth production from Government owned Naval Petroleum Reserves
- f. failure of Alaskan oil shipments to reach maximum outflow of 2 million barrels per day, due to:
  - (1) environmental opposition
  - (2) capital funds shortage
  - (3) insufficient profit incentive for producers
  - (4) inability to obtain necessary equipment for production and transportation
- 4. Increased consumption of oil products, due to:
  - a. lack of conservation habits, due to:
    - (1) lack of government energy policy
    - (2) consumer indifference
  - b. expansive economy

Having identified the major factors leading to the present crisis, the group pleaded for a regional effort towards a solution to the crisis. The quantitative summary is given in Appendix D.

C. DECISION SCENARIO III: Regional Electrical Shortage Caused by Insufficient On-line Generating Capacity

The movement in the mid and late seventies to obtain a secure energy supply led many regional industrial, commercial, and residential energy users to switch to electric power. Capacity to meet the electric demands of this region was not expanded sufficiently and, as a result, the area suffered repeated "brownouts" during the summer of 1980, a summer believed to be the hottest in 23 years. In two instances, local utilities were forced to "rolling blackouts" to maintain system security.

The area utilities attempted to reduce the impact of "brownouts" by cutting power to non-essential users during peak load periods. This strategy angered residential groups who felt they were forced to carry too heavy a burden. An organization of residential users was formed for the purpose of meeting with other users of electrical power, utility managers, and government officials to find a more equitable distribution system for the "brownouts".

The utilities, concerned with widespread consumer discontent, made an attempt to explain the shortage of generating capacity to the public through the regional media. In short, it was claimed that the situation was caused by two major constraints: (1) environmental opposition to new siting as well as to fuels used in present power plants, and (2) insufficient means of capital formation as a result of inadequate rate relief. The utilities claimed that environmentalist lawsuits had stopped six attempts to locate nuclear power stations in the region over the past eight years. In addition, they claimed that the environmental laws governing air standards made necessary the use of scarce capital funds for scrubbing devices instead of for new plants. It was estimated that the money spent on stack gas scrubbers in the region would have been sufficient to build enough new power plants to meet the extra demand the region now faces.

The utilities claimed the short term solution was for government officials to permit usage of high sulfur coal, thus allowing the reopening of closed coal-fired stations to help in meeting the excess demand caused by hot weather. In the long run, the utilities planned to install nuclear power plants to replace the high sulfur

coal plants, providing that government officials would lessen legal entanglements for nuclear siting and operation. The utilities also sought government assistance for present and future capital spending.

The regional environmental agencies saw the cause of the present situation differently. The agencies believed that the industry's capital formation was a true causal factor but they did not believe the rest of the industry's argument. The agencies discounted the industry's claim of restrictive environmental constraints. The utilities, the environmental agencies claimed, are able to use high sulfur coal in power plants equipped with proper cleaning devices for fuel and stack gases. The cost of such scrubbing equipment was recognized by the agencies as an additional burden to the utilities.

Also, the environmental agencies believed that technology was not adequately perfected to permit widespread building of nuclear power plants. They claimed that as the technology improved, the constraints on siting and operation would be relaxed.

Consumers, represented by the aforementioned organized group, also saw the problem differently. They felt that the utility industry was pressing for greater flexibility in regional regulation so they could charge higher rates, particularly to residential users who already shared an excessive amount of the cost. The residential group published a series of ads giving "proof" for an allegation that the utility industry is wasteful and is unconcerned with the ultimate consumer. The ads included many charges; one was that a regional utility had increased its dividend three times over the previous four years. Another charge was that a utility was engaged in excessive fringe benefit giving because over the years it had sponsored a country club for its employees. The utility industry, attempting to forestall public anger over these charges, published "valid" reasons for the described expenditures. The utility maintained that they were attempting to make their stock more attractive to bring in more outside capital and that they were attempting to boost employee morale by sponsoring the country club which, they claimed, was 80 percent self-supporting from dues and sales.

The residential organization decided that pressure from all sector users was the best means possible to alter the utilities "stranglehold" on the consumer. Since they had been unsuccessful in trying to win voluntary cooperation of the other groups in talks with them, the organization decided that court action was the next best solution. Their belief was that if the courts were to rule that the effects of any "brownout" should be distributed among all users, then the other sectors would become more demanding of changes in utility goals. The consumer organization won their case in high regional courts.

With the new court decision in effect, industrial and commercial users were forced to cut average regional work weeks by 15 to 20 percent. Workers complained of their shorter work hours and threatened strikes at certain locations. Business leaders called for a reversal of the court order, claiming that the present situation would lead to regional social and economic setbacks. Regional legislators and executives, fearing regional recession for the remainder of the year and possible reoccurrence in succeeding summers, decided to place the regional electric power capacity shortage at the top of the government agenda. A special regional panel was formed whose task was to determine the factors causing the region's electrical power crisis. The panel, after several weeks, found the following to be instigating factors to the crisis:

1. capital shortage
2. insufficient rate relief for utilities
3. high construction costs for power plants
4. presence of national and regional inflation
5. environmental opposition causing power plant construction delays
6. insufficient conservation by electric power users
7. higher than normal demand for electricity
8. overcommitment to nuclear power
9. national and regional government inconsistency
10. lack of national and regional energy policies

With this information given, the region's primary participants in electrical power decisions decided to work together to resolve the crisis.

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Section IV

Weighting Methodology

The purpose of the weighting methodology is to determine a composite scenario or resulting state of the energy environment system to which the reference scenario might evolve based on the priorities of the actors defined in the system and their relative influence over various factors (energy, economic, or environmental) measuring the state of the system. The priorities of these actors may change depending on the decisions these actors would have to make, i.e., the character of the decision environment. The composite scenario is actually developed as a linear combination of a number of possible future scenarios, each of which is described in terms of a common set of factors or state variables.

The weighting methodology provides a scheme for construction a preferred composite scenario for each actor, which is again described in terms of a common set of factors. Finally, based on the relative influence each actor has over the energy environment system, the overall composite scenario is constructed as a linear combination of the actor-preferred scenarios. The framework of the weighting methodology will be presented and then followed by an illustration of the application in a simple energy environment system. Section V discusses the actual application in a small scale Phase I game.

Methodology

From the descriptions of future scenarios, a matrix called a scenario matrix (A) is constructed, with entries A_{js} each of which is the value of a state variable j corresponding to the s^{th} scenario. A_s represents the s^{th} column of A, therefore the vector A_s describes the state of the s^{th} future scenario. There is no limit to the number of possible future scenarios that the energy environment system can have. For the scope of this feasibility study, five future scenarios have been constructed, that correspond to different possible futures to which the present system may evolve. They are described in Appendix D.

It is the actors' decisions which shape the ultimate future of the energy environment system. They make decisions according to their own set of objectives and priorities. A very useful tool to compare these objectives and prioritize them is the Eigenvalue Model developed at the Energy Center. (Appendix A). The Eigenvalue Model receives as input pairwise comparisons of the objectives of an actor in the form of a matrix. It returns a vector of priorities of these objectives of the actor. This can be represented schematically as follows:

$$B^i \xrightarrow{\text{EM}} \vec{B}^i$$

where B^i is the matrix of pairwise comparisons of objectives with respect to actor i, and $\vec{B}^i$ is the resultant vector of priorities with respect to actor i, i.e., the relative weights of the objectives of actor i. This notation will be adopted throughout.

Actors are then asked to compose their own desired future scenario from a set of future scenarios described by matrix A. Their decisions will depend on their objectives, the decision environment, and the present (reference) energy-environment state.

More explicitly, actors are asked to compare pairwise the future scenarios according to each of their objectives, bearing in mind the present energy environment state and the special decision environment given to them. This is represented by

matrix C^{io} with entries $C_{ss'}^{io}$, expressing the relative desirability of the s^{th} scenario over s' according to objective o of actor i . Again the Eigenvalue Model is applied to extract the ranking of the desirability of the future scenario according to objective C^{io} . If C^i denotes the matrix $[\vec{C}^{i1}, \vec{C}^{i2}, \dots, \vec{C}^{im}]$, then the vector $\vec{D}^i = C^i \cdot B^i$ is the overall relative desirability of the scenarios for actor i after taking into account the relative priorities of his objectives.

The composite overall desired future of actor i is obtained by $A \cdot \vec{D}^i = \vec{F}^i$, a vector with values of each state variable of the composite desired scenario of actor i .

Next, the resultant future state of the energy environment system depends on the desired composite scenario of each actor and the relative influence of the actors on the energy environment system.

To evaluate the relative influences of all actors in the overall energy environment system, the actors' influences are compared according to their ability to make decisions that would affect energy ($e = 1$), economy ($e = 2$), and environmental ($e = 3$) factors. A matrix G^e is constructed with entries $g_{ii'}^e$, which displays the dominance of the influence of actor i over actor i' in the system component designated by e . Again the Eigenvalue Model is applied to find a ranking for the actors' influence in subsystem e :

$$G^e \xrightarrow{EM} \vec{G}^e$$

Finally, the resultant future state of the energy environment system is the one accommodating the various influences of the actors on each of its subsystems. This is similar to compromises in the actual societal process, and therefore the weighting methodology is a simulator of the compromises which govern the evolution of the energy environment system.

Each $\vec{F}^i$, the vector with values of state variables desired by actor i , is divided into three portions F^{ie} , $e = 1, 2, 3$; that is, state variables are grouped according to the respective subsystem e . The new $\vec{F}^i = [F^{i1}, F^{i2}, F^{i3}]$. The resultant composite scenario is given by R^1, R^2, R^3 where

$$R^e = [F^{1e}, F^{2e}, \dots, F^{ne}] \cdot G^e \quad e = 1, 2, 3.$$

In short, this resultant composite scenario of the energy environment system is based on the relative influence of all actors in each subsystem, the priority of objectives of each actor, and the relative desirability of the scenarios according to each objective of an actor, under a specified decision environment.

To conclude, the steps of calculating the resultant composite scenario of the energy environment system are summarized as follows:

- Step 1. Construct $A = (A_{js})$ $j = 1, 2, \dots, J$ are the state variables
 $s = 1, 2, \dots, S$ are the future scenarios

A_{js} = value of state variable j in scenario s .

J = total number of state variables.

S = total number of future scenarios.

- Step 2. Apply the Eigenvalue Model to B^i to form $\vec{B}^i$ ($B^i \xrightarrow{EM} \vec{B}^i$),
 where $b_{OO'}^i$ (an element of $\vec{B}^i$) is the relative dominance of objective O over objective O' according to actor i .

- Step 3. Apply the Eigenvalue Model to C^{iO} to form $\vec{C}^{iO}$ ($C^{iO} \xrightarrow{EM} \vec{C}^{iO}$),
 where $c_{ss'}^{iO}$ (an element of $\vec{C}^{iO}$) is the desirability of the s^{th} scenario over s' for objective O of actor i .

Thus $C^i = [c^{i1} : c^{i2} : \dots : c^{im}]$ which is a matrix formed by concatenating the vectors $\vec{C}^{iO}$ for each objective of actor i .

- Step 4. Form $\vec{D}^i$, where d_s^i (an element of $\vec{D}^i$) is the relative desirability of the s^{th} scenario to actor i .

$$\vec{D}^i = C^i \cdot \vec{B}^i$$

- Step 5. Form $\vec{F}^i$, where f_j^i (an element of $\vec{F}^i$) is the value of state variable j of the composite preferred scenario of actor i .

$$\vec{F}^i = A \cdot \vec{D}^i$$

- Step 6. Apply the Eigenvalue Model to G^e to form $\vec{G}^e$ ($G^e \xrightarrow{EM} \vec{G}^e$),
 where $g_{ii'}$ (an element of G^e) is the dominance of influence of actor i over actor i' in subsystem e ; $e = 1, 2, 3$ for energy, economic, and environmental subsystems respectively.

Step 7. Group f_j^i into three categories according to their direct relationship with each subsystem

$$F^i = [F^{i1} ; F^{i2} ; F^{i3}]$$

Step 8. Form $R^e = [F^{1e} ; F^{2e} ; \dots ; F^{ne}] \cdot \vec{G}^e$ where

$$r_j^e = \sum_{i=1}^n f_{jc}^e g_i^e \quad (\text{an element of } R^e) \text{ is the value of}$$

state variable j of factor group e (energy, economics, or environmental) of the overall composite scenario of the energy environment system.

$$\text{Finally, } R = \begin{bmatrix} R^1 \\ R^2 \\ R^3 \end{bmatrix}$$

which is the desired resultant composite scenario of the energy environment system based on the relative influence of all actors in each subsystem, the priority of the sub-objectives of each actor, and the relative desirability of the future scenarios according to each objective of an actor under a specified decision environment.

Let us consider an illustration of the weighting methodology in determining the composite scenario of a simple energy environment system before discussing the actual application in a small scale Phase I game.

Illustration

Consider three actors in a simple energy environment system:

1. The government, which regulates the consumption of energy and the maintenance of environmental quality, and influences the level of reserves of energy resources.

2. A private profit-motivated utility which generates electricity at the rate demanded by a consuming public and which is subject to the regulatory influence of the government.

3. Consumers of electrical energy who are concerned about the price of energy, as well as the quality of the environment in which they live.

The actors can pursue any or all of the following objectives, some of which will be pursued more vigorously than others:

1. minimizing the cost of producing and consequently consuming energy
2. Maintenance of a high standard of environmental quality
3. preservation or conservation of precious natural energy resources

In actual application of the weighting methodology, the number of actors could be very large and the objectives need not be the same for each actor.

Let us presume that the factors or variables that measure the state of the energy environment system are the following (in three groups of factors):

1. energy $\begin{cases} f_1 = \text{consumption level of oil} \\ f_2 = \text{consumption level of coal} \end{cases}$
2. economic $\begin{cases} f_3 = \text{cost of electricity produced} \end{cases}$
3. environmental $\begin{cases} f_4 = \text{level of SO}_2 \text{ emissions} \end{cases}$

In actual application the number of factors would be very large (Section VI) but still divided into the three groups of energy, economic, and environmental indicators.

Suppose now that the above energy environment system has three alternatives for producing electric power in the future. These three alternatives constitute the possible future scenarios of the energy environment system:

1. use of oil-fired plants
2. use of coal-fired plants
3. use of nuclear plants

We recall that from the description of the weighting methodology, we must construct a scenario matrix (A) that describes the values of the state variables for each of

the alternative future scenarios. Let us consider the A matrix for our simple energy environment system to be the following:

			<u>Scenarios</u>		
			oil	coal	nuclear
<u>Factors</u>	energy	{ oil consumption	4×10^{15} btu	3×10^{15} btu	2×10^{15} btu
		{ coal consumption	2×10^{15} btu	4×10^{15} btu	1×10^{15} btu
	economy	{ cost of electrical energy	5¢/kwh	4¢/kwh	3¢/kwh
	environment	{ SO ₂ emissions	8×10^6 tons/year	9×10^6 tons/year	6×10^6 tons/year

In order to construct the composite scenario based on the preferences of the actors in the system, we first apply the eigenvalue model to the objectives pursued by each actor. Each actor pursues the defined objectives with varying degrees of emphasis. Pairwise comparison of the defined objectives of each actor can accordingly be made to determine the priority with which an actor views each of the sets of objectives.

In this simple hypothetical case, for instance, the government may in some decision environment emphasize the minimizing of energy cost to the maintenance of environmental quality and preservation of natural resources by, say, a factor of three. Accordingly, the emphasis of maintenance of environmental quality to minimization of energy cost would be one-third.

Let us call the matrix of comparisons of objectives for the government actor A1, that for the utility A2, and that for the consumers A3 in this simple illustration.

A typical set of matrix constructions of these comparisons might be:

<u>B1 = government</u>				<u>B2 = utility</u>				<u>B3 = consumer</u>			
	O ₁	O ₂	O ₃		O ₁	O ₂	O ₃		O ₁	O ₂	O ₃
O ₁	1.00	3.00	3.00	O ₁	1.00	8.00	4.00	O ₁	1.00	2.00	3.00
O ₂	.33	1.00	.33	O ₂	.13	1.00	.17	O ₂	.50	1.00	2.00
O ₃	.33	3.00	1.00	O ₃	.25	6.00	1.00	O ₃	.33	.50	1.00

O₁ = minimizing energy cost

O₂ = maintaining environmental quality

O₃ = preserving natural resources

The dominant eigenvectors of B1, B2, and B3, which we can call b₁, b₂, and b₃, respectively, describe the relative priorities of the objectives for each actor:

$$b_1 = \begin{bmatrix} .584 \\ .135 \\ .281 \end{bmatrix} \begin{matrix} O_1 \\ O_2 \\ O_3 \end{matrix} \quad b_2 = \begin{bmatrix} .691 \\ .060 \\ .249 \end{bmatrix} \begin{matrix} O_1 \\ O_2 \\ O_3 \end{matrix} \quad b_3 = \begin{bmatrix} .540 \\ .297 \\ .163 \end{bmatrix} \begin{matrix} O_1 \\ O_2 \\ O_3 \end{matrix}$$

Similarly we must construct the pairwise comparison matrices of the desirability of the future scenarios with respect to each objective for each actor. In our simple system we have three objectives that are common to all the actors. Hence we must find the relative weights of each of the three future scenarios with regard to each of the three objectives for each actor, a total of nine pairwise comparison matrices. For the purpose of illustration, let us presume that the pairwise comparison matrices of the scenarios for each of the electric utility actor's objectives are the following:

O1 = lower cost of energy				O2 = maintain environmental quality				O3 = preserve level of energy reserves			
	S1	S2	S3		S1	S2	S3		S1	S2	S3
S1	1.00	.33	.14	S1	1.00	6.00	5.00	S1	1.00	.11	.33
S2	3.00	1.00	.20	S2	.17	1.00	.50	S2	9.00	1.00	6.00
S3	7.00	5.00	1.00	S3	.20	2.00	1.00	S3	3.00	.17	1.00

S₁ = use of oil

S₂ = use of coal

S₃ = use of nuclear

Let us define the corresponding dominant eigenvectors to the matrices O1, O2, and O3 to be C_1 , C_2 , and C_3 , which when concatenated forming the matrix C yields:

$$C = [C_1 : C_2 : C_3] = \begin{matrix} & \begin{matrix} O1 & O2 & O3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .081 & .726 & .068 \\ .188 & .102 & .770 \\ .731 & .172 & .162 \end{bmatrix} \end{matrix}$$

This matrix C contains the relative weights of the three future scenarios for each objective of the electric utility. Multiplication of C by the vector b_2 gives the overall relative desirability of the scenarios for the electric utility based on the relative priorities of his objectives.

$$d_2 = Cb_2 = \begin{matrix} & \begin{matrix} O_1 & O_2 & O_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .081 & .726 & .068 \\ .188 & .102 & .770 \\ .731 & .172 & .162 \end{bmatrix} \end{matrix} \begin{bmatrix} .691 \\ .060 \\ .249 \end{bmatrix} = \begin{bmatrix} .116 \\ .328 \\ .556 \end{bmatrix} \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix}$$

Note that for the electric utility the nuclear scenario is the most preferred, which is expected.

We can calculate this d vector (weighting of scenarios) for each of the actors in the simple energy environment system:

Government Actor

O1 = lower cost of energy			O2 = maintain environmental quality			O3 = preserve energy resources		
S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
S_1	$\begin{bmatrix} 1.0 & .25 & .20 \end{bmatrix}$	S_1	$\begin{bmatrix} 1.0 & 5.0 & 2.0 \end{bmatrix}$	S_1	$\begin{bmatrix} 1.0 & .2 & .5 \end{bmatrix}$			
S_2	$\begin{bmatrix} 4.0 & 1.0 & .33 \end{bmatrix}$	S_2	$\begin{bmatrix} .20 & 1.0 & .33 \end{bmatrix}$	S_2	$\begin{bmatrix} 5.0 & 1.0 & 3.0 \end{bmatrix}$			
S_3	$\begin{bmatrix} 5.0 & 3.0 & 1.0 \end{bmatrix}$	S_3	$\begin{bmatrix} .50 & 3.0 & 1.0 \end{bmatrix}$	S_3	$\begin{bmatrix} 2.0 & .33 & 1.0 \end{bmatrix}$			

$$C_1 = \begin{matrix} & \begin{matrix} O_1 & O_2 & O_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .108 & .582 & .122 \\ .339 & .109 & .648 \\ .553 & .309 & .230 \end{bmatrix} \end{matrix}, \quad d_1 = C_1 b_1 = \begin{bmatrix} .176 \\ .395 \\ .429 \end{bmatrix} \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix}$$

Consumer

$$\begin{matrix} & \begin{matrix} O1 & & & O2 & & & O3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{matrix} \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{bmatrix} 1.0 & .33 & .25 \\ 3.0 & 1.0 & .5 \\ 4.0 & 2.0 & 1.0 \end{bmatrix} & \begin{matrix} \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{bmatrix} 1.0 & 4.0 & 3.0 \\ .25 & 1.0 & .5 \\ .33 & 2.0 & 1.0 \end{bmatrix} & \begin{matrix} \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{bmatrix} 1.0 & .25 & .33 \\ 4.0 & 1.0 & 4.0 \\ 3.0 & .25 & 1.0 \end{bmatrix} \end{matrix} \end{matrix}$$

$$C_3 = \begin{matrix} & \begin{matrix} O_1 & O_2 & O_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .122 & .625 & .113 \\ .320 & .136 & .652 \\ .558 & .238 & .235 \end{bmatrix} \end{matrix}, \quad d_3 = C_3 b_3 = \begin{bmatrix} .270 \\ .319 \\ .410 \end{bmatrix} \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix}$$

$S_1 \neq$ use of oil

$S_2 \neq$ use of coal

$S_3 \neq$ use of nuclear

Finally we have determined the relative desirability of each scenario for each actor (d_1, d_2, d_3) based on the relative priorities of each one's objectives.

We can concatenate these vectors to form the matrix D:

$$D = [d_1 : d_2 : d_3] = \begin{matrix} & \begin{matrix} A1 & A2 & A3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .176 & .116 & .270 \\ .395 & .328 & .319 \\ .429 & .556 & .410 \end{bmatrix} \end{matrix}$$

Multiplication of A, which we recall is the matrix of the reference values of the state variables for each of the future scenarios, by D results in a matrix F, the columns of which give the preferred composite scenarios of each of the actors.

$$F = AD = \begin{matrix} & \begin{matrix} S1 & S2 & S3 \end{matrix} \\ \begin{matrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{matrix} & \begin{bmatrix} 4 & 3 & 2 \\ 2 & 4 & 1 \\ 5 & 4 & 3 \\ 8 & 9 & 6 \end{bmatrix} \end{matrix} \quad \begin{matrix} & \begin{matrix} A1 & A2 & A3 \end{matrix} \\ \begin{matrix} S1 \\ S2 \\ S3 \end{matrix} & \begin{bmatrix} .176 & .116 & .270 \\ .390 & .328 & .319 \\ .429 & .556 & .410 \end{bmatrix} \end{matrix} \quad \begin{matrix} & \begin{matrix} A1 & A2 & A3 \end{matrix} \\ \begin{matrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{matrix} & \begin{bmatrix} 2.75 & 2.56 & 2.86 \\ 2.36 & 2.1 & 2.33 \\ 3.75 & 3.56 & 3.86 \\ 7.54 & 7.22 & 7.49 \end{bmatrix} \end{matrix}$$

To determine what the actual overall composite scenario (outcome of the simple Phase I game) is, we must account for the relative influence each of the actors has over the three groups of indicators (energy, economic, and environmental) in the simple energy environment system. We can construct a pairwise comparison matrix of actors' influence over each of the three groups of indicators, e.g.:

$$\begin{matrix} & \begin{matrix} \text{Energy} \\ A1 & A2 & A3 \end{matrix} \\ \begin{matrix} A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} 1.0 & 5.0 & 3.0 \\ .2 & 1.0 & 4.0 \\ .33 & .25 & 1.0 \end{bmatrix} \end{matrix} \quad \begin{matrix} & \begin{matrix} \text{Economy} \\ A1 & A2 & A3 \end{matrix} \\ \begin{matrix} A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} 1.0 & 7.0 & 5.0 \\ .143 & 1.0 & .167 \\ .2 & 6.0 & 1.0 \end{bmatrix} \end{matrix} \quad \begin{matrix} & \begin{matrix} \text{Environment} \\ A1 & A2 & A3 \end{matrix} \\ \begin{matrix} A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} 1.0 & 2.0 & 5.0 \\ .5 & 1.0 & 3.0 \\ .2 & .33 & 1.0 \end{bmatrix} \end{matrix}$$

A1 = Government

A2 = Electric Utility

A3 = Consumer

The dominant eigenvectors of these matrices (g_1 , g_2 , and g_3 , respectively) give the weighting of influence each actor has over energy, economic, and environmental factors in the simple energy environment system:

$$G = [g_1 : g_2 : g_3] = \begin{matrix} & \begin{matrix} \text{Energy} & \text{Economy} & \text{Environment} \end{matrix} \\ \begin{matrix} A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} .640 & .708 & .582 \\ .242 & .062 & .309 \\ .114 & .230 & .109 \end{bmatrix} \end{matrix}$$

Finally we can take the group of energy factors from F (a partition of F) which we recall describes the preferred values of energy factors for each of the actors, by g, which is the vector describing the relative influence each actor has over energy factors. The result is a vector (v_1) of the resulting values of energy factors based on the preferred values of each actor as well as the influence each actor has in determining those factors. In this simple case we can determine the resulting factors for each of the factor groups (energy, economic, and environmental) by the following:

$$1) \quad \begin{array}{l} \text{Energy} \\ \text{Economic} \\ \text{Environmental} \end{array} \begin{array}{l} \{f_1 \\ f_2 \\ f_3 \\ f_4\} \end{array} \begin{array}{c} A_1 \quad A_2 \quad A_3 \\ \left[\begin{array}{ccc} 2.75 & 2.56 & 2.86 \\ 2.36 & 2.1 & 2.23 \\ 3.75 & 3.56 & 3.86 \\ 7.54 & 7.22 & 7.49 \end{array} \right] \end{array} \begin{array}{l} A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} e_1 \quad e_2 \quad e_3 \\ \left[\begin{array}{ccc} .640 & .640 & .708 \\ .242 & .242 & .062 \\ .114 & .230 & .230 \end{array} \right] \end{array} \begin{array}{l} .582 \\ .309 \\ .109 \end{array}$$

2) The diagonal elements of the resulting matrix form the vector R, the composite scenario (off diagonal elements are meaningless).

$$R = \begin{bmatrix} 2.7 \\ 2.27 \\ 3.76 \\ 7.43 \end{bmatrix} \begin{array}{l} \times 10^{15} \text{ btu oil consumption} \\ \times 10^{15} \text{ btu coal consumption} \\ \text{¢/kwh cost of electricity} \\ \times 10^6 \text{ tons/year SO}_2 \text{ emissions} \end{array}$$

Note that in this simple example the preferred scenarios are closer to the nuclear scenario than the other two future scenarios. This is perhaps due to the fact that the decision environment, in the context of which all the judgmental matrices are formed, was chosen to be severe economic recession so that the need for cheap energy becomes emphasized. The emphasis on cheap energy then overshadows other objectives, i.e., maintenance of environmental quality and preservation of energy reserves. Since the preferred scenarios all emphasize the nuclear scenario, the resulting composite scenario likewise tends toward the nuclear future scenario.

In the next section we discuss how the weighting methodology just described and illustrated was employed in an actual small scale game with a highly expended set of factors, actors, and scenarios.

Section V
Application of the Weighting Methodology
The Phase I Game

The following ten actors were selected for use in the Phase I gaming application:

1. Electric Utility
2. Residential Consumers
3. Industrial Consumers
4. Environmentalists
5.   { Environmental Regulator
6. Government   { Executive Official (e.g., Governor)
7.   { Legislator
8. Oil & Gas Suppliers
9. Coal Suppliers
10. Nuclear Suppliers

This list of actors is a subset of those outlined in Section II. The choice of this subset was determined by the nature of the selected decision scenario (Electric Capacity Shortage). Another decision scenario might well require a different subset of those indicated in Section II.

The roles of the actors were played by members of the gaming research team. The players were asked to weigh their preferences of five different future scenarios according to their own sets of objectives which were also outlined for each actor in Section II. Hence, for each objective of each player, the future scenarios were weighted according to the player's preference. An interactive computer model then computes each player's preferred composite scenario by application of the weighting methodology presented in Section V. The players' preferred composite scenarios are presented in Tables 6-1 through 6-10. They are shown, as are all scenarios in this report, in terms of the quantitative summary factors (Appendix D).

An overall composite scenario is then composed by taking into consideration the various actors' relative influence over energy, economic, and environmental factors in the regional energy environment system (Appendix D).

A. Analysis of the Composite Scenario

All comparisons of the composite scenario are made with respect to the projected reference scenario (1990). (See Table 3-5.)

1. Energy Indicators - The composite scenario indicates that residential and commercial use of foreign oil in the region will be decreased significantly while maintaining the same consumption of domestic oil as depicted in the reference projection. Residential and commercial consumption of coal in the region is insignificant even though a very large per cent decrease is depicted in the composite scenario with respect to the reference.

In the transportation sector less consumption of foreign oil is depicted in the composite scenario while domestic oil consumption remains close to the reference. There is an overwhelming increase in electricity consumption in the transportation sector, indicating a move to electrification of both mass and private transportation modes.

The industrial sector shows a reduced consumption on extra-regional coal as well as a reduction in natural gas usage. A significant increase in industrial electricity consumption is indicated in the composite scenario.

Electric utilities in the composite scenario will use less coal imported from other regions while a step-up in their consumption of the coal produced within the region is indicated. The demand for other fossil fuels by the utilities is up significantly with respect to the reference, particularly the use of foreign oil and natural gas, indicating that actors might prefer some domestic development of oil and gas. The composite scenario also shows an overall 11% increase in fossil fuel consumption by the electric utilities over the reference projection. The electrical generation mix of the composite scenario indicates a higher percentage of fossil-fired generating plants, lower percentage of nuclear plants than the reference projection. However, the reference scenario reflects a very high utilization of nuclear generation.

2. Environmental Indicators - The level of particulate emissions in the composite scenario is lower than that of the reference scenario due to a slight decrease (4%) in overall coal consumption. However, sulphur oxide emissions have gone up due to the higher level of oil consumption by electric utilities. Water quality indicators show a higher rate of water consumption by the utilities due to increased production of electricity at normal heat rates. Effluent water quality is slightly worse than that of the reference scenario. Coal mines land use remains about the same as in the reference, due to balancing between the industry and utility sectors. Nuclear waste generation has declined slightly as a result of a smaller installed nuclear generating capacity. The environmental regulatory control levels for the coal and oil industries are moderately higher than those of the reference scenario, while environmental control levels for natural gas, fossil electricity, and nuclear electricity are less stringent than those in the reference.

3. Economic Indicators - In general, the regional actors prefer a higher gross regional product and income per capita, as reflected in the composite scenario. They favor a lower unemployment rate. However, the development of alternative energy resources would induce higher consumer and wholesale price indices. The composite scenario describes lower energy costs for coal, oil, and electricity while natural gas price is expected to be much higher than that of the status quo scenario.

In response to the decision scenario of an electric capacity shortage, actors choose to increase non-nuclear generation investment by five times, and increase investments in petroleum extraction and refining three times. The composite scenario contains a lower investment program for nuclear-generation-related plants than the reference. Again this may be due to the high nuclear utilization depicted in the reference scenario.

Although in the composite scenario there are more stringent environmental regulatory controls on the oil industry, the economical control level for domestic coal is lower than the reference. Importation of foreign oil appears to face tougher economic controls, while controls on prices of natural gas, intraregional coal, and electricity will be less stringent than those in the reference.

Table 3

Scenario: Composite Scenario (1990)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	3	62%	0	100	242	78	298	85
Intraregional coal	9	66	0	100	805	88	1072	113
Foreign oil	216	28	224	43	64	56	430	194
Domestic oil	1504	97	2232	96	465	93	976	107
Natural Gas	970	84	40	84	718	82	94	156
Electricity	1345	144	190	1677	748	148	0	100

Electrical generation mix: $\frac{36.8}{111\%}$ % fossil, $\frac{54.2}{95\%}$ % nuclear, $\frac{9.0}{89\%}$ % other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions	8.85×10^6	tons/yr	96%
SO _x emissions	9.81×10^6	tons/yr	108

Water quality:

Utility consumption rate	21.7×10^{12}	gals/yr	104
Effluent quality	102.7	index	102

Land use:

Coal mining land use rate	5729	acres/yr	99
Nuclear waste generation rate	159.4	m ³ /yr	95

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			6.0
Oil			5.4
Natural gas	4.4		
Fossil electricity	4.5		
Nuclear electricity	4.6		

Economic indicators

Gross regional product:	248.0 x 10 ⁹	\$	104%
Gross regional product per capita:	8350	\$/person	105
Unemployment rate:	4.65	%	93
Consumer price index:	258	index	104
Wholesale price index:	196	index	104
Energy price indices:			
Coal	454	index	96
Oil	772	"	95
Natural gas	410	"	141
Electricity	964	"	96

Capital investments:

	Cumulative		Current year	
All non-energy industry	48650	\$	6112	\$ 98
Coal mining	973	\$	105	\$ 100
Petroleum extraction & refining	4321	\$	307	\$ 307
Non-nuclear generation	4943	\$	630	\$ 630
Nuclear generation	21740	\$	3442	\$ 95
Nuclear fuel processing	1263	\$	180	\$ (98)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.6
Intraregional coal	4.2		
Domestic oil	4.5		
Foreign oil			6.1
Natural gas	3.9		
Fossil electricity	4.2		
Nuclear electricity	4.5		

B. Actor Preferences and Influence

Table 3-6 summarizes the degree of preference of each actor with respect to the five alternative future scenarios. The degree of preference is based on a scale from 0 to 100. A larger number indicates a stronger preference. The sum of each row is the total utility or sum of preferences and is equal to 100.

Table 3-6 indicates that the conservation scenario is ranked among the least preferred by all actors except the environmentalist, the environmental regulator, and the individual consumer. Therefore, in the overall composite scenario, the conservation scenario is the least preferred one in both the energy and the economic subsystem. However, it is ranked third in the environmental subsystem, due to strong influences of the executive actor and the environmental regulator.

The reference extended is the next least preferred scenario. It is not strongly chosen by any actor but is ranked favorably among the individual consumer, environmental regulator, and nuclear supplier. Overall, the reference is slightly preferred for its energy and economic subsystem but is lower for environmental indicators.

Actors' decisions towards nuclear, coal and oil, and gas scenarios are mixed. The nuclear scenario is considered best by electric utilities, individual consumer, the executive, legislative, and the nuclear supplier. The coal scenario is chosen as most favorable (or second) by the electric utility, individual consumer, executive, legislative, and coal supplier. The oil and gas scenario is considered as one of the top two favorable scenarios by the industrial consumer, and the oil and gas supplier.

When all actors' influences in the energy subsystem are accounted for, the nuclear scenario comes out first, followed by oil and gas, and coal scenarios. However, with respect to actors' influences on the environment, the nuclear scenario stands out as most preferred, followed by coal, conservation, and oil and gas scenarios. The nuclear scenario and the oil and gas scenario are equally ranked when actors' influences in the economic subsystem are weighed, followed closely by the coal scenario, and less so by the reference and conservation scenarios.

TABLE 3-6

ACTOR-SCENARIO PREFERENCES (In Percent)

ACTOR \ SCENARIO	SCENARIO				
	NUCLEAR	CONSERVATION	COAL	OIL & GAS	REFERENCE
Elect. Utility	46	4	28	9	13
Indiv. Consumer	42	19	10	10	19
Indus. Consumer	24	7	30	28	11
Environmentalists	29	47	3	6	15
Env. Regulator	23	46	4	7	20
Executive	40	6	29	19	6
Legislature	33	10	33	19	5
Oil & Gas Supplier	6	4	10	67	13
Coal Supplier	7	3	65	9	16
Nuclear Supplier	58	10	5	6	21
OVERALL (Energy)	24	7	30	26	13
OVERALL (Environment)	29	20	22	16	13
OVERALL (Economic)	27	9	26	27	12

Section VI

Transition to Phase II Gaming

Goals of Phase I

As mentioned in the Introduction, three principal goals were set for the Phase I approach to the Regional Energy Environment Game (REEG). These goals were:

(1) To limit the scope of the game to a specific set of energy environment related activities. In particular, this was the definition of a particular decision scenario that can be investigated with a restricted set of actors (or players of the game) and state variables (that describe the performance of the system). Phase I offers a procedure by which we can choose a limited set of relevant REEG system components (sectors, state variables, etc.) and test to see if the prescribed set of components properly describes the mechanisms we wish to consider in the regional energy environment system (the Decision Scenario). Successive testing results in a set of system components that adequately describe the regional system's operation in the context of this decision scenario.

(2) Another important result in the Phase I approach was to quantify the scenarios developed to describe various patterns of operation of the regional energy environment system. This quantification is presented in terms of the set of state variables (quantitative summaries) just described. The Phase I results include the preferred values of these state variables for each actor as well as the reference values which constitute a quantification of the reference scenario and values of the state variables for various possible future scenarios.

(3) Finally the third goal of the Phase I approach was to particularize the regional energy environment system modeling to the defined target region. The composite scenario based on application of the weighting methodology and resulting from actor responses to a particular decision scenario will serve as an order of magnitude guide for initial plays of the Phase II interactive operational game, i.e., some consistency is expected between the Phase I composite scenario and initial plays of the

Phase II game. Both the Phase I and the Phase II versions of the game are played in the context of the same decision scenario, i.e., in this case an assumed electric capacity shortage.

Contributions of Phase I to Phase II Design

The specific contributions of the Phase I study that provide a basis for development of the Phase II game are the following:

(1) Characterization of the Target Region - In particular, the target region definition, the summary of data used in constructing the reference scenario (Appendix A and Section III), and the classification of the important actors and state variables in the region all led to a better understanding of the energy environment mechanisms at work within the target region which will be modeled in more detail in the Phase II study.

(2) Regional Energy Environment Actors - The classification of the objectives of each actor (Section II) provided the framework by which the actors can be grouped together according to their objectives. The actors, or aggregated actor groups, as a result of the Phase I analysis, can then be operationalized in the Phase II game in the scheme shown in Figure 3-2.

Figure 3-2

Player Organization

The Phase I results include a restricted set of actors each of which will be assigned to one of the player categories in the course of Phase II. Also included are defined sets of objectives for each actor which will lead to corresponding policies, strategies, and actions that will be operationalized in the Phase II study. As mentioned in Section II the characterization of actors is undergoing considerable refinement in the Phase II work. In particular, actor groups involved in supplying capital and labor to energy industry are being added, as well as factors related to these actor groups, e.g., regional capital formation and an index of labor earnings. Also in the Phase II study, attention will be focused on the time horizons involved in particular actor interests. For instance, some actors, such as investors and legislators, are interested in long term considerations while consumers and regulators are also concerned with the day to day operation of the energy environment system.

(3) Reference Scenario Projections - Included in Phase I results are characterizations of the Reference Scenario (1980) and projections to the years 1990 and 2000. Many of the state variables employed in the Phase II game are likely to be the same as those used in Phase I. The only difference might be that those state variables that are impractical for small scale modeling would be eliminated from the Phase II set of state variables. The reference projections indicate the degree to which various patterns of player interaction effect changes in the state of the energy environment system from the projected reference scenario. In Phase II a player will then be able to gauge his performance in two ways, i.e., comparison of the resulting state of the system with respect to (1) the projected reference and (2) his preferred outcome.

The results of Phase I appear reasonable, hence we can feel confident in employing the major gaming components (actors, state variables, etc.) resulting from Phase I in the Phase II gaming effort.

PART 4

THE REGIONAL ENERGY ENVIRONMENT GAME

I. Introduction

This report reviews the considerations in the development and application of a methodology for a regional energy environment game as a part of a regional assessment study program. A scenario approach has been adopted to describe the context within which the game will be played. An actual small-scale game will be built on the scenario approach. It is clear that the small-scale game will be very limited in its capability, but it will serve the purpose of allowing the investigators to explore the various ramifications associated with the interacting elements of game structure, policy options, objectives set, number of players, and conflict resolution. The scenario approach is developed in a manner which serves to limit the game so that it fits the scope of a regional assessment study program.

In general, the major goals of the small-scale game are to explore the applicability of interactive operational gaming to:

1. educate the game players in the complex mechanisms governing the evolution of a regional energy environment game.
2. serve as a potential policy selection tool that brings into account the conflicting interests of the important actors in a regional energy environment system.
3. identify the scope, set purposes, goals, and objectives for a regional assessment study program.

The methodology development was approached in two phases of study. The first phase might be characterized as a "first generation" approach in that one attempts to encompass, in a highly aggregated sense, the essential elements of a regional energy environment system and its evolution while retaining the ability to enrich the elements in a subsequent generation. This phase serves as a tool to assist in the development of more meaningful games.

A fundamental weakness in previous operational gaming efforts has been the lack of a systemic method for determining a set of components (i.e., actors, relationships among those actors, and

the factors involved in these relationships), all of which collectively determine the environment in which the game is to be played. The first phase of the two phase approach employed in this study is an attempt to solve this problem. It is clear that the operational small-scale game developed in Phase II requires careful characterization of the various elements of the game in order to insure realistic and useful results. Phase I offers a procedure by which we can choose a limited set of relevant components of the energy environment system which is being investigated (see Progress Report COO-2547-2) and tested, in a qualitative sense, to see if they properly describe the mechanisms involved in the energy environment system.

The purpose of Phase II of this study was to design and implement a small-scale interactive regional energy environment game building upon the results of the Phase I investigation. Those results included the identification of a set of relevant variables that describe the state of an energy environment system, a restricted set of actors who control these state variables and the objectives of the actors. The relevant components, i.e., actors, state variables and candidate impact analysis models were chosen with reference to possible decision environments, i.e., situations in which actors would be required to solve a problem (energy shortfall, excessive pollution levels, etc). A decision environment is described in terms of the set of state variables, some of which (the decision state variables) can be influenced by actors in order to effect changes in the energy environment system. It was found in designing an operational game that most decisions can be described in terms of these decision state variables. For instance, an electric utility may decide to invest in more nuclear generation as a solution to a projected capacity shortage. Other actors in the energy environment system (e.g. environmentalists, regulators, etc.) may respond to this decision by the utilities.

In order to demonstrate the usefulness of the game, the decision environment as well as the characterization of the regional energy environment system components (actors, state variables, etc.) was particularized to a target region. Hence, another result of the phase I studies, used in designing the Phase II game, was the characterization of a specific target region by means of a reference scenario. Decision scenarios then describe deviations from this reference scenario that would require action from actors involved in the system evaluation.

This decision environment is composed of the reference scenario and proposed deviations from this reference called decision scenarios. Phase I also included determination of a restricted set of possible future scenarios, which describe the states to which the energy environment system might evolve upon actor interaction in response to a particular decision environment. The Phase I weighting methodology weights actor objectives and their relative influence in realizing their objectives. to yield a composite scenario which is an estimate of the state of the energy environment subsequent to actor interaction. Their composite scenario is a weighted combination of the possible future scenarios. Their state estimate or composite scenario can be used in Phase II to check the degree of validity of Phase II results which includes an exhaustive description of the resultant state subsequent to actor interaction.

In light of the results of the Phase I approach, just described, a more comprehensive game was designed to explore the applicability of interactive operational gaming in attaining the following goals:

1. Educate game players to multi-disciplinary considerations (make players aware of needs and interests of other players) in a regional energy environment system.
2. Serve as a potential policy analysis tool that brings into account the conflicting interests of important actors in a regional energy environment system.

3. Define compromise planning objectives for a regional assessment study program.

Improvements Over Past Gaming Efforts

A. Two Phase Approach to Validation

Operational gaming has been applied to a number of energy-environment related systems in the literature. Some previous games that were of interest in the development of REEG were the Energy Resources Game [58] (Wolf and Laessig, 1973) and the City Games (Moriarty, 1974) and Metro (Duke, 1969). All of these game construction projects began with a specific procedure that was set forth to guide the development of the game structure. However, Peter House [25] (City Games, 1970) notes that the structure of the development is particularly important and warns:

"For us, building CITY was never sufficiently structured to suggest that there was a pattern for others to follow... Specifically, the process of the day-to-day model-building is not consistent with any predefined steps or rules."

Heeding House's warning the conceptual design of REEG was formulated in two phases the first of which was to serve not as a simple game, but as a mechanism by means of which the proper game elements for more comprehensive games could be identified. The first phase provides much of the structure required in the Phase II effort.

Another problem encountered in the design of REEG is that it was designed for a specific target region. This raises the question of validation. The two phase design process consists of first compiling a set of game components (actor characterization, state variables, models, etc.) and to achieve order or magnitude results which appear reasonable, and then refining the model components in the interactive operational game of Phase II. A game construction effort that emphasizes reasonable results lays the groundwork toward policy analysis oriented-games in

contrast to traditional education-oriented games. Both of the goals of educating players to important energy-environment mechanisms and of investigating policy options are implicit in the present effort and both contribute to setting the scope and objectives for a regional assessment study program.

B. Computer Implementation

Most game simulations fall into one of two basic categories, 1) a free-form game or 2) a rigid-form game. The free-form game is unstructured with little attempt to quantify the given scenarios that provide the context within which the game is played. In fact, game components (variables, actors, rules, etc.) are changed and created as the game proceeds. It is often argued that free-form games are unscientific because they cannot be replicated and actual results are not easily seen. SIMPOLIS (Abt Associates, 1966) and TRADE-OFF (Berger and Walford, 1968) are examples of free-form games related to environmental planning.

The other extreme is, of course, the rigid-form game which has its roots in classical mathematical game theory. By nature such games require complete, rigorous, a priori, specification of the game components and the rules that govern play. (Figure 4-1)

Most present gaming efforts can be classified as hybrid games which fall somewhere in between the extremes of free-form and rigid-form games since they attempt to interface player interactions with a sophisticated mathematical model of the system of interest. This implies that both the model and the player interfaces can be adequately implemented to facilitate obtaining reasonable results. This is usually done on the digital computer in a general scientific language such as FORTRAN. The player interface is simply implemented by asking each player to enter values of specific quantifiable variables. Most of the present gaming efforts are played in a batch processing computer environment, where the player can only make reference to the results of a previous game play in his own decision making process. No readily

Figure 4-1
TYPES OF GAMES

Free-Form Games

- unstructured and dynamic creation of gaming elements, principally non-quantitative

Hybrid Games

- including a system for interfacing player options with a mathematical model

Rigid-Form Games

- rooted in classical mathematical game theory, rigorous definition of game elements, highly quantitative

available analytical tools are available to him so that he might test his policy options out before actually playing an option.

Time-sharing and interactive computing facilities now available at nearly all large computer centers provide a unique and potentially powerful setting for constructing interactive multiplayer operational games. The present effort has been programmed in APLSV, a relatively new high-level computer language that is concise and sufficiently powerful to facilitate easy programming of mathematical models. The language is also interactive and provides a unique feature (the shared variable processor) which allows communication among many players while the game is in progress.

The interactive nature of APL permits a dynamic interface between a player and a mathematical model, which determines system states, to be constructed. This interface, which can be utilized between many players through the communication capability just described, considerably enhances the structure and operation of hybrid games and allows some free-form game features as well. The present computer implementation offers the following capabilities for interactive gaming simulation:

1. Players can be placed at remote locations. They need only have a teletype terminal and a telephone.
2. Extensive independent analysis of options is available to each player which he can perform before actual final play in a game step.
3. Interactive computing allows immediate return of results, both when players are analyzing options and when game step results are being processed.
4. Comprehensive editing facilities make debugging, testing, and refining of model components simpler as the game development proceeds.
5. Facilities exist to provide on-line, i.e. while the game is being run, creation of game components such as player strategies, a simple example of a free-form game feature.

C. Generalized Input-Output Gaming Methodology

As in all operational games that involve players making decisions, these decisions, as well as their impacts must be recorded and assessed. That is, all games have a model that both serves as an accounting system and an impact analysis model. The model that we have chosen for these purposes is the Input-Output Model, with substantial modification which will be outlined later.

The results of Phase I indicated that players' decisions are reached through consideration of a set of economic, energy and environment factors. For most influential players in the energy-environment game, economic factors, particularly variables relating to the actor's own economic well being, are the most important in reaching energy decisions. This implies that an economic based model would best serve as the core model upon which additional models can be appended accounting for other factors. Hence, the model must be general enough to account for energy flows in the system as well as environmental effects:

The model adopted as a core model in this study was the economic input/output model. Economic input/output related models have been used extensively in energy and environment policy studies (e.g., Jorgensen [28] (1975) Just [29] (1973) etc) the Input-Output (I/O) model's distinctive features, that are particularly well suited to energy environment gaming, are that:

1. it exhibits the effect of final consumer demands on industrial production
2. it displays the technological aspects of industrial production, particularly energy production
3. it allows for participation of all the important actors identified in the Phase I study
4. it is computationally simple since the equations are all linear
5. in its generalized form, it accounts for energy flows and environmental pollution emission levels in the system.

It should be emphasized that the model that was developed for REEG is quite different from the traditional economic I/O models. This is due to the fact that the gaming I/O model was designed especially for gaming applications.

The significant departures from traditional I/O models include:

1. the technical coefficients, which I/O modelers traditionally regard as exogenous variables, can be furnished by players in the game as part of their decisions, i.e. actions in response to the decision environment. For example, the demand for electricity by residential customers is determined by the player whose role is residential customers.
2. the coefficients that reflect the technology of production of a particular industry change from period to period in response to input price changes and environmental regulation. The technological coefficients are made dynamic by different input price levels and environmental regulations.
3. the game is designed in a regional setting, i.e. regional players interact while they pursue their own objectives in response to changes in the national economic, energy, and environmental policies. There is no feedback or regional players to national policy determination.
4. two new industries are added, i.e. the nuclear fuel industry and pollution equipment manufacturing industry. It was recognized and suggested by the Phase I study, that nuclear power generation and pollution abatement are becoming increasingly important, enough so that they should be included as distinct sectors in the model structure. In traditional microeconomics, pollution abatement equipment is not regarded as a productive input yet it is required by the industrial players to meet environmental regulations.
5. in the gaming I/O scheme industries are allowed to make profits. Traditional I/O assumes zero profit, i.e. industries are operating in long run competitive equilibrium.

D. Policy Area

Little is known about games in the social sciences which have

been offered as policy testing tools, except for military and business games. In fact, inadequacies of gaming for testing alternative policies have been cited by several gaming experts (Schran, Pitcase, Berger).

In REEG design the framework for evaluation of energy environment policies is provided. Player decisions are formulated in three states, i.e. from (1) policy to (2) strategy to (3) action.

In this feasibility study, several alternative policies, strategies and actions (for some of the actors), have been developed, although this by no means implies that they are exhaustive. They serve to demonstrate the feasibility of gaming with a variety of energy and environment policies.

The man-machine interactive nature of REEG is particularly suitable to decision makers who know little about computer programming. Instead it enables them to focus their attention on the problem of policy decisions.

The basis for the model developed in REEG for impact analysis of decisions is well accepted by economists and energy policy modelers.

In REEG players are allowed to perform their own analysis of alternatives before a final decision is made. Each can test policies of other players together with their own to get a feel for what may be a realistic goal in negotiations.

II Game Organization

The Regional Energy Environment Game (REEG) has been constructed to accommodate ten specific actor interests that shape the state of the target region energy environment system. Both the target region energy environment system and the actor interests were developed and characterized in Phase I of the study. The relevant actor interests aggregated in Phase I were the following:

1. Electric Utility & Gas Utility
2. Industrial Consumers
3. Individual Consumers
4. Environmental Regulators
5. Financiers & Investors
6. Crude Oil & Gas Suppliers & Refined Petroleum Suppliers
7. Coal Suppliers
8. Nuclear Suppliers
9. Executive Government
10. Legislative Government

The target region energy environment system consists geographically of the states of Delaware, Maryland, New Jersey, Pennsylvania and the District of Columbia. A detailed characterization of the region is given in Appendix A of the Phase I report.

A complete set of personnel for the present game would require ten participating players (or player groups) and a director, who controls the decision environment and monitors the game progress. For a variety of reasons, particularly for expanding the model, flexibility was built into the game so that only some subset of the 10 actor interests need actually be participating (see section V). In fact, the game can be reduced to no active players, or a completely computerized simulation model in which all actor interests are characterized by computer programs.

A. Description of Game Play

At the beginning of a game the game director assigns actor roles to players, briefs them on the game rules, instructs them

on interacting with the computer, and constructs their decision environment. In general, the game director is responsible for managing the decision environment and monitoring the game progress.

Briefing Session

In an initial briefing session the game director briefs novice players on the general use of the computer as an input device to the gaming model and as an analytical tool for reviewing and analyzing policy options. No computer programming knowledge is required of players. In fact, great care was taken to design the computer interface so that only minimal understanding of the computer system is needed. All use of the computer by players takes place interactively, i.e. the computer generally prompts the player for information and the player responds, or vice versa.

Each player is then instructed as to the specific decisions he can make and their general consequences. There is discussion of the goals and interests of corresponding actor roles in the real world. Certain relevant facts about the region are given to all players to make them aware of the particular concerns of the target region.

Decision Environment Session

The game play begins. At the beginning of each game play, which generally represents a period of five years, the environment in which players make their decisions (called decision environment) is described to the players. The description is partly verbal and partly quantitative. The quantitative summary is stored in the computer and can be retrieved and reviewed by each player at any time during the session.

Policy Analysis Session

After the decision environment description, each player is allowed to perform his own analyses assisted by the computer.

He can anticipate potential actions by other players in addition to analyzing his own decision options. The analysis session provides information for the players to use in their negotiations with other players during the subsequent interaction session. The policy analysis session identifies critical issues for each player and the other critical players, whose decisions influence his welfare.

Interaction Session

During this session, players are free to interact with other players before final decisions are submitted to the game director. They can negotiate, argue, persuade, make deals, or initiate formal procedures against other players. The purpose of this session is to resolve conflicts between players. The game director is notified of conflicts between players. The director is the final judge where such conflicts are not resolved.

Impact Session

When all conflicts are resolved and decisions reached by the players, they input their decisions through the computer. The computer model returns the results of all their decisions (immediately) to each player's terminal. The impact results together with the new decision scenario supplied by the Game Director, constitute the Decision Environment for the next game play. The game then proceeds to the next step. The results of each game step are recorded in a game step library.

The game play is divided into two stages. In game stage I, players input decisions on a trial basis, so that each can pursue his interests and goals independently. They would go through the decision environment session, policy analysis session and impact session quickly, without interaction. The game stage I results are displayed to each player. In game stage II, the players go through the same sessions plus the interaction session. The game stage II results are taken into account for the new decision scenario and are stored for the next decision environment.

B. Organizational Framework

The basic organizational unit of the game is called a workspace. Each workspace corresponds to an independent computer typewriter-like teletype terminal. The director and each active player can operate from independent workspaces, or any number of players can operate from a single workspace. The simplest organization is where the director and all presently active players operate from the same workspace. The most comprehensive game organization (in the present form) would consist of 11 active workspaces, one for each player and one for the game director. The workspaces can be located at completely remote sites (only a telephone is a necessity) and are interconnected by a communication network, as in Figure 4-2, that is under implicit control of the game director. The control is implicit in that it operates automatically but can be overridden by the game director.

Following the Phase I study, for a particular decision environment, an actor's interest can be satisfied by either of the following types of player status at the discretion of the game director:

Actor Interest

Active Player

Behavior inter-actively controlled by a game player

Passive Player

Behavior simulated by a computer program

Decision Environment Review

The game proceeds in game steps. At the beginning of each game step players are given the opportunity to review the decision environment, i.e. the present state of the energy environment system, which has been constructed by the game director. Should the player wish to review the decision environment (DENV) the

Figure 4-2

REEG ORGANIZATIONAL STRUCTURE

game director transmits to that player, wherever he may be, (over the communications network described earlier) the description and comprehensive list of the values of relevant state variables describing the DENV. Each player can examine the decision environment using a number of "analyzer functions" that are available to him in his active workspace. This is why in more comprehensive games it is better to allow players individual workspaces so that all decision environment reviews can take place concurrently rather than sequentially. However, if a player is representing more than one actor interest he may only require one decision environment review. The specific components of this operational decision environment are described in Section III. In the process of examining the DENV the player can also review his policy options. The computer initially assigns a default policy which can either be accepted by the player or overridden. In general, the default policy is the status quo operation of that actor's interest.

Policy Implementation

A player influences the state of the Energy Environment System by the following hierarchy of choices:

POLICY   -   STRATEGY   -   ACTION

that is, associated with each general policy there are a number of specific strategies available to the player, each consistent with the overall policy. As an example the industrial consumer player may have the following general policy alternatives:

1. Variation in Output Price
2. Install Pollution Abatement Equipment
3. Change Energy Consumption Profile
4. Alter Production Technology

The computer prompts the player for a particular policy choice and then presents him with a number of strategy alternatives that are consistent with the policy choice. The strategy

choice determines what state variables the player may access in order to implement that strategy. Finally, in executing the strategy (action) the player is reminded of previous values, or trends, of the state variables and is prompted for new values. This kind of strategy has been termed "limited strategy" since it only uses a limited number of decision state variables, i.e. those that a player is allowed to access. Another option is available for the player to construct his own strategy by synthesizing a number of strategies (constructed strategy). For less technically oriented players a number of "executive strategies" are available that do not prompt the player for values of state variables but simply ask for direction of change of a present trend. This is particularly important for policy oriented players who are not interested in actual numerical results but only in general results. For very technical players "comprehensive strategies" are available that allow the player control over all decision state variables accessible to his role. The policy-strategy-action sequence and its flexibility is discussed in some detail in Sections IV and V. However, whatever strategy is finally executed by the player (executive, limited, constructed, or comprehensive) the actions are ultimately sent back to the game director (through the communications network again) in the form of values set on specific decision state variables.

Impact Analysis

Once all presently active players have registered their actions with the game director, impact analysis for that game step begins. Actually, the game director does not perform all the management chores alluded to thus far since a management program, which is discussed in some detail in Section V, controls the actual game sequence while the game director simply monitors the game progress. He can override the management program control at any time but, in general, will not need to do so. In many instances, the functions of the game director could be relegated to one of the players since the management program performs most of the game monitoring tasks automatically.

The impact analysis module takes as input the decision state variables, as well as the other state variables describing the decision environment and determines the resulting state of the energy environment system for that game step. The game step length, usually given in years, is controlled by the game director and can be changed during a sequence of game steps. The resulting state is then used along with updating procedures (growth rates, etc.) to construct the decision environment for the next game step. The game sequence cannot proceed to the next game step until all players indicate (through the communications network again) that they are ready to proceed. Of course, the game director can override this condition in the management control. The structure of an entire game step is shown in Figure 4-3.

Figure 4-3
Game Sequence

III. Gaming Methodology

A. Structure for Policy Making System

The context within which energy and environment problems arise in society forms a complex and interrelated policy making system. In such a system there is a wide variety of decisions which encompass economic, environmental, technological, social and energy factors. Various energy policy makers differ not only in geographic scope (i.e. national, regional, local) but also in objective and interest (e.g. profit, preservation of environmental quality, safety, etc.) Their interactions are characterized by formal rules, regulations and procedures (e.g. rate hearings, power plant licensing hearings, interstate gas price regulations etc.).

The future of an energy environment system is influenced by a large number of policy makers. These decision makers adopt policies suitable for the pursuit of their goals and objectives. In the process they interact not only with the physical system but also with each other. Thus, the future of the system is the outcome of what the actors collectively do.

Current comprehensive energy policy analysis models usually take into account impacts of decisions by a single policy maker on the energy system. Before 1973 the preponderance of energy models used for projection purposes employed extrapolation on trend analysis and did not account for the impact of price changes made by decision makers on the supply and demand for different sources of energy. After the Arab oil embargo, it became clear that economic forces are fundamental to energy system dynamics. Recently there has been a profusion of energy models which either impose or assume market clearing conditions [26], [14], [24], [6], [53]. These models are normative in nature, with cost minimization (or profit maximization) as their sole objective. Some models also include explicit resource and technological constraints

[14] , [53], [24]. Environmental impacts are frequently derived from economic and energy activities and are treated as a secondary output [14], [22], [23], [32], [29].

By modeling the evolution of an energy system on the basis of one objective, other objectives vital to the energy future are overlooked. For example, the preservation of environmental quality, health and safety are important objectives which are often left out of the consideration. In the case of nuclear power, earlier projections have been overly optimistic [55], [17], about the nuclear generating capacity attainable in the near future. The models used failed to include public concern regarding nuclear safety. Thus, in order to model the evolution of an energy system we need to incorporate multiple interests and objectives of each energy policy maker together with their interactions. Thus far, there have been scant efforts to model the problem in this rich context. For example, Mesarovic attempted a multi-objective approach to model the world energy systems as a goal seeking system [40]. Others [16] have constructed a dynamic simulation of the effects of alternative political, economic and technical policies for electrical generation on the sulfur-dioxide problem.

Operational gaming is an alternative approach to policy analysis particularly in severely stochastic situations involving a high degree of risk taking, or to prepare policies oriented to deal with crises. The form of current games varies from "free" to "rigid" [19], [20], [3], [50]. In "free-form" games new rules, relationships, and even completely new actors are admitted into the game as it proceeds. In "rigid-form" games such creations are restricted. The former have been employed in disciplines such as military strategic planning, political science, sociology, education and resources [19], [18], [36], [13] [35].

It is interesting to note that because of their fixed mathematical structure, the latter have been employed in disciplines such as economics, engineering and management [58], [44], [25], [37]. Today games have a "hybrid" form, combining features from both the "free" and the "rigid" forms.

Recent advances in interactive computing [7], and structuring of the policy making process [48], [34], [8] are important developments in the formalization of gaming for policy analysis. The purpose of policy analysis games is to assess the implications of decisions made by the important policy makers.

Some systems have no general overall purpose but rather have purposes for each of their subsystems. The interaction of these subsystems with their individual purposes drives the overall system from state to state. Subsystems are structured among themselves hierarchically so that some of them on higher levels control and regulate others on lower levels. Regulation is the control of subsystems to adjust their functions in harmony with those of other subsystems to produce overall system stability[4]. To make regulation feasible, feedback among subsystems is used. Feedback means modification of subsystems' output by actually modifying the input in order to improve the stability of the entire system. In complex human systems only conscious and explicit interaction can reveal the significance of feedback information and the impact of various types of adjustment of subsystems on the stability of the overall system. Gaming is a useful vehicle for this purpose since it provides a framework for such explicit interaction and adaptation among the players. Let us formalize the structure of interactions of such a complex system. A policy making system consists of:

- (i) a set of policy makers which form purposeful subsystems of the system considered in the game;
- (ii) a set of variables used to define the objectives and constraints of the policy makers; and

- (iii) a set of relationships between the policy makers and the state variables.

The state of the policy making systems at time t is described in terms of system variables, $X(t)$ and $Y(t)$ defined as follows:

$X(t)$ = a vector which consists of all decision or control variables, the values of which are determined by policy makers in period t ;

$Y(t)$ = a vector which defines the state of the physical system at the end of period t (state variables)

$Z(t)$ = the history of the system up to period t , is defined by:

$$Z(t) = \prod_{s=1}^t (X(s), Y(s)) \text{ which is the cartesian product of}$$

previous values of X and Y . The current state of the policy making systems is related to $Z(t-1)$ by the following system process function (omitting stochasticity for notational simplicity):

$$\left. \begin{array}{l} Y(t) = F(t, X(t), Z(t-1)) \\ \text{with the system constraints:} \\ H(t, X(t), Z(t-1)) \leq b(t) \end{array} \right\} \dots (1)$$

As we shall see later in a complex system $Y(t)$ is hierarchically structured. The policy makers themselves in the policy making system are also hierarchically structured. Included in (1) are accounting identities (such as the level of resources still available, or the profits of an industry) and restrictions on the system such as resource and technological constraints. The interactions among policy making subsystems are governed by a set of institutional rules and procedures.

Suppose that we have n policy makers, P_i , $i = 1, 2, \dots, n$. We define:

- 1) $X_i(t)$ = the decision variables controlled by policy maker P_i during period t . It is the mathematical projection of $X(t)$ onto some appropriate coordinates.

2) $\tilde{X}_i(t)$ = future decision variables of P_i ; $\tilde{X}_i(t) = \prod_{s=t+1}^{\infty} X_i(s)$.

3) $Y_i(t)$ and $\tilde{Y}_i(t)$ are the current and future state variables of concern to P_i .

4) b_i and $\tilde{b}_i$ are current and future decision constraints set by P_i .

We next define the notion of monitor or policy variables:

5) $V_i(t)$ = current system variables important to fulfilling the objectives of P_i . $V_i(t)$ is equal to some mathematical projection of the history of the system $Z(t)$.

6) $\tilde{V}_i(t)$ = future state variables important to fulfill his objectives in period t . $\tilde{V}_i(t)$ is equal to some mathematical projection of $\prod_{s=t+1}^{\infty} (X(s), Y(s))$.

We shall represent the pairs $(X_i(t), \tilde{X}_i(t))$, $(Y_i(t), \tilde{Y}_i(t))$, $(V_i(t), \tilde{V}_i(t))$, and $(b_i(t), \tilde{b}_i(t))$ by $\bar{X}_i(t)$, $\bar{Y}_i(t)$, $\bar{V}_i(t)$, and $\bar{b}_i(t)$ respectively. A policy is defined by the choice of $\bar{V}_i(t)$ and by its rate of change.

Each P_i has a set of objectives $g_i(t)$ that are functions of $\bar{V}_i(t)$ and may change over time (see for example Shalun-Lewin's theory of situational normativism [34]). Thus how well a subsystem P_i attains his objectives is related not only to his history of the system $Z_i(t)$ but also to $\tilde{V}_i(t)$ the forecasted future state of the system. In addition, the decisions of other policy makers $\bar{X}_j(t)$ $j \neq i$ are related to the objectives of P_i .

Policy maker P_i has a perception (or model) of how his and other policy makers' decisions would affect the future of the system, and hence his policy variables $\bar{V}_i(t)$. Thus there is a perceived process function f_i such that:

$$\left. \begin{aligned} \bar{V}_i(t) &= f_i(t, \bar{X}(t), Z(t-1)) \\ \text{and subsystem perceived constraints:} \\ h_i(t, \bar{X}(t), Z(t-1)) &\leq \bar{b}_i(t) \end{aligned} \right\} \dots (2)$$

Although the form of the functions f_i and h_i are not usually known, this general formulation serves to characterize how purposeful subsystems interact.

In a policy making system, decision makers will attempt to influence, bargain or negotiate with other decision makers to achieve their objectives. Thus, in addition to direct control of his own $X_i(t)$, $b_i(t)$, a policy maker P_i has various degrees of indirect influence on $X_j(t)$, $b_j(t)$, ($j \neq i$) through a set of institutional rules and procedures. Also P_i may have to compromise his multi-dimensional objectives g_i (a vector valued function) during the negotiation process. To represent this interactive decision process mathematically for each P_i , $i = 1, 2, \dots, n$, we have the following dynamic optimization problem:

$$\left. \begin{array}{l} \text{Find } \bar{X}_i(t) \text{ and } \bar{X}_j(t), j \neq i \text{ which:} \\ \text{Maximize } g_i(t, \bar{V}_i(t)) \\ \text{subject to the process functions and constraints:} \\ \bar{Y}_i(t) = f_i(t, \bar{X}(t), Z(t-1)) \\ h_i(t, \bar{X}(t), Z(t-1)) \leq \bar{b}_i(t) \\ \text{and also subject to a set of structural constraints known} \\ \text{as system interaction rules and procedures such as, for} \\ \text{example, a utility rate hearing.} \end{array} \right\} \dots (3)$$

The latter constraints are difficult to systematize and are not stated analytically here, but will eventually need formalization. Note that $x_i(t)$ represents a commitment by P_i concerning his future actions.

Therefore, in order for a policy making system to evolve from one dynamically stable state $(X(t), Y(t))$ to another such state $(X(t+1), Y(t+1))$, there are two requirements that must be met: 1) all of P_i must arrive at a set of decisions which satisfy the "perceived" constraints in (3), and they should have arrived at a prescribed level for their objectives; 2) their decisions must satisfy the overall system constraints in (1).

There are a number of approaches to the multi-objective decision making process for individual decision makers [8], [27], [33]. They comprise a special case of the generalized policy making model presented here with explicit linking of multiple objectives to the system process functions in (1). The special case has been treated by Mesarovic et al. in world modeling [38] and by Ford in the electric utility industry [15] . A potentially fruitful new approach to resolving this multi-objective problem is goal programming, first developed by Charnes and Cooper [10] .

Reaching a consensus in a hierarchical policy making system in case of conflict has been studied by Saaty [47], and Lewin and Shakun [34] . In this paper we examine how operational gaming may be used to arrive at compromise solutions to (3) by the interaction of policy makers in a gaming environment.

B. Gaming for Policy Analysis

Operational gaming can be used to simulate the dynamic interactions in an actual policy making system. The basic components of an operational game are (i) the decision environment, (ii) interactive decision making (iii) impact analysis, and (iv) objective attainment evaluation (see Figure 4-4.

We define a decision environment as the environment within which policy makers are required to make decisions. In systems terms, the decision environment is the environment which includes the acts of 'nature' and other decision makers not in the policy making system. This is controlled by a set of computer programs called the game operating system (with functions similar to those of the operating system in a large computer). We identify two types of decision environment: (i) a reference environment in which historical trends are extrapolated without discontinuities;

Game Components

Figure 4-4

and (ii) a crisis environment in which there are abrupt unanticipated changes in $X_0(t)$ (the decision variables controlled by the game operating system), $b_0(t)$ (system decision constraints), the functional forms of F and H in each period or in the systems interaction rules and procedures. Therefore in policy analysis situations, the conditions which accompany "what if" questions constitute a crisis environment.

Not all policy makers that affect the system should be included in a game. It is sometimes desirable to restrict the number of policy makers in order to make policy evaluations. Thus we distinguish between two types of policy makers in a particular game: the active policy maker who makes his own decisions and negotiations and the passive policy maker whose decision making is taken over by the game operating system (i.e. X_i , b_i become part of X_0 , b_0 respectively). In this sense, the decision environment is a passive policy maker. Therefore, the game operating system contains behavioral models of the decision process in computer program form for each passive policy maker (a set of decision rules). Hence the status of a policy maker in a game is dependent upon a particular policy evaluation situation. In our terminology, a normative model is a degenerate operational game with no active policy makers.

Operational gaming also includes an interactive decision process during which policy makers set objectives, formulate policies and influence the decisions of others (Figure 2). They can select their objectives g_i and determine policy variables V_i to maximize g_i . At the same time, a policy maker P_i also analyzes how various policies (his own and anticipated policies of others) might affect his goal attainment. This involves the analysis of how P_i perceives the overall system (i.e. f_i and h_i in period t). As a result of his decision analysis, P_i may modify his decision and constraint variables ($X_i(t)$ and $b_i(t)$) and may attempt

to influence or negotiate with other policy makers on decision and constraint variables $X_j(t)$, $b_j(t)$, ($j \neq i$) through the set of systems interaction rules and procedures. As an illustration of this interactive decision process a regional electric utility controls the supply of electricity (represented by $X_i(t)$) to that region and influences local regulatory agencies in order to receive permission to install low cost nuclear generation that would contribute to the objective of minimizing cost. The electric utility may have records of the historical trends of the system variables leading up to the current decision period, i.e. historical costs, consumption patterns etc., represented by $Z(t)$ and estimates of the projected impact of proposed decisions, $f_i(t, X(t), Z(t-1))$. Also the utility may be required to make future commitments, e.g. capital for expansion, represented by $X_i(t)$.

Some individual consumers, in addition to desiring low cost electricity, may perceive a higher probability of nuclear hazards. Should a conflict exist, regulators may be required to resolve it.

This process of goal formulation of objectives, individual decisions analysis and negotiation is not necessarily carried out in a sequence, but rather iteratively. We shall call it the interactive decision process. It is continued until a joint feasible solution which satisfies all constraints in (3) for all P_i is reached. The values of g_i must also be acceptable to every P_i .

The result of this interactive decision process is a set of values of decision variables and constraints $X_i(t)$ and $b_i(t)$ for each P_i . The combined decisions are then checked to ensure that all systems constraints are met. Otherwise the interactive decision process must be repeated (see Fig. 4-5). Finally global impacts of all

Dynamics of Operational Gaming for Policy Analysis

decisions are determined for the relation $Y(t) = F(t, X(t), Z(t-1))$.

Assessment of decisions by P_i , $i=1, 2, \dots, n$, is made by how well $V_i(t)$ serves to maximize $g_i(t)$. Clearly there is an incentive for P_i to improve his performance and those of others in order to increase g_i . Thus, interaction is useful.

In the next time period $X(t)$ and $Y(t)$ lead to a new decision environment. This in turn initiates a new round of the interactive decision process among policy makers, and so on. In this manner operational gaming becomes a dynamic process (see Figure 4-5)

We now briefly describe a methodology for applying operational gaming to policy analysis for an individual policy maker. Different 'what if' questions that he supplies constitute a set of decision environments (or scenarios) which the policy maker wishes to explore. Such environments would not be designed from the start. Instead, they are modifications of the reference environment (scenario) which is an element of the initial design of the game. The policy maker participates not only in establishing the decision environment specifications (and therefore his own assumptions) but also in formulating his policies, specifying his objectives as well as testing his policies by participating as an active policy maker in the game. Thus, the policy maker becomes an integral part of the overall policy evaluation process. He observes how other policy makers respond to his policies. The ability to influence and negotiate with other players gives him some control over the forces shaping the future of the system. After the game, the policy maker would also participate in the policy evaluation process. This process is facilitated by the set of his goal attainment g_i being made available in each period as a result of the game. His ability to evaluate policies would be enhanced by his personal experience in the game.

C. The Gaming Approach

The purpose of this section is to present a new approach to quantitative simulation of the evolution of the energy environment system in a region. This approach combines the efforts of humans with a mathematical model to simulate the behavior of the energy environment sectors. It is recognized that the complex, interactive and evolving nature of the system is best simulated by several "human actors" acting out the goals, interests and roles of the important energy environment sectors. A dynamic interactive simulation model is devised to keep track of their actions and assess the important impacts of all their decisions on the system.

The Interindustry Model

The core of the model is an econometric model of inter-industry transactions for eleven aggregated regional industries. The industrial producers are grouped into eleven sectors, in order to provide for the detailed analysis of the evolution of the system most directly affected by energy environment policy changes. Clearly, a substantial portion of energy is consumed in intermediate production sectors. These eleven sectors include five non-energy producers (agriculture, manufacturing, transportation, communications and pollution equipment manufacturing) and six energy producers (coal mining, crude petroleum and natural gas, petroleum refining, electric utilities, gas utilities and nuclear fuel processing) as shown in Figure 4-6

The interindustry transaction approach (Input-Output Model) is chosen for several reasons. First, a substantial portion of energy and environmental pollutions are generated in intermediate production processes. Second, it reflects how final demand affects industrial production in an interdependent economy. Third, it succinctly describes the technological aspects of industry production which is crucial in understanding the production of energy and emission of pollution associated with industrial activity. Fourth, it facilitates participation of a rich variety of players in a

Figure 4- 6

INTERMEDIATE SECTORS:

1. AGRICULTURE, NONFUEL MINING AND CONSTRUCTION
2. MANUFACTURING, EXCLUDING PETROLEUM REFINING
3. TRANSPORT
4. COMMUNICATIONS, TRADE SERVICES
5. POLLUTION ABATEMENT EQUIPMENT MANUFACTURING
6. COAL MINING
7. CRUDE PETROLEUM AND NATURAL GAS
8. PETROLEUM REFINING
9. ELECTRIC UTILITIES
10. GAS UTILITIES
11. NUCLEAR FUEL MINING AND PROCESSING

PRIMARY INPUTS, ROWS:

12. IMPORTS
13. CAPITAL SERVICES
14. LABOR SERVICES

FINAL DEMANDS, COLUMNS:

12. PERSONAL CONSUMPTION EXPENDITURES
13. GROSS PRIVATE INVESTMENT
14. GOVERNMENT PURCHASES
15. EXPORTS

gaming environment. Fifth, it is a linear model and therefore easier to use computationally.

The distinctive novelty of this interindustry model is that the input-output coefficients, which represent the production technologies of each industry are determined in each game step, primarily by all input prices, and subsequently modified (within limits) by industrial actors and other actors of importance. This approach is a far superior alternative to either that of actors determining completely the input-output technology (which would be very complex and exhausting) or that of being kept constant throughout the simulation period (which does not represent the dynamic nature of technological changes).

The gaming model operates as follows. For game stage I the model receives as inputs the costs of labor and capital for each industry (determined by labor unions, financiers, industries and government in the manner described in Section IV), the costs of competitive imports from other regions (determined by government, industry and computer), amount of product demands (determined by individual consumers, government, investors and other regions), pollution emission regulations, and prices of products delivered to the consumers. Outputs from the model include input-output technical coefficients, inter-industry product prices, final industrial output and values of output, amount of labor and capital employed, energy production, pollution emissions, violations of pollution regulations, and violations of computer imposed constraints.

Game stage I is characterized by the following features:

- 1) it is a trial run to prepare the players for bargaining and negotiation in game stage 2,
- 2) each actor pursues his own goals independently without interaction; in particular, industrial sectors pursue a single course of profit maximization in determination of industrial product prices and technology of production,
- 3) the game model returns to players with a picture of "What the world would be like if everyone pursued his own interests and goals".

In game stage II, players participate first in an "interaction session". This is when players can influence other players in their final decision making process. This is treated in more detail in Section IV.

Implementation of the final decisions by players after interaction is concluded takes the form of a sequential policy-strategy-action choice for each player. For example, although the dynamic gaming model outlined below determines profit-maximizing product output prices and technical coefficients, an industrial player can choose a strategy of modifying some technical coefficients (for instance to reduce pollution emissions). The policy implementation aspects of the model is discussed in Section V.

The Structure of the Gaming Model

The first part of the model determines, given prices of labor, capital services and competitive imports of each industry (except pollution equipment manufacturing) technical coefficients of each industry's production process and the industry prices of their outputs.

The crux of the gaming model is a set of 33 equations representing industrial product price relations estimated from historical national data. This approach was pioneered by Hudson and Jorgenson. These equations are termed translog price possibility frontiers, a short term for transcendental logarithmic price possibility frontiers.

Hudson-Jorgenson (H-J) model parameters are incorporated in the gaming model. Two other industries, nuclear fuel processing and pollution abatement equipment manufacturing are added to the nine-industry H-J model in order to enrich the simulation of the energy-environment system. However, pollution abatement equipment manufacturing is not treated as a competitive production factor of any industry. The players have to supply these technical coefficients during the game policy implementation session. The symbols employed are defined as follows:

X_{ij} = intermediate demand for output from industry i
by industry j ($i, j = 1, 2, \dots, 11$)
 X_i = total output from industry i ($i=1, \dots, 11$)
 Y_i = aggregated final demand for outputs from industry
i ($i=1 \dots 11$)
 P_i = industry price of output from industry i to all
other industries
 P_i^* = consumer price of output from industry i to final
demand
 P_{L_i}, L_i = price and quantity of labor required by industry i
 P_{K_i}, K_i = price and quantity of capital required by industry i
 P_{R_i}, R_i = price and quantity of imports required by industry i
 P_{U_i}, U_i = price and quantity of pollution abatement equipment
required by industry i
 C_i = personal consumption of outputs from industry i
 I_i = private investment in output of industry i
 G_i = government purchases of outputs of industry i
 Z_i = net exports of outputs of industry i

Final demands for regional industry outputs have four components: private consumption, investment, government purchases and net exports, i.e.

$$Y_i = C_i + I_i + G_i + Z_i$$

Input-Output coefficients A_{ij} are defined as the quantity of output from industry i required to produce 1 quantity of output from industry j. (i.e. $a_{ij} = \frac{X_{ij}}{X_j}$). These are also called

technical coefficients.

Hudson and Jorgenson modeled the technical coefficients a_{ij} with a two-level approach. (2) First, the relations are determined between price of outputs from each industry and prices of the industrial aggregate inputs, which are capital price, labor price, aggregate energy price and aggregate non-energy materials price of that industry (except for pollution equipment, which is dealt with separately). Transcendental logarithmic functions are used to fit these relationships using historical data. They are of the form:

$$\begin{aligned} \ln a_{ij} P_i = & \alpha_0^i + \alpha_K^i \ln PK_i + \alpha_L^i \ln PL_i + \alpha_E^i \ln PE_i + \alpha_M^i \ln PM_i \\ & + \frac{1}{2} \left[\beta_{KK}^i (\ln PL_i)^2 + \beta_{KL}^i \ln PK_i \ln PL_i + \beta_{KE}^i \ln PK_i \ln PE_i + \beta_{KM}^i \ln PK_i \ln PM_i \right] \\ & + \frac{1}{2} \left[\beta_{LL}^i (\ln PL_i)^2 + \beta_{LE}^i \ln PL_i \ln PE_i + \beta_{LM}^i \ln PL_i \ln PM_i + \beta_{LK}^i \ln PL_i \ln PK_i \right] \\ & + \frac{1}{2} \left[\beta_{EE}^i (\ln PE_i)^2 + \beta_{EM}^i \ln PE_i \ln PM_i + \beta_{EK}^i \ln PE_i \ln PK_i + \beta_{EL}^i \ln PE_i \ln PL_i \right] \\ & + \frac{1}{2} \left[\beta_{MM}^i (\ln PM_i)^2 + \beta_{MK}^i \ln PM_i \ln PK_i + \beta_{ML}^i \ln PM_i \ln PL_i + \beta_{ME}^i \ln PM_i \ln PE_i \right] \\ & i = 1, 2, \dots, 11 \\ & \dots \dots \dots (1) \end{aligned}$$

where PE_i , PM_i are the prices of aggregate energy and non-energy materials required by industry i

Taking derivatives of both sides with respect to PK_i ,

$$\frac{1}{P_i} \frac{\partial P_i}{\partial PK_i} = \frac{1}{PK_i} (\alpha_K^i + \beta_{KK}^i \ln PK_i + \beta_{KL}^i \ln PL_i + \beta_{KE}^i \ln PE_i + \beta_{KM}^i \ln PM_i)$$

At equilibrium,

$$\frac{\partial P_i}{\partial K_i} = \frac{K_i}{X_i}$$

Therefore,

$$a_{K_i} = \frac{K_i}{X_i} = \frac{P_i}{PK_i} (\alpha_K^i + \beta_{KK}^i \ln PK_i + \beta_{KL}^i \ln PL_i + \beta_{KE}^i \ln PE_i + \beta_{KM}^i \ln PM_i) \quad (2)$$

Similarly,

$$a_{L_i} = \frac{L_i}{X_i} = \frac{P_i}{PL_i} (\alpha_L^i + \beta_{LK}^i \ln PK_i + \beta_{LL}^i \ln PL_i + \beta_{LE}^i \ln PE_i + \beta_{LM}^i \ln PM_i) \quad (3)$$

$$a_{E_i} = \frac{E_i}{X_i} = \frac{P_i}{PE_i} (\alpha_E^i + \beta_{EK}^i \ln PK_i + \beta_{EL}^i \ln PL_i + \beta_{EE}^i \ln PE_i + \beta_{EM}^i \ln PM_i) \quad (4)$$

$$a_{M_i} = \frac{M_i}{X_i} = \frac{P_i}{PM_i} (\alpha_M^i + \beta_{MK}^i \ln PK_i + \beta_{ML}^i \ln PL_i + \beta_{ME}^i \ln PE_i + \beta_{MM}^i \ln PM_i) \quad (5)$$

The input-output coefficients of each input, a_{K_i} , a_{L_i} , a_{E_i} , a_{M_i} , is therefore generated from the translog price possibility frontier.

Second, the aggregate energy and non-energy materials prices of each industry are further decomposed to show their dependence on its components. For the aggregate energy prices, again there are a set of 11 translog equations of the form

$$\begin{aligned} \ln PE_i = & \alpha_0^{E_i} + \alpha_1^{E_i} \ln PE_i^1 + \alpha_2^{E_i} \ln PE_i^2 + \alpha_3^{E_i} \ln PE_i^3 + \alpha_4^{E_i} \ln PE_i^4 \\ & + \alpha_5^{E_i} \ln PE_i^5 + \alpha_6^{E_i} \ln PE_i^6 + \frac{1}{2} \left[\beta_{11}^{E_i} (\ln PE_i^i)^2 \right. \\ & \left. + \beta_{12}^{E_i} \ln PE_i^1 \ln PE_i^2 + \dots \right] \quad i=1, 2, \dots, 11 \\ & \dots \dots \dots (6) \end{aligned}$$

where PE_i^1 , PE_i^2 , PE_i^3 , PE_i^4 , PE_i^5 , PE_i^6 are the prices of coal, crude petroleum and natural gas, refined petroleum products, electricity, gas as a product of gas utilities and price of uranium fuel required by industry 1, respectively.

By the same procedures taken to derive a_{ki} ,

$$a_{jE_i} = \frac{X_{ji}}{E_i} = \frac{PE_i}{P_j} \cdot f_{jE_i} (PE_i^1, PE_i^2, PE_i^3, PE_i^4, PE_i^5, PE_i^6)$$

$j' = 1, 2, \dots, 6$

Or, equivalently

$$a_{jE_i} = \frac{X_{ji}}{E_i} = \frac{PE_i}{PE_i} \cdot f_{jE_i} (P_6, P_7, P_8, P_9, P_{10}, P_{11})$$

$j = 6, 7, \dots, 11$ (7)

Therefore,

$$a_{ji} = \frac{X_{ji}}{X_i} = \frac{E_i}{X_i} \cdot \frac{X_{ji}}{E_i} = a_{E_i} \cdot a_{jE_i} \quad \dots \dots \dots (8)$$

In this way, the technical coefficients, a_{ij} , ($i=1, 2, \dots, 11$; $j=6, 7, \dots, 11$) which represent the intensity of industrial consumption of each type of energy, are derived as dependent variables.

In a similar manner, the aggregate non-energy material prices of each industry can be decomposed into non-energy components.

$$\begin{aligned} \ln PM_i = & \alpha_0^{M_i} + \alpha_1^{M_i} \ln PM_i^1 + \alpha_2^{M_i} \ln PM_i^2 + \alpha_3^{M_i} \ln PM_i^3 \\ & + \alpha_4^{M_i} \ln PM_i^4 + \alpha_5^{M_i} \ln PM_i^5 + \frac{1}{2} \left[\beta_{11}^{M_i} (\ln PM_i^1)^2 \right. \\ & \left. + \beta_{12}^{M_i} \ln PM_i^1 \ln PM_i^2 + \dots \right] \\ & i = 1, 2, \dots, 11 \quad \text{--- (9)} \end{aligned}$$

here PM_i^1 , PM_i^2 , PM_i^3 , PM_i^4 , and PM_i^5 are prices of agriculture (including non-fuel mining and construction), manufacturing, transportation, communications (including trade and services) and competitive imports delivered to industry i . These respectively correspond to P_1 , P_2 , P_3 , P_4 and P_I in the earlier definition. It should be noted that pollution equipment is not counted as one of the productive non-energy input requirements.

Again, the following are obtained

$$a_{jM_i} = \frac{X_{ji}}{M_i} = \frac{PM_i^j}{P_j} f_{jM_i} (PM_i^1, PM_i^2, PM_i^3, PM_i^4, PM_i^5) \quad j=1, 2, 3, 4 \quad \text{--- (10)}$$

$$a_{IM_i} = \frac{X_{Ii}}{M_i} = \frac{PM_i^5}{P_I} f_{IM_i} (PM_i^1, PM_i^2, PM_i^3, PM_i^4, PM_i^5) \quad \text{--- (11)}$$

$$a_{ji} = \frac{X_{ji}}{X_i} = \frac{M_i}{X_i} \frac{X_{ji}}{M_i} = a_{M_i} a_{jM_i} \quad j=1, 2, 3, 4 \quad \text{--- (12)}$$

$$a_{Ii} = \frac{X_{Ii}}{X_i} = \frac{M_i}{X_i} \frac{X_{Ii}}{M_i} = a_{M_i} a_{IM_i} \quad \text{--- (13)}$$

All technical coefficients, except for the row A_{zi} ($i=1, \dots, 11$), are determined by prices. The technical coefficients of which represent the industrial use of pollution abatement equipment, would be determined exogeneously by the players themselves. The model also determines industry output prices simultaneously from equation 1 after aggregate energy and non-energy material prices are determined in the systems of equations (6) and (9).

The second part of the model generates the set of required industrial outputs to satisfy intermediate and final demands.

The equations representing the balance of demand and supply for each of the eleven industrial sectors can be presented in the form:

$$X = AX + Y$$

where

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_{11} \end{bmatrix}$$

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_{11} \end{bmatrix}$$

and A is the matrix of input-output technical coefficients determined by equations (8) and (12)

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,11} \\ a_{2,1} & a_{2,2} & \dots & a_{2,11} \\ \vdots & \vdots & \ddots & \vdots \\ a_{11,1} & a_{11,2} & \dots & a_{11,11} \end{bmatrix}$$

Levels of regional industrial outputs are obtained by the following equations

$$X = (I-A)^{-1}Y$$

Total capital and labor requirements and competitive imports are computed from the levels of regional outputs and a_{K_i} , a_{L_i} , a_{I_i} computed in equations (2), (3) and (13) as follows:

$$K_i = a_{K_i} \cdot X_i$$

$$L_i = a_{L_i} \cdot X_i$$

$$I_i = a_{I_i} \cdot X_i$$

$$i = 1, 2, \dots, 11$$

From the set of industrial output levels, X_i , the impact model then computes the energy balances and pollutions emission levels. This is described in Section IV.

IV. Model Components

A. Decision Environment

At the beginning of each game step a player is permitted to review the decision environment which is a description of the present state of the regional energy environment system. This description is composed of two parts, a verbal description (primarily used by policy oriented players who utilize executive strategies) and a quantitative summary which contains the present values of the state variables of the energy-environment system. The state variables are divided into three basic groups of factors, energy consumption, environmental factors, and economic factors. The principal impact analysis model is based on economics. The state of the regional economy is represented as a regional input-output table, the rows of which describe the allocation of industrial outputs in the region, the columns of which describe the input requirements of industry within the region. Associated with this input-output transactions table is a set of additional columns that indicate final demands or sales of industrial output to final consumers, i.e. personal consumption, private investment, government, and net exports. Similarly a number of additional rows reflect the values of some so-called "value-added" items such as imports, capital services, and labor services. The result, in the present game, is an input-output model consisting of 11 industrial sectors, 4 final demand sectors and 3 value added sectors, or a 14 x 15 matrix of transactions (210 variables).

Associated with the interindustry flows, which are measured in dollars, are the physical units of exchange accompanying these dollar flows. In particular, concern is focused on the amount of energy, of each type represented in the interindustry table, that flows from the energy surplus sectors to the energy consuming sectors. Of course, energy

supply sectors are also energy consuming sectors. If one physically collects (or estimates) data reflecting the amount of energy transacted in the reference case (the amount of energy associated with each dollar transaction between an energy consumer and an energy supply supplier) then one can derive a set of implied energy prices (P) that relate a dollar transaction to its equivalent amount of energy (for this reference case). If the I/O tables for successive years are computed in constant dollars the implied energy prices can be used to determine the energy flows in these tables as compared to the reference case. Such a set of implied inverse energy prices, of dimension 6 (the number of energy sectors) by 11 (the number of consuming sectors), is used in the present effort for this purpose. Hence a subset of the REEG state variables is a table of energy flows (a total of 55 state variables) that is computed from the I/O transactions table for the current game step and the reference energy coefficients matrix P . Of course, P changes with each game step and, hence elements of P are also decision state variables.

Environmental pollution factors also vary with industrial output. Levels of pollution for the current game step are computed from a set of pollution coefficients (Q) that are in units of pollution per dollar of output (e.g. lbs. SO_2 /output of electric utilities). The values of current regulations such as minimum emissions standards are also included as part of the decision environment. Computation of the values of all decision environment state variables for the current step is discussed later. The decision environment is summarized in Table 4-1.

B. Policy Analysis and Implementation

When players have been acquainted with the decision environment for the current game step each is ready to adopt a policy that will guide his behavior for that game step. In

DECISION ENVIRONMENT

TABLE 4-1

I. Verbal Description

A verbal summary of directions and trends of state variables (those included in the Quantitative Summary).

II. Quantitative Summary (state variables)

A. Economic Factors

Total Industrial outputs, Final Demands (net exports, government purchases, private investment), energy prices, output prices, labor and capital service prices, pollution abatement cost.

B. Environmental Factors

Levels of air pollution (SO_2 , NO_x , HC, CO) relative levels with respect to previous game step and reference case.

C. Energy Consumption Factors

Total energy consumption, energy consumption by industry, relative consumption with respect to previous game step and reference case.

D. Employment Factors

Total employment, employment by industry, relative level of employment with respect to previous game step and reference case

III. Dynamic variables

A. Growth Rates

B. Dynamically Imposed Regulatory Standards

C. Resource Constraints

particular, a player selects from a prescribed set of alternative policy options. The list of those policy options available to players in the present implementation of the REEG is given in Appendix D. As an illustration, a typical set of options for the electric utility player is given in figure 4-7. As can be seen, perhaps more easily in the mathematical representation of the policy analysis sequence (in Appendix B), the choice of a policy actually determines the state variable on which an actor (player) has presently focused his interest for the current game step.

A given player only has direct influence over a restricted set of decision variables which, in turn, may or may not affect the relevant state variables, i.e. those with which the player is initially most concerned, depending upon other factors simultaneously applying. Further, a player may have the option to influence a state variable in a number of different ways. These options are characterized as strategies. Mathematically (see Appendix B) the choice of a strategy is defined as a prescribed set of decision variables that are both under direct control of the actor and also influence the state variables that are relevant to the actor's current policy. In the current implementation most strategies are prescribed, there is a restricted set of strategy options associated with each actor policy option, varying from slight to drastic deviation from previous strategies.

In a typical game step the electric utility actor might choose to pursue the first of his policy options, i.e. emphasize minimizing the cost to supply electricity. In the actual mechanics of REEG, this choice corresponds to expressing a preference for influencing a number of state variables describing the regional energy environment system namely the capital, fuel, and other costs associated with generating electric power. Choice of another policy might indicate preference for a different set of REEG state variables. In any case, the electric utility may

Figure 4-7

Policy Options

Actor: Electric Utility

1. Minimize cost to supply electricity
2. Increase total sales
3. Improve reliability of services
4. Alter technology
5. ** Generated strategy
6. * Executive - alter technology
7. * Executive - minimize cost
8. * Executive - protect environment
9. * Executive - generated
10. Comprehensive strategy

influence the cost of producing power, i.e. the state variables involved in that production, in a number of different ways. The alternative avenues of influence are defined as strategies.

In general, each state variable is a function of a number of decision variables. One can influence a particular state variable by changing any of the decision variables that affect it. Decision variables and state variables are not necessarily mutually exclusive, i.e. the set of decision variables is often a subset of the system of state variables. The choice of a strategy indicates which decision variables a player has chosen to alter in order to effect a given state variable or state variables. Certainly, this could be done in an almost infinite number of ways. However, a given player also only has access to a certain number of decision variables and hence strategies can only use decision variables which the player has direct control. For example the cost of producing power depends in part on the price of pollution abatement equipment and the cost associated with operating that equipment. The electric utility, in most cases, will not have direct control over these state variables, however, he might negotiate with the players who do control them. In any case, once the relevant decision variables (i.e. strategy) have been chosen the next step is to change the current values of these variables in a manner that moves the affected state variable in the desired direction. This constitutes tactics or action steps on the policy-strategy-action sequence. As mentioned earlier the state variables other than the one of present concern, will certainly be affected by the change in the single decision variable. These secondary effects are of considerable importance since they exhibit the tradeoffs inherent in many policy decisions. For instance, the strategy choice of an electric utility to build more generating capacity might bring, with reduced cost in generation, perhaps an increased environmental load.

Finally, let us review how policies, strategies, and actions

are implemented in the REEG. First, an action player makes a policy choice during each game step, a convenient time period over which the game is divided, say five years. During each game step the game director constructs the decision environment from the previous game step's results and relevant data in the current period's capital and labor prices. The player then is permitted to review the decision environment and make policy, strategy, and action decisions. The results are returned for player review. This is stage I of the current game step. Now players review these results and interact, negotiating when necessary. Finally, all players submit a final sequence of policy, strategy and action choices, which are now recorded by the game director and used to compute the final results for the current game step. This is stage II for the current game step. At any time during the policy-strategy-action sequence for either stage I or stage II the player can perform independent policy analysis experiments before making a final decision. This is a unique feature provided by interactive computing.

C. Interaction

Interaction sessions allow players to negotiate before final actions are undertaken. Based on modern theories of policy making behavior, there are two stages in each game step, i.e. stage I and stage II. In stage I, players pursue goals, norms and values most satisfying to their role under a specific decision environment. The resultant state obtained during the Impact Analysis Session would be either feasible but unsatisfying, or totally infeasible.

The resultant state may be unsatisfying to some players since each is acting in his own interest which generally conflicts with the interests of other players. For example, conflict arises when the electric utility industry desires to burn cheap high sulphur coal in their power plants, while the regional office of the Environmental Protection Agency desires a low ambient concentration

of sulphur dioxide to preserve the health and safety of citizens. Therefore, stage I makes these conflicts known to all players and sets the stage for negotiation during the Interaction Session.

Infeasibility indicates that there are conflicts in values of decision variables. For example, the electric utility may want to increase the price of electricity to cover costs incurred in sulphur dioxide emission control; while the Public Utility Commission seeks lower electric rates in light of lower generation costs due to installation of cheaper nuclear power generation. Again, these conflicts would be settled during the Interaction Session, perhaps by modifying player policies, strategies, or tactics to reach a compromise position for both players.

The Interaction Session therefore enables players to negotiate decision values, articulate their positions, influence other players' decisions, and modify each player's own goals to adapt to other players actions. It is a compromise period for all players. The end product of the Interaction Session is a set of final decision values, in some sense negotiated, between various players. These decision values are then sent to the computer model as input during the Policy Implementation session.

D. Impact Analysis

As Section III, the dynamic technical coefficients for each industry (A) and value added sectors (Av) were obtained. In addition, there are a set of inter-industry prices (Pi) determined jointly by the gaming model and players representing the industries.

Following the same notations defined in Section III, the industrial total output required to meet final demand is computed as below

$$X = (I - A)^{-1} Y$$

$$\text{where } X = (X_1, X_2, \dots, X_{11}) \text{ and } Y = (Y_1, Y_2, \dots, Y_{11})$$

The transaction in physical units from industry i to industry j derives from

$$X_{ij} = a_{ij} \cdot X_j$$

and the transaction in dollars from industry i to industry j is obtained by the expression

$$X\$_{ij} = X_{ij} \cdot P_i$$

A matrix of multipliers, which relate inter-industry transactions to energy flows from energy sectors to all other sectors, is derived from fuel inputs to the electric utility industry for the study region [43] (NPC News) and results of Herendeen's work. Since the quantity of inter-industry transactions, X_{ij} , depends on A_{ij} , the flow of energy will change according to changes in technology of production. Therefore, the amount of energy type i from sector i to sector j, E_{ij} is given by $E_{ij} = e_{ij} X_{ij}$ where the e_{ij} are the energy multipliers. The total amount of energy directly consumed by an industry i is calculated by adding up its net consumption of coal, crude oil and gas, refined petroleum, electricity, gas and nuclear fuel, some of which may be zero.

A similar methodology is followed to compute the total amount of environmental pollutants emitted in the production process; except that environmental pollution multipliers relate pollution of various types to total industry output. That is,

$B_{ik} = b_{ik} \cdot X_i$ where B_{ik} is the level of pollution of type k emitted by industry i and b_{ik} is the corresponding pollution multiplier. Research on estimation of b_{ik} have been carried out by Leontief [32], Just [29] and Brookhaven National Laboratory (Ref).

Labor requirements, capital needs, and imports are also calculated by multiplying labor coefficients A_{li} , A_{ki} , and A_{ri} , with levels of industrial output.

The Impact Analysis Session also includes two other features. One is converting units in model use such as BTU to conventional units more easily understood by non-technical players such as tons of coal and million barrels of oil. Another feature is checking violations of constraints imposed by the players (for instance, the government constraint on oil imports) or by the computer as a part of the decision scenario (for example, upper bounds on product levels).

V Computer Organization

As mentioned in the Introduction, the two phase approach to the design of the REEG served to structure the development of the interactive game in Phase II. Among the most important results was a firm characterization of the components that would be required in a computer implementation of the interactive game. This characterization dictated the following features in the computer implementation of the REEG:

A. Language Capabilities

The game, in its present form, has been programmed in APLSV, the shared variable version of a relatively new high-level computer language, APL (A Programming Language) that is concise and very powerful and which allows relatively easy implementation of mathematical models used in the game's impact analysis and player analyzer modules. The shared variable feature of the present implementation of the language facilitates construction of a sophisticated communication network among users (players) located at remote locations. APL is an interactive language which means that the players' policy analysis and the game's impact analysis functions, when executed, return the results immediately.

The present system is implemented on an APL system with two auxiliary processors: 1) the Shared Variable Processor (SV) which allows the communication between players just mentioned and 2) the Time Sharing Input-Output (TSIO) processor which allows communication with a secondary data file (on-line storage) called the game step library where a complete set of results for each game step are saved for later retrieval and review. The present game has been implemented on an IBM 370/168 computer.

B. Modular Programming Structure

The REEG game has been designed and implemented in 7 basic programmed modules that were developed separately and finally interfaced in the present version. The gaming modules mentioned

earlier form a subset of the complete set of programmed modules. The basic organizational unit of the game is called a workspace. There are two basic types of workspaces used in the REEG, i.e. a director's workspace and a player's workspace. When the game is being played, a workspace actually corresponds to a single typewriter-like computer terminal, hence a game usually consists of a single director's workspace and a number of players' workspaces. The director's workspace contains many of the computer programs used in controlling the game progress. The Game Director, the person who operates the director's workspace, is responsible for management of the game progress. However, little management is required since a block of computer programs (called the monitor) automatically handles most of the game management chores.

Hence, a player can also operate from the director's workspace, i.e. the director's workspace has all the features of a player workspace plus the game management features as well. A player workspace contains the policy analysis, decision environment review, game step results review, as well as other functions (computer programs). An active player, who operates a player workspace, needs to play the role assigned to him by the game director. In practice more than one player can actually operate from a single player workspace, hence a single player could also play dual roles.

The basic program modules of the REEG game structure that are contained in the director and player workspaces are the following: (See Fig. 4 -8)

- 1) Communication Module. This module makes use of the APLSV shared variable feature to establish communication links between the game director, who operates in the game director's workspace, and various remote player workspaces. In addition, a communication link is established with a number of on-line storage files through the TSIO processor so that game step results can be saved for later retrieval.

- 2) Monitor. The Monitor handles the communication module as well as controlling the game's sequence of events. Information

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Figure 4-8
Modular Programmed Structure

concerning the completion of the decision environment setup (performed by the game director), policy strategy action sequences by each player, computation of impact analysis, player reviews of game step results, and saving of game step data in storage files, are all controlled by the Monitor. The Monitor also handles much of the error processing of the game sequence. The Monitor resides in the director's workspace.

3) Director. The Director controls the creation and updating of (during subsequent game steps) the decision environment. The Director programs are the only ones that have complete access to all decision state variables. The principal function of the Director programs are to create initially the decision environment and then to process the game step results in order to create the decision environment for the next game step. The Director also controls, through the Monitor, the status of players, either active, passive (computer simulated), or dormant (ignored), as the game progresses. The Director, of course, resides in the game director's workspace.

4) Policy Implementation Module. This module informs players of available policy and strategy options, prompts players for their choices of policies and strategies for each game step, and finally executes the strategy interactively if the player is in active status or processes relevant information from the decision environment to choose a strategy internally if the player is in passive status, i.e. the behavior of the passive player is supplied by the computer. If the player is in dormant status, i.e. if that player interest is deemed not important to the particular decision environment by the game director, the policy implementation module for that actor interest is overridden. The Policy Implementation Module (PIM) resides in the player workspace.

5) Impact Analysis Module. When the Monitor determines that all actions have been received for a game step it passes the set of decision state variables on to the Impact Analysis Module where the results of the current game step are computed. This is where

the basic generalized input-output gaming model (Section III) has been implemented. The Impact Analysis Module (IAM) resides in the Director's Workspace.

6) Interaction Module. This module, through the links set up by the Communication Module, allows players to communicate with each other during the policy-strategy-action sequences. The Interaction Module (IM) resides in all workspaces but, in the present implementation, only consists of simple message sending functions. Few functions exist for transferral of data (e.g. policy analysis results) among players.

7) Player Analyzer Module. A Player Analyzer Module exists for each actor interest, and if that actor interest is in active status, a variety of functions exist for his own analysis of the decision environment and analysis of game step results.

A summary of the programming modules is given in Table 4-2 along with the workspaces in which they reside.

C. Game Communication

As mentioned above the communication module establishes links between the director's workspace and both the player's workspace and the game step results library. Figure IV-9 shows the communication links (shared variables) between the director workspace and a player workspace.

Table 4-2
REEG Program Modules

Program Module Name	Workspace Location		Module Function
	D-Director	P-Player	
1. Communication	D/P		Makes use of the APLSV shared variable feature to establish communication links between the game director workspace and various remote player workspaces. In addition a link is established via the TSIO processor between the director workspace and an on-line storage file-the Game Step Library.
2. Monitor	D		Handles the communication module as well as monitoring and controlling the game's sequence of events.
3. Director	D		Controls creation and updating of the game's decision, the Director Module has access to all of the game's state variables, i.e. those variables that describe the state of the energy environment system.
4. Interaction	D/P		Controls communication between game players while the game is in progress.
5. Policy Analyzer	P		Allows each player to analyze decisions before actually making them in a game step.
6. Policy Implementation	P		Executes a player strategy by passing values of relevant decision state variables to the monitor.
7. Player Management	P		Controls the sequence of events in a player workspace.
8. Impact Analysis	D		Collects actions (values of decision state variables) from all players and computes the resultant state of the energy environment system for that game step.
9. Game Step Library	-		An on-line data file that stores the decision environment data, a players' action summary, and finally the results for each game step.

Figure 4-9

REEG Communication Network-Shared Variable Links

4 shared variable links always exist between the game director and a player

SVC1, SVC2 - contains game sequence control information
 SVN1, SVN2 - contains decision environment verbal description
 SVD1, SVD2 - passes decision environment data to the Player and action steps back to the Director
 SVR1, SVR2 - passes game step results to the Player from the Director

SVnm - links two players
 CTL1, DAT1 - links the Director to the GSL via TSIO

Values of various elements in the control vector (CV) indicate the status of the game sequence. For instance, if element two (the decision environment status element) is on, i.e. set to 1, the decision environment is completed for the current game step. The Monitor polls the CV periodically to determine when programs such as the Impact Analysis Module or the updating procedures, should be executed or when data, such as decision environment data or game step results, should be sent to the active players. The CV also retains the information on player status, i.e. whether one is active, passive, dormant, internal or external, as described earlier. A more complete description of game sequence control is given in Appendix II (REEG Programmers Guide).

D. Decision Environment Construction and Modification

As mentioned earlier, the Director Module effects the construction and maintenance of the state variables that make up the decision environment. The Game Director controls the Director Module interactively. He can either instruct the Director to enter a previously-constructed decision environment (perhaps stored in the game-step library) or he can interactively construct the decision environment himself and modify it at the beginning of each game step. As mentioned, the game director need only enter a number of aggregated variables, e.g. average price of capital or of labor, and the director then automatically constructs the disaggregated variables (state-variables) for the current game step, or which there are some 500 in number including energy consumption coefficients, pollution coefficients, technological coefficients, and prices of materials and energy, and many others. It is not feasible for the game director to set individually all of these state variables initially. This is the reason for the feature of construction of individual state variables from convenient aggregates. However, the Game Director, once the state variables have been constructed, can change them individually if he wishes to do so. At the end of each game step the results, the current decision environment plus

some additional state variables, are used to construct the decision environment for the next game step. Depending upon the time per game step (e.g. 1 or 5 years, etc.) the state variables are updated accordingly. Further, any additional effects can be programmed in, such as availability of a new technology or establishment of a new regulatory standard. The Director Module contains the programs for modifying the Decision Environment in this manner as well as constructing it initially at the beginning of the game.

E. Policy Analysis and Implementation

Policy analysis can be undertaken by any player while he is reviewing the decision environment. This means that a policy analyzer module is available in each player workspace. The player can, in performing policy analysis, do any of the following:

1. Review his policy options
2. Review his strategy options
3. Obtain descriptions of policy and strategy options
4. Determine the impact of his own policies and strategies
5. Test his own, along with those of other players, policies and strategies before making a choice.

A player implements a set of decisions in the sequence of first choosing a policy, then a strategy, and finally a set of actions dictated by that strategy. In particular, a number of strategies are associated with a given policy, each of which represents an alternative for achieving the objective implied in the statement of the policy. In practice there are four different types of strategies, all of which must ultimately be stated in terms of a number of decision state variables (as discussed in Section IV). These strategies are the following:

1. limited
2. comprehensive
3. executive
4. generated.

The first two strategy types, i.e. limited and comprehensive, are technically oriented in that they prompt the player for particular values of decision state variables. On the other hand the other two strategies, executive and generated, are less technically oriented in that they do not prompt the player for actual values but simply for trends or degrees of emphasis. This type of strategy is more sympathetic to the needs of a high level policy maker. A player, by virtue of his role, has access to a subset of the entire set of decision state variables. The player's entire subset of these variables is called his decision set. A limited strategy allows the player access to only several variables in his decision set. A comprehensive strategy accesses the player's entire decision set. The executive strategy is much like the limited strategy except the values assigned to the decision variables are assigned by a computer program based on emphasis and priorities entered by the player that are not numerical. The generated strategy is a combination of a number of limited and/or executive strategies.

In policy analysis the player can execute a number of his own strategies, as well as those of other actors, and determine an approximation of the results if the policies were actually implemented without actually committing himself to a particular policy and strategy. A player commits himself for a game step when he makes his final policy, strategy and action choice. At this point the values of the decision variables and results from the policy-strategy-action sequence, are passed to the game director, as they are for all players, where impact analysis is then performed.

Some players in a particular game step may be in passive status, i.e. their behavior is computer simulated. A strategy for an active player is an interactive computer program that returns the values of a number of decision state variables. A passive strategy is simply a computer program that assigns values to decision state variables based on the values of other state variables. For instance, the environmental regulator may limit

industrial production if pollution levels become too high.

Actions, i.e. the values of decision state variables, that result from the player policy-strategy-action sequence are passed to the Game Director on the shared variable link that links the director's workspace with the player workspace. The strategy execution also changes an element in the control variable that links the two workspaces, thus notifying the monitor that a player has completed his action step for that game step.

F. Game Step Library

At the end of each game step the Monitor Module sets up a communication link (through the TSIO processor) by means of the communicator module of programs with the Game Step Library (GSL). The GSL is simply a data file where a comprehensive list of information relevant to each game step is recorded. The following information is recorded for each game step.

1. a complete description of the decision environment. Both a verbal description and a complete list of all state variables is saved.

2. a complete summary of all player actions. Who makes the actions, the decision variables that were accessed, and the values assigned to those decision variables are all saved.

3. a complete summary of the results of impact analysis, including industrial outputs, pollution emissions, energy consumption levels, regulations exceeded, labor requirements, capital requirements and other results of that game step.

These large files of data are stored for later retrieval by high speed printer output so that a complete review of the game can be made. Data handling was a particularly sticky problem in implementing the REEG. Inclusion of the GSL allowed high speed printer output of data that was not otherwise possible on the current APL system. The use of cathode ray tube type terminals also sped up game steps when players wished to review large portions of data describing the decision environment.

Vl. Illustration of Operational Version of REEG

Reeg has been used to illustrate the economic-environmental quality conflict inherent in the use of coal for producing electric power. A decision environment encouraging coal development is identified to evaluate alternative political, economic, and technical policies of electric utilities and government. Three broad regional government policy options are examined. The first policy option is characterized by minimal government regulations on sulfur dioxide emissions and electric consumption. The second policy option includes a strict sulfur dioxide standard on electric power generation. The third option has moderate sulfur dioxide regulation plus some energy conservation efforts on electricity consumption. Figure 4-10 to 4-14 are plotted to show the different evolution of the regional energy environment system under various policies. Under the first policy option, the electric utility, taking advantage of low-price coal (as compared to oil), opts for more coal-fired generating capacity. As a result we see sharp increased in sulfur dioxide emissions, leading to a reduction of oil burned in oil-fired generators. The Gross Regional Product (GRP) increased steadily. Under this decision environment over seven periods, the price of electricity increased at a rate of 9.6% per year (Table 4-5).

The situation changes dramatically under the second policy option, where a strict sulfur dioxide standard is imposed. We see a sizable drop in the level of SO_2 emissions from 1.42 million tons per year to 1.29 M tons per year in the last period (Figure 4-10). This is accompanied by a much slower rate of GRP growth (note the drop in the fifth period (Figure 4-11)). In response to stricter regulations, pollution abatement equipment is purchased, diverting some available capital from other industries. Attempts by the electric utility to increase its rates were limited by

government regulation. As a result, we see lower electric rates (Table 4-12). The utility has also cut down its energy generated from coal-fired plants, which is the major source of SO_2 emitted. The push for cleaner air prompts the electric utility to expand its nuclear generation, which is more economical (Figure 4-13).

The third policy option involves a moderate SO_2 standard plus encouragement of electricity conservation. Under this option we see an even smaller level of SO_2 emissions primarily due to demand conservation, (Figure 4-14), and a slightly higher GRP growth pattern than that of the first policy option. More coal is used in this case than under the second option (Figure 4-11). The utility reduces its nuclear expansion program because of a lower electric demand. The electric rates are even lower than those under the second policy option. However, the GRP is still much lower than that of the first option (where no environmental concern is reflected).

The results illustrate the tradeoffs between a high economic standard of living and environmental quality. They also demonstrate that severe constraints on SO_2 emissions by the electric utilities could seriously hamper increases in future use of coal for power generation in the region.

Figure 4-10
Electric Utility Emission of SO_2

Figure 4-11
Gross Regional Product

Electric Utility Coal Consumption
Figure 4-12

Electric Utility Nuclear Consumption
Figure 4-13

Electric Utility Refined Oil Consumption
Figure 4-14

Energy Price Changes (%)
Table 4-15

Policy Options	Coal	Crude	Ref-Oil	Elec.	Gas
I	1.6	6.4	5.4	9.6	4.75
II.	-2.1	3.57	2.0	7.3	2.6
III.	-2.1	3.57	2.0	5.0	2.6

PART 5
DESIGN CONSIDERATION
FOR
FULL SCALE IMPLEMENTATION

I. Future Computing Requirements

Introduction

No matter what kind of computational structure underpins an energy game, it is certain that to be rich enough to be at all useful or instructive, the implementation of the game will require substantial computer programs and some of the best computer communications technology that is currently available. In this section methods that might be used to extend the present game, both in its power and availability, are explored. It will be argued that a "distributed" game, that is a game distributed over a network of computers, will prove the only effective method for large-scale (national) implementation.

The present situation.

The game which has been described is implemented in APL on an IBM 370/168 computer. It currently has provisions for up to ten players, but it is not clear whether the game or the system could efficiently accommodate all ten simultaneously. Each player requires almost the largest standard allocation for an APL workspace, namely 124K bytes in the paged system. Although the present programs amply demonstrate the potential of Energy Gaming, the designers would clearly like to increase its power. It is reasonable to assume that, with tighter coding and expanded workspaces, the present set of programs could be expanded by a factor of two or three, but thereafter the whole system will have to be rewritten and redesigned for a different computing environment.

In order to understand how the system might be redesigned, it will help to review the important (from a computational standpoint) components of the game. Each player is an interactive user of the system. He has, from time to time, to make

decisions which influence the future course of the game. At his disposal are a number of models which may be of predictive value; he also has access to a large and heterogeneous quantity of data describing the current state of the game. There is one distinguished player, the "game director", who is responsible for collecting the responses of the other players, checking for their legality, and advancing the game by using some predetermined models and data. The director need not be an interactive user for his function is defined at the start of the game. However, in order to monitor the course of any game, it should be useful to see what the director is doing and to occasionally alter his actions. In any but the most standard version of the game, the director will appear as an interactive user, just as any other player.

Any number of different kinds of models could be employed, either by a player or by the game itself: linear programs, simulations, pattern matching, user (or player) defined programs. The present version of the game is largely based on a linear input-output economic model. Each such model must be as simple to use as possible and should include a description both of what it does and of how it may be used. At present, the models are all implemented as APL functions.

Both users and models require access to data. Even the simplest scenarios require large amounts of data in order to make them interesting. Moreover, there is not likely to be any very uniform structure on this data. In APL, data is normally held in the user's workspace, i.e. in core. It is unlikely that this situation can be maintained much longer. Even in the present system, it will soon be necessary to keep some data in slow on-line storage, even if this does cause a serious degradation in performance.

The Communication Problem

In order that a player can make decisions which influence the course of the game, and in order that he can receive information about the current state of the game, he must be in communication with the director. There are various possibilities for achieving this communication. First, the game could consist of one monolithic program with several terminals attached. The problem with this solution is that few operating systems are designed to make this an easy thing to implement, and some do not even allow such a configuration. Apart from this, there are dangers with running the game as one program: one is that the size of the game is limited by the size of the computer, another is that modularity is difficult to maintain. In a system as complicated as the present game, it is essential to decompose it as far as possible, into relatively simple components, each with a well defined function. What is required is a computing environment which encourages such modularity, rather than forcing one to sacrifice it for the sake of efficiency.

The second solution is that which has been adopted for the present model. APL, as currently implemented on the IBM 370/168, allows the use of shared variables. One APL job may share with another an APL data structure; this sharing is done through virtual memory; there is no user-defined input/output. APL has an elaborate protocol for setting up such variables, by means of which the read and write privileges are established.

The use of shared variables has proved an excellent method for developing the present game; it has allowed all those features which are fundamental to a successful interactive game to be programmed with great simplicity. However, for the following reasons, this method does not lend itself to an extended game:

1. The shared variable procedures are at the moment limited to use by APL programs and by the 370

operating system (they can also be used for conventional i/o). They are not available in other languages, interactive or otherwise, supported on this system. Therefore, there is no possibility of communicating with programs written in other languages, unless there is a special program to set up a mechanism by which APL could call FORTRAN subroutines.

2. Communication between different machines using shared variables is not possible. The size of a game is therefore limited to the size of the largest machine supporting APL.
3. The way in which APL shared variables are set up does not allow a queue of messages to build up between jobs. The reason that this is desirable is to allow for the desynchronisation of the various players and the monitor. For example, in the present system, the director can get "hung up" waiting for the responses from all players unless he chooses to override the monitor. It is quite possible that the director could do some useful work while the players are making decisions. It is also likely that a player may want to run some model which requires some length of time to do its work; the player should be able to explore some other ideas while the model is running.

It is possible that APL will be improved so that some of these restrictions are relaxed; but it is unlikely that this will allow the whole of the game development to continue in APL. Nor should this be expected; there are at present many valuable models which have been developed in other languages and on other systems which one may wish to incorporate, as easily as possible, into the game. The third method, which is now suggested, is to use disk files as a method of communication among users and programs.

Communicating through files

The techniques of file communication are not quite straight-

forward: as with APL shared variables there must be some sort of protocol for establishing communication. This being done, the form of communication should be as follows. Suppose A and B are two jobs (by this is meant active or potentially active programs); each job owns a file to which it, and only it, is privileged to write but which can be read by other jobs. Into A's file goes some control information and the sequence of messages which A wishes to send to B. B's file is symmetrically organised. Either on the occurrence of a direct signal from A, or by occasionally inspecting A's file, B can determine whether or not he has any messages from A. New messages from A to B are appended to the end of A's file.

Before such a method of communication can be implemented careful decisions should be made about the form of the messages that are to be transmitted. It is well to have this form standardised so that the programs which do the file communication can be as general as possible. They will, of course, be subject to the usual incompatibilities, especially in i/o, that beset the implementation of the same language on different systems and therefore there will be extra programming effort involved. However, a uniform and simple design of the message format should go a long way towards lightening this task.

Whether or not all the messages that A sends to B remain in A's file is a matter of choice. If A wished to delete some of these messages, he should only do so when he knows that B has read them. This information can of course be communicated from B to A through B's file. It may prove preferable, especially for debugging purposes, not to do this, but to leave all the messages which pile up during one session of the game in each communication file. This way the whole course of the game may be reconstructed, and this is more likely to be the case if each message is postmarked with the time of its sending. There may be cases, one will be dealt with below, in which communication

files can get unmanageably long, in which case the former solution should be adopted.

For ease of debugging, it will also be an advantage to design the messages in a way that allows their easy interpretation by programmers and perhaps even users of the game. Since this rules out relocatable machine code, each job will need an interpreter for these messages, i.e. something which will turn a message into some executable instructions. Within these constraints there is still a wide choice for possible "languages" for communication. One which naturally offers itself is the language of subroutine calling as it is used, say, in ALGOL or FORTRAN.

Would this approach mean that huge overheads are incurred for the i/o used in file communication? If the amount of i/o is comparable with the amount of text that appears at users' terminals then the answer is that this form of communication should not seriously degrade response times or increase cost. The one situation, that of a model accessing large amounts of data through file communication, will be dealt with below.

A Distributed Game

It is now argued that file communication makes it relatively easy to distribute a game across a network of computers and that this frees the game from all those restrictions listed earlier. There are already several networks that would be satisfactory: the ARPA net being the most obvious and available for use in academic and research organisations in the USA. The minimum necessary form of communication is the ability of one computer installation to read files which are physically located at another installation. It should be emphasized that the extra cost of this method lies only in the increased i/o and the cost of using the network, which should in both cases be marginal. The

advantages it confers are partly listed below:

1. The total size of the game is limited by the capacity of the network. In the case of the ARPA net there is no practical limit.
2. Different components of the game may be programmed in the language most suitable for their implementation. The interactive components, i.e. those programs which are reasonable for communication with the players could continue to be written in APL while models which involve heavy arithmetical computation could be programmed in ALGOL or FORTRAN. The only thing that would have to be standard in each component would be the format of the input and output.
3. Modularity would be encouraged by such a system; it would not have to be sacrificed for efficiency of for size restrictions.
4. It is in many cases better for a player to be physically close to the computer with which he is directly communicating. Obvious advantages are reliability of lines and proximity to line-printers. Another advantage is that many managers are familiar with the local operating system. It will be much easier for them to use a game through that system rather than through a distant machine of which they have little first-hand knowledge.
5. There are already some extensive energy-related models which are in current use. Some of these require constant updating and are also in a state of constant development. It is best that these

models remain in the hands of their designers and that no attempt be made to transport them to another system. With the method proposed, it will simply be necessary to link to that model and describe the data on which it is to be run.

6. The game may comprise many more components than it is possible, or desirable to run simultaneously. It would be a straightforward matter to bring in the data or programs as they are required during the progress of a particular game.

There is one necessary caution with this sort of communication. If a player requires access to some data, the amount of i/o is going to be roughly proportional to the amount that appears at his terminal; and this is, or should be limited. If however, a program defined by the player, or some other model requires access to data there is no such bound. The system described therefore requires careful consideration of the relative location of data files and the models that are to access them. In the case of a model requiring frequent access to a very large file, it would be best to keep both at the same installation. If necessary, copies of the data file should be kept near the programs that wish to examine them.

A method has been suggested that would remove all the present restrictions from the computational development of an Energy Game. The only obstacle to developing along these lines is that the form of messages used in communications has not yet been defined and this should be done as soon as possible. There is enough expertise among the implementers of the present game to say what is required, but thought should be given to possible

extensions of the game that might be required in the future. It is of course essential that whoever continues development of this game should be intimately acquainted with the design of computer networks. It is also essential that anyone whose programming efforts may ultimately be incorporated into the game should be informed of its nature.

II. Design Requirements for Policy Analysis

There are several important considerations in the design of large-scale computerized games. Perhaps the most important is the interface between policy makers and computers. Policy makers are not normally comfortable with computers and models. Hence there is a need for a decision input mechanism that is computer language independent, simple, and efficient. The policy-strategy-action hierarchy defined earlier is particularly helpful. Computer output from models should be relevant and simple to understand. In this respect we find that tailoring the output to the individual policy maker is useful. In addition to the above design considerations, information retrieval procedures should be hierarchically organized and responsive to the level of aggregation desired by the policy makers. Questions concerning what information should be made available to each player must also be addressed in the initial game design. At the end of a game step, it is also important to record the results. They should include a complete description of the decision environment, player actions, and game results. This complete record would be useful for post-game analysis.

A national game should be designed from the analysis of different energy policy problems. Policy makers would be chosen on the basis of whether or not their actions or decisions have significant impact on the future of the national energy picture. The levels of aggregation of a subsystem, however, are dependent on a particular policy issue. For instance, in the study of the deregulation of natural gas, one should not treat the gas industry as a single policy maker, since interactions among gas industry drillers, pipeline distributors, wholesalers and retailers are also important and must be represented by several players.

In the natural gas problem, only a handful of states produce the majority of gas requirements of all other states. Hence, there is a need for regional decision makers in a

national game. The set of energy policy makers can be grouped into three categories: (i) industry (which produce goods and services), (ii) public interest groups (which are made of citizens representing a special interest, e.g. environmentalists), and (iii) government (which has regulatory and conflict resolution functions). We may include regional policy makers in each category. For example, we may include both a national regulatory agency (e.g. Nuclear Regulatory Commission), a regional regulatory agency (e.g. Delaware Valley River Basin Commission), or local industry (e.g. Philadelphia Electric Company).

Another key consideration is the design of models used in a large-scale national game. We do not find it desirable to design new models from the start for individual subsystems. Many sectoral models are already in existence. For instance, we have models for refined petroleum [1] production, for the capacity expansion of electric utilities [2] , gas models [37] , nuclear fuel cycle models [56] , coal models [52] , and crude oil models [14] . Similarly, we have models for non-energy industries [41] , [30] . And finally we have environmental models as well [21] , [45] , [42] . We find recent development of social indicator models potentially useful in social modeling [31] [57] . However, for a truly national game, these models must include regional considerations.

There remains the task of interfacing these subsystems models for a faithful representation of the overall system (i.e. the design of F in (1) [28]). The interfacing requirement between sectoral models would be less severe than interfacing two global models of the overall system, which would require enforcing consistency on overlapping variables.

The design of computerized energy models could profitably avoid collection of large volumes of survey data, and

use the existing data collection mechanism. To use gaming for policy analysis, the data base must be updated periodically. Hence a formalized data processing procedure must be included as a part of the initial design. At present there is no need to collect extra data for a large-scale energy game. However, a new data structure and organization design for a national energy game would differ from that used in REEG, because of its size and complexity.

Existing computer hardware is sufficient for the implementation of large-scale energy games. On the other hand, a different design for a communication network (than that used in REEG) would be needed. In a fully computerized game, communication links should be established among policy makers and the game operating system. Using the computer, policy makers should be able to record decisions, retrieve information about current and previous states of the system, communicate with each other, and test policies with their own models. In REEG, this was accomplished through use of APL (A Programming Language) shared variable features. For the national energy game we propose a disk file communication approach to distribute the game across a network of computers, such as the well-known ARPA network. This would solve problems of handling large data files, interfacing models written in different computer languages and restrictions on players' decision analysis capabilities. With this new approach, the extra cost in the increased input-output and in using such a network would be marginal.

PART 6
APPENDICES

Appendix A

Target Region Summary

The target region chosen for the Regional Energy Environment Game is an area serviced principally by a single, large Eastern power pool - the Pennsylvania-Jersey-Maryland interconnection. A primary reason for this choice is that the Decision Scenario adopted (Electric Capacity Shortage) would primarily affect this region similarly throughout. The region includes the District of Columbia, and the states of Delaware, Maryland, New Jersey, and Pennsylvania. Covering 64,421 square miles with a 1970 population of 24,189,000 the region supports diverse heavy and light industry, petroleum refineries, coal mines, agriculture, and tourism. Steel making facilities, generation stations, refineries and chemical processing contribute significantly to the generally poor air quality within the area. Other major problems arise from numerous surface and deep coal mines, petroleum port facilities, and industrial effluent discharges. Future problems can be expected from deep water ports and off-shore oil wells in the Atlantic bordering this region.

State Descriptions

Delaware

Delaware, the smallest state within the region, is 96 miles long and from 9 to 35 miles wide. The land slopes from rolling hills in the north to a near sea-level plain.

Second smallest of all states in the area, Delaware has a high per capita income (\$5,530 in 1973), with large chemical and other industries, prosperous farms and important shellfish production.

Important in Delaware's total of value added by manufacture are canned and frozen foods, leather and metal products, textiles and machinery. Total value added by manufacture is over \$1.28 billion. Broiler chickens are the largest item of farm income. Farm receipts for 1973 were \$245 million. Mineral production is mainly sand, gravel, and stone used for construction. Total value in 1973 was

estimated as \$3 million. There is also a sizable fishing catch valued at over \$1.9 million. Delaware's major tourist attractions include several famed beaches, race-tracks, and historic sites. Annual value of tourism is about \$300 million.

Maryland

Maryland stretches from the Atlantic Ocean to the Allegheny Mountains with two major interruptions - the Chesapeake Bay and the District of Columbia. Both contribute importantly to the state's economy.

The bay cuts off the low coastal plain of the Eastern Shore from the rest of the state, provides both commercial and sport fishing, and leads to the port of Baltimore, which handles some \$3 billion in imports and exports a year.

Maryland has a diversified economy. Leading industries in number of workers are wholesale and retail trade, 326,000; government, 324,100; services, 254,100; and manufacturing, 250,400. Value added by manufacturing totals over \$4.28 billion annually. Important manufacturing industries are food products, primary metals, electrical equipment, printing and publishing, apparel, and machinery. Per capita income was \$5,331 in 1973.

Almost half of the land area is covered with forests. About 40% of timber cut is softwood. Stone and cement are leading mineral products; there is some coal mining. Mineral output was valued at \$122 million in 1973. Seafood is an important industry. In a typical year, the fish and shellfish catch has a value of about \$20 million. Maryland is a leader in production of striped bass, oysters, and soft-shelled crabs. Much of Maryland's farms are fertile though not extensive. The state's largest cash crops are tobacco, corn, soybeans, apples, and tomatoes.

New Jersey

New Jersey has the heaviest population per square mile of any state, ranks near the top in manufacturing, is rich in poultry and vegetable production, and has a flourishing tourist trade.

There are vast shipping facilities, and New Jersey divides authority over important airports, harbors, tunnels and bridges with New York, Pennsylvania, and Delaware.

About 63% of the state's land is in farms and forests, small in area. New Jersey has a heavy concentration of factories, highways, railroads, and farms. Per capita income was \$5,759 in 1973, second highest in the U.S. next to Connecticut. Highly industrialized, New Jersey ranks 7th among the states in value added by manufacture, over \$14 billion annually. It ranks first among the states in chemical products, having large pharmaceutical, basic chemical, and paint industries. It is also a leader in manufacturing: apparel, food processing, electrical and other machinery, stone-clay-glass products, printing, rubber and plastics, petroleum products and leather products. It has a large concentration of research installations in many lines.

New Jersey also ranks high in the U.S. in gross income per farm acre. Chief crops are tomatoes, corn, asparagus, apples, cranberries, peaches, and spinach. Total farm receipts in 1973 were \$297 million, more than half from crops.

Mineral production is mostly stone, sand, and gravel mainly for construction work. Zinc, peat, and clays were among other products. Total value was \$110 million. Large refineries, which process oil from out of state, have a crude capacity of more than 500,000 barrels a day.

Atlantic City, Ocean City, Cape May, Asbury Park, Ocean Grove, and Wildwood are among more than 100 resorts. The resort industry generates over \$2.6 million in business annually.

Pennsylvania

Pennsylvania has extensive mineral resources, fertile farmlands, and is a leader in manufacturing.

Roughly rectangular in shape, Pennsylvania has prosperous farmlands in the southeast and west. Through the center, running NE to SW, are parallel mountain ridges with valleys between.

Many of the nation's largest steel plants are in Pennsylvania, with the greatest accumulation in the Pittsburgh area. Pennsylvania ranks first among the

states in steel wire and structural metal. Mill and factory products are many and varied; value added by manufacture is over \$23.2 million. Primary metals are the most important, over \$3.6 billion. Other large lines are machinery and electrical machinery, food processing, chemicals, metal products, transportation equipment, women's dresses and men's suits.

Per capita income was \$4,984 in 1973.

Pennsylvania produces almost all of the nation's anthracite coal; it ranked third in 1973 in output of bituminous coal. Also important are cement, stone, petroleum, natural gas, lime, clays, zinc, and iron. Total mineral production in 1973 was \$1.3 billion.

Prosperous farms brought in total livestock and crop receipts for the state of \$1.3 billion in 1973, much of it from dairy and poultry products. Forest products are valued at over \$3.1 billion annually.

Pennsylvania is among the leaders in hunting, fishing, golf and winter sports. Tourism, it was estimated, produces direct sales of \$5.4 billion annually.

General Statistics

I. Population, Area, Density

	Population (1970)	Area	Population/mi ²
Delaware	3.922 x 10 ⁶	1982 mi ²	276.5
Maryland	.548	9891	396.6
New Jersey	7.168	7521	953.1
Pennsylvania	11.794	44,966	263.2
District of Col.	.757	61	12,401.8
Total	24.189	64,421	375.5 (avg.)

Delaware

New Jersey

II. Principal Cities (1970 population 10^5)

	<u>Population</u>
Baltimore, Md.	906×10^3
Camden, N. J.	103
Elizabeth, N. J.	113
Jersey City, N. J.	261
Newark, N. J.	382
Paterson, N. J.	145
Trenton, N. J.	105
Allentown, Pa.	110
Erie, Pa.	129
Philadelphia, Pa.	1,949
Pittsburgh, Pa.	520
Scranton, Pa.	104
Washington, D. C.	757

III. Average Air Quality: Particulates

Wilmington, Del.	127 $\mu\text{g}/\text{m}^3$
Washington, D. C.	77
Baltimore, Md.	118
Newark, N. J.	74
Philadelphia, Pa.	129
Pittsburgh, Pa.	165

IV. % Population Below Poverty Level (1970)

Delaware	15.7%
Maryland	10.3
New Jersey	7.1
Pennsylvania	10.7
<u>Washington, D. C.</u>	<u>13.6</u>
U. S.	12.3%

V. 1968 Manufacturing Expenditures for New Plants & Equipment

Delaware	\$95 x 10 ⁶
Maryland	240
New Jersey	767
Pennsylvania	1,606
<u>Washington, D.C.</u>	<u>20</u>
U.S. total	\$20,590 x 10 ⁶

DELAWARE (Pop. 571,000)

Salient Fuel Statistics - 1972

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Crude oil (thousand bbl)	Natural gas liquids (thousand bbl)	Natural gas (MMcf)	Uranium (thousand pounds recoverable U ₃ O ₈)
Reserves.....	0	0	0	0	0	0
Production:						
Quantity.....	0	0	0	0	0	0
Value, thousands.....	0	0	0	0	0	0

Average number of active operations - Coal mines: 0   Crude oil wells: 0   Natural gas wells: 0   Uranium mines: 0

Labor force - Total: 271,200   Fuel sector (excluding processing): 0

	Petroleum refineries	Natural gas processing plants	Uranium mills
Processing plants:			
Number.....	1	0	0
Daily capacity.....	140,000 bbl	0 MMcf	0 tons of ore

CONSUMPTION						
	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	^{1/}	Petroleum products (thousand bbl)	Natural gas (MMcf)	Hydropower and nuclear (million kW-hr)
Household-commercial..	0	0		5,462	11,563	0
Industrial.....	0	0		5,903	10,003	0
Transportation.....	0	0		8,321	0	0
Electric power.....	0	0		4,252	2,430	0
Miscellaneous.....	19	0		725	0	0
Total.....	19	0		24,663	23,996	0

Salient Energy Statistics - 1972

ENERGY CONSUMPTION, TRILLION BTU								
	Anthracite	Bituminous coal and lignite	Petroleum products 1/	Natural gas	Hydropower- nuclear	Total gross inputs	Utility electricity distributed	Total net inputs (three sectors)
Household-commercial..	0	0	31.5	11.9	0	43.4	9.0	52.4
Industrial.....	0	0	32.1	10.3	0	42.4	10.7	53.1
Transportation.....	0	0	44.8	0	0	44.8	0	44.8
Electric power.....	0	0	26.7	2.5	0	29.2	...	...
Miscellaneous.....	0.5	0	4.5	0	0	5.0	...	5.0
Total.....	0.5	0	139.6	24.7	0	164.8	19.7	155.3
Percentages.....	0.3	0	84.7	15.0	0	100.0	...	...

	Fossil fuel	Nuclear	Hydropower	Total
Generating plants:				
Number.....	13	0	0	13
Installed capacity (thousand kW).....	999	0	0	999
Production (million kW-hr).....	5,400	0	0	5,400

Total gross energy input: 164.8 trillion Btu
Total gross energy input per capita: 289 million BtuTotal net energy input: 155.3 trillion Btu
Total net energy input per capita: 272 million Btu^{1/} Included in Maryland and District of Columbia.

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MARYLAND & DISTRICT OF COLUMBIA (Pop. 4,800,000) Salient Fuel Statistics - 1972

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Crude oil (thousand bbl)	Natural gas liquids (thousand bbl)	Natural gas (MMcf)	Uranium (thousand pounds recoverable U ₃ O ₈)
Reserves.....	0	1,048,210	0	0	W	0
Production:						
Quantity.....	0	1,640	0	0	244	0
Value, thousands.....	0	8,961	0	0	51	0

Average number of active operations - Coal mines: 55   Crude oil wells: 0   Natural gas wells: 16   Uranium mines: 0

Labor force - Total: 2,968,100   Fuel sector (excluding processing): 476

	Petroleum refineries	Natural gas processing plants	Uranium mills
Processing plants:			
Number.....	2	0	0
Daily capacity.....	25,000 bbl	0 MMcf	0 tons of ore

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Petroleum products (thousand bbl)	Natural gas (MMcf)	Hydropower and nuclear (million kW-hr)
Household-commercial..	0	55	33,259	127,386	0
Industrial.....	0	4,593	10,027	74,575	0
Transportation.....	0	0	58,549	3,601	0
Electric power.....	0	5,705	28,845	7,043	2,284
Miscellaneous.....	75	0	575	0	0
Total.....	75	10,353	131,255	212,605	2,284

Salient Energy Statistics - 1972

	Anthracite	Bituminous coal and lignite 1/	Petroleum products	Natural gas	Hydropower- nuclear	Total gross inputs	Utility electricity distributed	Total net inputs (three sectors)
Household-commercial..	0	1.5	198.2	131.4	0	331.1	71.3	402.4
Industrial.....	0	125.2	61.3	76.9	0	263.4	46.3	309.7
Transportation.....	0	0	314.3	3.7	0	318.0	0.7	318.7
Electric power.....	0	127.4	180.3	7.2	23.7	338.6	...	...
Miscellaneous.....	1.9	0	3.4	0	0	5.3	...	5.3
Total.....	1.9	254.1	757.5	219.2	23.7	1,256.4	118.3	1,036.1
Percentages.....	0.2	20.2	60.3	17.4	1.9	100.0	...	...

	Fossil fuel	Nuclear	Hydropower	Total
Generating plants:				
Number.....	31	0	3	34
Installed capacity (thousand kW)...	7,271	0	497	7,768
Production (million kW-hr).....	27,802	0	2,284	30,086

Total gross energy input: 1,256.4 trillion Btu   Total net energy input: 1,036.1 trillion Btu
Total gross energy input per capita: 262 million Btu   Total net energy input per capita: 216 million Btu

1/ Includes Delaware.

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NEW JERSEY (Pop. 7,349,000)

Salient Fuel Statistics - 1972

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Crude oil (thousand bbl)	Natural gas liquids (thousand bbl)	Natural gas (MMcf)	Uranium (thousand pounds recoverable U ₃ O ₈)
Reserves.....	0	0	0	0	0	0
Production:						
Quantity.....	0	0	0	0	0	0
Value, thousands.....	0	0	0	0	0	0

Average number of active operations - Coal mines: 0   Crude oil wells: 0   Natural gas wells: 0   Uranium mines: 0

Labor force - Total: 3,195,500   Fuel sector (excluding processing): 0

	Petroleum refineries	Natural gas processing plants	Uranium mills
Processing plants:			
Number.....	5	0	0
Daily capacity.....	594,000 bbl	0 MMcf	0 tons of ore

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Petroleum products (thousand bbl)	Natural gas (MMcf)	Hydropower and nuclear (million kW-hr)
Household-commercial..	0	2	76,026	210,038	0
Industrial.....	0	42	21,481	97,106	0
Transportation.....	0	0	101,475	729	4,132
Electric power.....	0	1,107	49,009	25,039	0
Miscellaneous.....	266	0	522	0	0
Total.....	266	1,151	248,513	332,912	4,132

Salient Energy Statistics - 1972

	Anthracite	Bituminous coal and lignite	Petroleum products	Natural gas	Hydropower- nuclear	Total gross inputs	Utility electricity distributed	Total net inputs (three sectors)
Household-commercial..	0	0.1	451.9	216.5	0	668.5	97.6	766.1
Industrial.....	0	1.1	123.9	100.1	0	225.0	63.0	288.1
Transportation.....	0	0	551.4	.8	0	552.2	0	552.2
Electric power.....	0	24.7	306.5	25.8	44.1	399.1	...	...
Miscellaneous.....	6.8	0	3.1	0	0	9.9	...	9.9
Total.....	6.8	25.9	1,434.8	343.2	44.1	1,854.8	160.6	1,616.3
Percentages.....	0.4	1.4	77.3	18.5	2.4	100.0	...	...

	Fossil fuel	Nuclear	Hydropower	Total
Generating plants:				
Number.....	41	1	2	44
Installed capacity (thousand kW)...	9,984	550	341	10,875
Production (million kW-hr).....	30,327	4,356	-224	34,459

Total gross energy input: 1,854.8 trillion Btu
Total gross energy input per capita: 252 million BtuTotal net energy input: 1,616.3 trillion Btu
Total net energy input per capita: 220 million Btu

INT. 8776-76

PENNSYLVANIA (Pop. 11,905,000)

Salient Fuel Statistics - 1972

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Crude oil (thousand bbl)	Natural gas liquids (thousand bbl)	Natural gas (MMcf)	Uranium (thousand pounds recoverable U ₃ O ₈)
Reserves.....	7,120,530	23,880,010	37,345	735	1,406,948	0
Production:						
Quantity.....	7,106	75,939	3,441	W	73,958	0
Value, thousands.....	85,251	694,267	16,414	W	22,389	0

Average number of active operations - Coal mines: 1,139   Crude oil wells: 32,596   Natural gas wells: 16,600   Uranium mines: 0

Labor force - Total: 5,117,100   Fuel sector (excluding processing): 26,736

	Petroleum refineries	Natural gas processing plants	Uranium mills
Processing plants:			
Number.....	11	2	0
Daily capacity.....	648,620 bbl	5 MMcf	0 tons of ore

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Petroleum products (thousand bbl)	Natural gas (MMcf)	Hydropower and nuclear (million kW-hr)
Household-commercial..	0	446	75,233	418,606	0
Industrial.....	0	28,592	24,589	395,951	0
Transportation.....	0	0	144,520	27,555	0
Electric power.....	0	35,053	27,204	5,474	1,822
Miscellaneous.....	4,322	0	1,385	0	0
Total.....	4,322	64,091	272,931	847,586	1,822

Salient Energy Statistics - 1972

	Anthracite	Bituminous coal and lignite	Petroleum products	Natural gas	Hydropower- nuclear	Total gross inputs	Utility electricity distributed	Total net inputs (three sectors)
Household-commercial..	0	12.2	445.5	431.6	0	889.3	154.4	1,043.7
Industrial.....	0	779.6	146.2	408.2	0	1,334.0	160.3	1,494.3
Transportation.....	0	0	774.4	28.4	0	802.8	3.3	806.1
Electric power.....	0	783.0	167.7	5.7	19.0	975.4	...	...
Miscellaneous.....	109.8	0	8.5	0	0	118.3	...	118.3
Total.....	109.8	1,574.8	1,542.3	873.9	19.0	4,119.8	318.0	3,462.4
Percentages.....	2.7	38.2	37.4	21.2	0.5	100.0	...	...

	Fossil fuel	Nuclear	Hydropower	Total
Generating plants:				
Number.....	101	3	9	113
Installed capacity (thousand kW)...	20,967	156	1,652	22,775
Production (million kW-hr).....	96,034	289	1,533	97,856

Total gross energy input: 4,119.8 trillion Btu
Total gross energy input per capita: 346 million Btu

Total net energy input: 3,462.4 trillion Btu
Total net energy input per capita: 291 million Btu

INT. 5776-76

UNITED STATES SUMMARY (Pop. 208,230,000)

Salient Fuel Statistics - 1972

	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Crude oil (thousand bbl)	Natural gas liquids (thousand bbl)	Natural gas (MMcf)	Uranium (thousand pounds recoverable U ₃ O ₈)
Reserves.....	7,384,460	420,457,450	36,339,408	6,786,559	266,084,846	546,378
Production:						
Quantity.....	7,106	595,386	3,455,368	638,216	22,531,698	25,758
Value, thousands.....	85,251	4,561,983	11,706,510	1,433,074	4,185,869	162,272

Average number of active operations - Coal mines: 5,182   Crude oil wells: 508,443   Natural gas wells: 121,153   Uranium mines: 212

Labor force - Total: 90,271,600   Fuel sector (excluding processing): 400,000

	Petroleum refineries	Natural gas processing plants	Uranium mills
Processing plants:			
Number.....	252	786	18
Daily capacity.....	13,454,471 bbl	73,260 MMcf	30,250 tons of ore

CONSUMPTION					
	Anthracite (thousand tons)	Bituminous coal and lignite (thousand tons)	Petroleum products (thousand bbl)	Natural gas (MMcf)	Hydropower and nuclear (million kW-hr)
Household-commercial..	2,960	11,748	1,168,900	7,412,543	0
Industrial.....	1,371	159,253	1,062,200	10,272,082	3,389
Transportation.....	0	163	3,213,000	766,156	0
Electric power.....	1,584	348,612	503,700	3,978,673	334,508
Miscellaneous.....	0	0	42,500	0	0
Total.....	5,915	519,776	5,990,300	22,429,454	337,897

Salient Energy Statistics - 1972

ENERGY CONSUMPTION, TRILLION BTU							
	Anthracite	Bituminous coal and lignite	Petroleum products	Natural gas	Hydropower- nuclear	Total gross inputs	Total net inputs (three sectors)
Household-commercial..	75.2	312.2	6,667.4	7,642.4	0	14,697.2	18,175.2
Industrial.....	34.8	4,231.8	5,668.0	10,590.5	35.0	20,560.1	23,053.1
Transportation.....	0	4.3	17,263.9	789.9	0	18,058.1	18,075.1
Electric power.....	40.2	7,796.4	3,133.8	4,102.0	3,487.0	18,559.4	...
Miscellaneous.....	0	0	232.6	0	0	232.6	232.6
Total.....	150.2	12,344.7	32,965.7	23,124.8	3,522.0	72,107.4	59,536.0
Percentages.....	0.2	17.1	45.7	32.1	4.9	100.0	...
Generating plants:							
	Fossil fuel	Nuclear	Hydropower	Total			
Number.....	2,401	26	1,176	3,603			
Installed capacity (thousand kW)...	327,740	15,300	56,566	399,606			
Production (million kW-hr).....	1,420,558	54,031	272,734	1,747,323			

Total gross energy input: 72,107.4   trillion Btu
Total gross energy input per capita: 346   million Btu

Total net energy input: 59,536.0   trillion Btu
Total net energy input per capita: 286   million Btu

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Coal fields of the United States. (Adapted from U. S. Geological Survey maps; coal types not distinguished in Alaska.)

Oil and gas fields of the United States

Appendix B

Notes on the Eigenvalue Prioritization Model

A major problem in a modeling approach to decision making is the scaling of judgments. Any method of scaling must stand the test of several criteria. For example, it should reflect accurately the feelings embodied in the judgments; it should allow for a moderate uncertainty in judgments without changing the judgment value on the scale; strong changes in judgment should be reflected in appropriate variations up and down the scale. The results of the model should not change drastically by making small changes in judgment values.

. In performing numerical pairwise comparisons between complex activities, ordinarily one has difficulty in translating feeling and experience to numbers which say exactly how much more one activity impacts on a given objective than another. The business of assigning numbers seems arbitrary, and the numerical approach to prioritization acquires the semblance of artificiality. We use a systematic way of placing the activities in various importance ranks and then assigning numerical values to each rank. With increased experience, the initial scale chosen for the pairwise comparisons can be modified until it acquires greater autonomy and its use might be expanded.

In order to assign numerically meaningful numbers when comparing two activities, one needs thorough understanding of both activities and the extent of the properties they have

relevant to the objective being considered. The model requires that judgments be supplied by questioning experienced people who know the activities and the objectives and their interactions. These judgments indicate the relative importance of one activity over another for each objective.

In constructing a scale of importance, one customarily asks a decision-maker to state (a) which of two activities, in his opinion, is more important, and (b) his perception of this intensity of difference in importance, expressed as a rank number on a given numerical scale. Only direct effects of the activities on the objectives are considered in the judgment process. One method for dealing with indirect effects is to consider input-output type of relations between the activities. We do this elsewhere when considering, for example, the allocation of energy to interdependent industries according to priority.

As a preliminary step towards the construction of an intensity scale of importance for activities, we have broken down the importance ranks as follows:

<u>Intensity of Importance</u>	<u>Definition</u>	<u>Explanation</u>
0	Not comparable.	It is not meaningful to compare the two activities
1	Equal importance.	Two activities contribute equally to the objective.
3	Weak importance of one over another.	There is evidence favoring one activity over another, but it is not conclusive.

5	Essential or strong importance.	Good evidence and logical criteria exist to show that one is more important.
7	Demonstrated importance.	Conclusive evidence as to the importance of one activity over another.
9	Absolute importance.	The evidence in favor of one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments.	When compromise is needed.
Reciprocals of above non-zero numbers	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	See below.
Rationals	Ratios arising from the scale.	In the consistent case (see consistency discussion for these numbers).

To explain the various numbers note that the integers assigned attempt to estimate a scale of values $(w_1, \dots, w_n)$ of the activities. Each value a_{ij} assigned in the matrix of pairwise comparison A may be regarded as an estimate of the ratio w_i/w_j taken to the nearest integer after appropriate scaling to make values between the (unknown) underlying scale and the approximation scale appropriately correspond through ratios.

If we assume that the values are estimated precisely, i.e., $a_{ij} = w_i/w_j$, it is then sufficient to require consistency of the judgment matrix to obtain such equality. Consistency means

$a_{ij}a_{jk} = a_{ik}$ from which we have for the main diagonal entries $a_{ii} = 1$ and the reciprocal relations $a_{ji} = 1/a_{ij}$. In general, we do not expect consistency to hold everywhere in the matrix because people's feelings do not conform to an exact formula such as the one just given. However, to improve consistency in the numerical judgments, it is recommended to those who supply the judgments that whatever values a_{ij} they may assign in comparing the i th activity with the j th one, they should consider assigning the reciprocal value to a_{ji} thus putting $a_{ji} = \frac{1}{a_{ij}}$. It follows that $a_{ii} = 1$. Roughly speaking, if one activity is judged to be α times stronger than another, then the latter is only $1/\alpha$ times as strong as the former. It can be easily seen that when we have consistency, the matrix has unit rank and it is sufficient to know one row of the matrix to construct the remaining entries. For example, if we know the first row then $a_{ij} = a_{1j}/a_{1i}$ (a rational) assuming, of course, that $a_{1i} \neq 0$ for all i . The use of zero is reserved for the general case to indicate that a pair is not comparable.

We do not insist that judgments be consistent and, hence, they need not be transitive; i.e., if the relative importance of C_1 is greater than that of C_2 and the relative importance of C_2 is greater than that of C_3 , then the relation of importance of C_1 need not be greater than that of C_3 , a common occurrence in human judgments. An interesting illustration is afforded by tournaments regarding inconsistency or lack of transitivity of

preferences. A team C_1 may lose against another team C_2 which has lost to a third team C_3 , yet C_1 may have won against C_3 . Thus, team behavior is inconsistent -- a fact which has to be accepted in the formulation, and nothing can be done about it.

The treatment of the easier and more elegant case of consistency is a special case. The point is that one must develop rational means for making decisions in spite of inconsistency. We shall assume that our judgmental inputs are all provided by a single individual expert or are the collective view of several individuals as the case may be if no single individual knows enough to supply all the judgments by himself. A major difficulty lies in the large number of questions an individual must answer in order to obtain the $\frac{n(n-1)}{2}$ judgments for each objective, where n is the number of activities, and reciprocals are used. There is room for improvement in facilitating the process of supplying these judgments.

With inconsistency we no longer have $a_{ij} \frac{w_j}{w_i} = 1, i, j = 1, \dots, n$. We seek a condition on each row of the matrix. We note that with consistency $\sum_{j=1}^n a_{ij} w_j / w_i = n, i = 1, \dots, n$, where the right side is the same constant n , the largest eigenvalue of A , whose other eigenvalues are all zero since the rank of A is unity and the sum of the eigenvalues is equal to the trace $\sum a_{ii} = n$.

It is possible to argue for the general case that the desired scale $w = (w_1, \dots, w_n)$ must satisfy the eigenvalue problem $Aw = \lambda_{\max} w$ where $\lambda_{\max}$ is the largest eigenvalue of A , which by

Perron Frobenius' theory, turns out to have an essentially unique non-negative solution w if A is non-negative and irreducible.

To see how one arrives at this eigenvalue formulation for the general problem, note first that in the consistent case if we take a typical row $a_{i1}, a_{i2}, \dots, a_{in}$ and multiply a_{i1} by w_1, a_{i2} by $w_2, \dots, a_{in}$ by w_n we would obtain $w_i, \dots, w_i$. In this case all these values are exact and therefore when we perform the operation Aw we obtain the vector nw and hence, as just stated, we solve the problem $Aw = nw$ to obtain the vector w which we normalize by dividing each of its entries by $\sum_{i=1}^n w_i$ to obtain the desired scale.

In the general case the process of multiplying the i th row as above does not yield exact values $w_1, \dots, w_i$ but deviations about them which amount to perturbations of the exact values. It is known in matrix theory that the eigenvalues of a matrix are continuous functions of the coefficients. If we perturb the coefficients of a consistent matrix, the largest eigenvalue would remain near n and the remaining ones near zero. Thus, our problem becomes: find w which satisfies $Aw = \lambda_{\max} w$ and the results would be the more valid the closer $\lambda_{\max}$ is to n as indicated in an index of consistency. It is for this reason that use of the relation $a_{ji} = 1/a_{ij}$ should be encouraged to improve consistency. The deviation of $\lambda_{\max}$ from n could be used as a measure of the consistency and hence usefulness (in some sense) of the results.

It is worth noting that we have a ratio scale (invariant under positive similarity transformations) as it easily follows from the fact that the scale is derived from the solution to the (linear) eigenvalue problem.

Once ratio judgments are elicited from the subjects to form one row or column, the use of paired comparisons can make further contributions to locating the stimuli by possibly enhancing stability where the data are nearly but not quite perfectly consistent. More importantly, requiring each subject to rate each pair of stimuli separately permits tests of dimensionality to be undertaken.

Our use of metric information in the matrix of subjects' judgments generates strong parallels with principal component analysis, except that the data give dominance rather than similarity information. W.H. Ferris has studied the power capabilities of nation states by using principal component analysis. In such analysis the nature of the stimuli and the task presented to subjects are also similar to the "psychophysical" scaling school, as typified by S.S. Stevens and recently used widely in many attempts to construct composite measures of political variables including "national power." Stevens' technique imposes consistency by asking the subjects to simultaneously compare each stimulus with all others. This means that the hypothesis of unidimensionality cannot be tested directly.

Thus, the formal problem of constructing a scale as the normalized eigenvector w in the equation $Aw = \lambda w$, for λ a maximum, is

similar to the extraction of the first principal component. When subjects are asked to fill in the cells of only one row or one column and the other cells are computed from these (to insure "perfect consistency"), the first eigenvalue, n , represents 100% of the variance in the matrix. If, however, "perfect consistency" applies to the data except that a normally distributed random component is added to each cell of the matrix, then one's theory of data would lead to principal factor analysis, and a "single-factor" solution would result. Thus, the imposition of perfect consistency by the experimenter produces an uninteresting result of exact scalability, which was assured by the experimental design of single-comparisons. In fact, one can see that if the subjects fill out only one row or column of the matrix and if the subjects' task is to generate ratios between pairs of stimuli, then the procedure is formally equivalent to having the subjects locate each stimulus along a continuum with a natural zero at one end: this is the "direct-intensity" technique of psycho-physical scaling.

We have not argued so far, as people do in principal component analysis, that the remaining eigenvalues and eigenvectors would serve some purpose.

To summarize: The process begins with a listing of the activities against themselves in a matrix. An objective is chosen and numerical values are supplied from the amount of evidence available that an activity is more important than another, thus filling

out the matrix. The process is repeated for each objective, resulting in several matrices. The objectives themselves are expressed pairwise in the same way with respect to a general overriding objective such as economic and social development. The theory is then applied.

The vector associated with each judgment matrix is known to be the unique solution vector w , of the eigenvalue problem $Aw = \lambda_{\max} w$ where A is the judgment matrix and $\lambda_{\max}$ is its largest eigenvalue. This solution w for each judgment matrix A gives (after dividing by the sum of its entries) the priority weights representing the impact of the nations being compared on one of the objectives. After doing this for each objective and then in a separate matrix comparing the objectives, e.g., human resources, wealth, etc. with respect to world influence, we weigh each priority vector of the nations with the corresponding priority of its objective and add the resulting weight vectors of objectives to obtain the overall priority measure.

Our method has several significant virtues:

1. It is natural; that is, it provides a fairly direct translation from the knowledge of qualified observers (used to determine A) to the derivation of priorities.
2. It is easy to compute with, and in various test applications, has yielded results which agree nicely with observed data.
3. It satisfies various technical restrictions; e.g., a small change in the a_{ij} 's produces a small change in the answer.

Appendix C

Excerpts from "Federal Energy Regulation: An Organizational Study"

Federal Power Commission (FPC)

The Federal Power Commission has regulatory responsibilities with regard to electric power and natural gas sold in interstate commerce.

With respect to natural gas, the FPC does the following: issues permits for the construction and operation of interstate gas pipelines and storage facilities used in conjunction with such pipelines; prescribes accounting systems and reporting procedures for interstate natural gas companies; passes upon proposals for allocation of limited supplies of natural gas; directs interstate pipeline companies to sell gas to local distributors; regulates the price of gas bought and sold in interstate commerce; authorizes the abandonment of facilities and discontinuance of service where gas is bought and sold in interstate commerce; assures nondiscriminatory transportation and purchase of gas in submerged lands of the Outer Continental Shelf; authorizes import and export of natural gas; and issues permits for maintaining facilities at international borders for import and export.

With regard to electric power, the FPC does the following: regulates the rates and services of public utilities selling electricity in interstate commerce at wholesale (but does not regulate retail power rates); prescribes accounting systems and reporting procedures for interstate electric power companies; issues and administers permits and licenses for construction and operation of non-Federal hydroelectric projects on waters or lands subject to Federal jurisdiction; in emergencies, directs the interconnection of electric power systems, regulates certain insurances and sales of securities by electric public utilities and the merger or consolidation of such utilities; regulates the holding of interlocking positions between electric public utility companies and between public utilities and electric supply companies or companies authorized to underwrite securities; authorizes the exportation of

electricity to a foreign country; and issues permits for maintaining facilities at international borders for transmission of electric energy between the United States and a foreign country.

Nuclear Regulatory Commission (NRC)

The NRC sets standards, issues licenses, and enforces regulations pertaining to the construction and operation of facilities which produce and use fissionable materials. These include nuclear power plants, uranium milling facilities, uranium enrichment facilities, fuel fabrication plants, fuel reprocessing plants, plutonium production facilities and radioactive waste treatment facilities. The NRC also regulates transportation and storage of fissionable materials and radioactive waste.

In carrying out these regulatory functions, the NRC promulgates and enforces regulations pertaining to siting, thermal and radioactive emissions, and public and worker health and safety. The Commission also establishes and enforces industrial security and safeguards regulations. The purpose of these is to prevent sabotage and to reduce the potential for theft of materials which might be used in the assembly of nuclear explosives. The NRC in all its activities has a general responsibility to consider antitrust factors; and in regard to nuclear power plants there is a specific program to examine such factors before a construction permit is granted. The NRC has a further responsibility to determine that licensees hold maximum available liability coverage and are in a position to bear the costs of construction and operation of a proposed facility.

Energy Research and Development Administration (ERDA)

ERDA's responsibility is to coordinate and direct Federal activity related to research and development on the various sources of energy. ERDA carries out other functions including, but not limited to, basic nuclear research. The goal of ERDA is to develop and increase the efficiency and reliability of use of all energy sources to meet the needs of present and future generations, to increase the productivity of the national economy and strengthen its position with regard to international trade, and to make the nation self-sufficient in energy.

Federal Energy Administration (FEA)

FEA has the following responsibilities:

ECONOMIC AND DATA ANALYSIS

Collect, evaluate, compile, analyze and publish data on energy requirements, production, and resources.

Analyze economic impact of energy resources and energy programs.

POLICY PLANNING AND REGULATION

Develop policy and program alternatives.

Develop and promulgate energy allocation regulations.

Develop, promulgate and administer energy resource pricing regulations.

Evaluate agency policy and program.

OPERATIONS AND COMPLIANCE

Implement and administer energy allocation programs.

Maintain relations with state and local governments, industry and the public with respect to energy allocation.

ENERGY CONSERVATION AND ENVIRONMENT

Develop and administer energy conservation programs.

Conduct and support energy conservation studies.

Coordinate and evaluate Federal agencies' energy conservation programs.

Review and evaluate the impact of energy activities on the environment and of environmental programs on energy supply and demand.

ENERGY RESOURCE DEVELOPMENT

Identify and develop means for overcoming constraints that hold up building and operation of energy facilities such as construction, regulatory activities, and materials and labor shortages.

Develop incentives for increasing domestic energy production.

Coordinate FEA's energy resource strategy with the Energy Research and Development Administration (ERDA).

INTERNATIONAL POLICY AND PROGRAMS

Maintain current understanding of the international and national security aspects of energy resource management.

Develop and monitor international energy resource management programs.

Coordinate with other government agencies with respect to international energy resource policy.

Corps of Engineers (C/E)

The corps of Engineers promulgates regulations, issues permits and engages in enforcement activities with regard to:

Construction of structures, including wharves, piers, jetties, aerial transmission lines, pipelines and oil drilling structures in or affecting navigable waters of the United States and ocean waters.

The withdrawal of water from or discharge of water into navigable waters when such withdrawal or discharge will affect the course, location, condition, or capacity of the affected navigable waters.

The discharge of dredged or fill material into navigable waters and ocean waters.

The Corps of Engineers' jurisdiction covers construction of artificial islands on the Outer Continental Shelf. The intake and outfall structures which collect and discharge waters used for power plant cooling require C/E permits. Oil refineries supplied by tanker or barge require Corps permits for dock construction and for dredging.

Environmental Protection Agency (EPA)

The Environmental Protection Agency is the agency with primary responsibility for protecting the public health and welfare from the effects of pollution. Since energy facilities and activities produce air emissions, water effluents and other production residuals, nearly all such facilities and activities are subject to regulation under the EPA pollution control authorities. These authorities frequently provide significant implementation and enforcement roles for the states.

The Nation's air pollution control program is carried out under the Clean Air Act of 1970. Under this law, the EPA establishes national ambient air quality standards for air pollutants. The mechanism for achieving these standards is the state implementation plan, which provides for state implementation, maintenance and enforcement of ambient standards established by EPA. To achieve these standards, the states must set and enforce limits on emissions from pollution sources. If a state fails to set such limits, or if EPA determines such limits inadequate to achieve the national ambient standards, EPA is authorized to set the required emission limits for the states.

In addition, EPA establishes uniform, national air pollution control standards for new plants and factories, emission limitations for hazardous air pollutants and motor vehicle emission standards.

The Nation's program to prevent, reduce and eliminate water pollution is carried out under the Federal Water Pollution Control Act of 1972. Under this law, EPA establishes effluent limitations which specify the maximum amount of a pollutant that an entity is permitted to discharge into a water body. Effluent limits may permit some discharge or none, depending on the specific pollutants to be controlled. EPA is currently establishing effluent limitations for various classes of sources.

In addition, EPA issues guidelines and criteria to help the states set ambient water quality standards for specified use objectives. EPA is required to set water quality standards for waters if a state does not do so, or if a state's proposed standards do not meet the Federal requirements. If EPA finds that established effluent limits are not adequate to meet water quality standards, the state must impose more stringent controls on pollution sources.

The 1972 law created a new national system of permits for discharges of pollutants into the Nation's waters; no discharge of any pollutant is allowed without a permit. A permit tells an entity what it may or may not discharge, consistent with effluent limitations and water quality standards. EPA is authorized to issue permits for discharges or a state wishing to operate the permit program within its borders is authorized to do so if its program meets EPA requirements.

The EPA participates with the Corps of Engineers in regulating the disposal of dredged or fill materials in navigable waters and with the Coast Guard in operating a program for the prevention and cleanup of oil discharges.

EPA is involved in the regulation of nuclear power in two respects. First, it has responsibilities in regard to thermal effluents from nuclear power plants. Second, EPA regulates radiation exposure under the authority of the Clean Air Act and the Federal Water Pollution Control Act in situations not covered under the Atomic Energy Act, principally exposures to radioactivity associated with or resulting from uranium mining.

United States Geological Survey (USGS)

The Geological Survey's energy-related responsibilities are concerned primarily with energy activities on public domain, acquired and Indian lands. This encompasses lands administered by the Bureau of Land Management (including lands on the Outer Continental Shelf, and lands managed by the Forest Service). The Survey:

- Defines leasing areas subject to competitive bidding.

- Reviews noncompetitive lease applications and applications for prospecting permits; reports to BLM whether lands applied for should be leased by competitive bidding or whether noncompetitive lease applications or prospecting permits should be issued.

- Supervises conduct of oil and gas and mining operations performed by a private industry under prospecting permits or leases to prevent waste of resources, to prevent pollution, to minimize surface damage, and to assure compliance with all lease terms.

- Determines, before a well is drilled, worked over, or abandoned, whether an oil and gas or geothermal lessee is employing equipment, material and operating practices that conform to orders of the GS supervisor and to standards established by regulations issued by the Secretary of the Interior.

- Grants authorizations to conduct geological and geophysical exploratory operations on the Outer Continental Shelf.

- Recommends to BLM, prior to Outer Continental Shelf lease sales, the areas suitable for lease sale and the tracts most promising for hydrocarbon exploration and production.

Prior to Outer Continental Shelf lease sales, performs a tract-by-tract evaluation to determine fair market value and advises BLM.

Immediately following Outer Continental Shelf lease sales, makes an evaluation and analysis of bids received and recommends to BLM acceptances and rejections of bids.

Prior to Outer Continental Shelf lease sales, participates in the preparation of Environmental Impact Statements and participates in public hearings as advisor on Environmental Impact Statements.

With respect to Outer Continental Shelf operations on existing leases, consults with BLM, NSF, NOAA, SFW, Coast Guard and DOD, as necessary, in preparation of environmental impact analyses or statements.

Grants rights of use and easements for Outer Continental Shelf pipelines where the pipeline is owned and maintained by the lessee.

Provides to NRC expertise and evaluations on the geologic and seismologic aspects of nuclear installation sites.

Prepares environmental analyses on oil and gas exploration, development, and mining plans to determine if an Environmental Impact Statement is necessary.

Bureau of Land Management (BLM)

The Bureau of Land Management issues leases, permits, and licenses pursuant to the Mineral Leasing Act of 1920. Its authority includes implementation of the mineral leasing laws and amendments thereto with respect to minerals management on public domain and acquired lands, including lands under jurisdiction of the Forest Service and Wildlife Refuge lands. Oil and gas, coal, oil shale, native asphalt, solid and semi-solid bitumen, bituminous rock, and geothermal resources come under this authority.

BLM has authority for competitive leasing of oil and gas, sulphur and other minerals in submerged lands of the Outer Continental Shelf. This authority is contained in the Outer Continental Shelf Lands Act of August, 1953.

BLM promulgates regulations as directed by the Secretary of the Interior. It has authority to take action to lease minerals under such regulations.

BLM collects and distributes moneys from rentals and bonuses.

BLM administers the Mining Law of 1872, as amended, for solid (hardrock) minerals - such as uranium and other source materials - on public domain lands. These "hardrock" minerals are leasable when found on acquired lands and are then subject to the Leasing Act for Acquired Lands of 1947, and President's Reorganization Plan No. 3 of 1946.

BLM regulations provide for protection and conservation of nonmineral resources during operations for exploration, development, surface mining, and on-site processing of energy minerals under leases, permits, licenses, or contracts, issued pursuant to the public land laws, including the Mineral Leasing Act and Mineral Leasing Act for Acquired Lands.

The Bureau has responsibility to prepare and review environmental impact statements concerning exploration and development of energy minerals.

Mining Enforcement and Safety Administration (MESA)

MESA is charged with promoting and protecting the health and safety of persons working in the mining industries of the United States. MESA, by delegation from the Secretary of the Interior, sets mine health and safety standards to improve working conditions, equipment and practices, and enforces those standards through mine inspections and other means so that a "miner will be able to work a lifetime in his chosen occupation without fear of injury or occupational disease".

The statutes pertaining to mine health and safety (one covering specifically coal mining and the other dealing with all other mines except where material is extracted in liquid form) also authorize requirements for education and training of miners, certification of certain occupations in coal mines, extensive research to improve worker health and safety, technical assistance in eliminating hazards, and cooperation with state mine safety agencies. Those statutes also direct the assessment of civil and criminal penalties for violation of coal mine standards.

MESA's health and safety regulations are estimated to have caused mine operators to incur some additional production costs, and, therefore, are believed to have had an impact upon the cost of coal, and to a lesser degree on that of

uranium ores. These added costs have varied in amount from mine to mine, and have not been measurable for the industry as a whole.

Interstate Commerce Commission (ICC)

The ICC issues permits for railroads to extend or abandon service; this is significant insofar as such service affects transportation of coal from mines and to power plants. The ICC does not license construction or operation of pipelines.

The ICC considers antitrust and competition in proceedings concerning rates and new routes; it insures that interstate oil (but not gas) pipelines act as common carriers.

The ICC regulates rates for interstate transportation of fuels by railroad and highway. It regulates rates charged by interstate oil pipelines, although rates proposed for such pipelines are not generally contested in rate proceedings.

The ICC establishes rules and regulations to insure an adequate supply of hopper cars for delivery of coal from mines to electric power generating stations.

Appendix D

Summaries of Scenarios

This section summarizes several future scenarios to which the energy environment system might evolve in the course of player interaction. Each scenario is a derived state which is the result of a specific strategy for fulfilling energy demand in 1990. Five possible future scenarios are outlined in this report, each being the evolutionary result of one of the following strategies.

1. Status Quo Extended
2. Nuclear Expansion
3. Extensive Conservation
4. Coal Development
5. Oil & Gas Development

The scenarios are presented in the context of the comparative factors presented in Section III and each scenario concludes with a quantitative summary indicating the values of those factors chosen to describe that scenario. The scenario descriptions do not trace the path from the present situation but only provide the future values of the identified state variables that might occur in such a future.

Future Scenario I - Status Quo 1990

The Status Quo 1990 scenario assumes the continuation of historical rates of growth in the PJM region (Pennsylvania, Maryland, New Jersey, Delaware, and Washington, D.C.) from 1975 to 1990. The resultant status of the energy environment and economic systems is summarized in the accompanying tables. Each of the factors and its derivation will be discussed below. Historical trends tempered with judgment based on present circumstances have been applied throughout.

Overall energy consumption by fuel type and by consuming sector is listed in the first table. These data come from Bureau of Mines projections for the U.S.¹ scaled down to the region. Regional population increases from 26×10^6 people in 1975 (or 12% of U.S. population) to 29.7×10^6 people in 1990, a 0.9% growth rate per year.

The most striking change in the whole scenario is the rapid transition to a largely nuclear electrical power system. These projections are based largely on the FPC 1970 National Power Survey,² which was published before both nuclear and fossil plants met the recent environmental and economic obstacles. The PJM region has traditionally been in the vanguard of nuclear power development, so this outcome is not unexpected. However, while total MW_e of fossil-fueled generation stays approximately the same for the 15 year period (going from 78% to 33% of total generating capacity) nuclear steam increases from 3000 MW_e to 58,000 MW_e (or from 7% to 57% in the period 1975 to 1990). Generation with gas turbines or hydro-power grows slowly, increasing from 3000 to 10,500 MW_e .

This phenomenal growth of nuclear capacity results in an anomalous growth in capital investments by the utilities. Investments are assumed to increase linearly with capacity additions, in constant dollars, so capital grows at 35%/yr from 1975 to 1980, and at 12.6%/yr from 1980 to 1990. Although historically business investment in new plants and equipment has been around an 8% increase per year (on a national average - data from U.S. Statistical Abstracts),³ this figure has been increased to 10%/yr for this high growth period, but still is inadequate to reflect the impact of tremendous nuclear construction in the region.

Notable environmental effects of the transition to nuclear power are problems of air and water quality, preservation of coal and land resources, and significant increase in the consumption of water and generation of nuclear wastes. Air quality deteriorates because of the growth of transportation and industry in the region, since no new stringent controls are assumed for most of this period.

Water consumption goes up because once-through cooling is no longer permitted at power stations. Consequently both fossil and nuclear plants must use cooling towers or ponds. In addition, somewhat more waste heat is emitted to air and water for nuclear plants than for fossil plants. However, stringent water quality standards are already in place, and effluents to regional waters may actually decrease. No relaxation or increase in environmental standards, as indicated by environmental regulatory control level, is incorporated into this scenario.

The listed economic indicators show that the regional economy is expected to be strong (data mostly derived from U.S. Statistical Abstract Trends).⁴ Energy prices (using ¢/MBtu as an index) surge greatly, but the large nuclear capacity keeps electricity price increases relatively moderate. The consumer and wholesale price indices increase at the historical rates of 6% and 4%, respectively; per capita income increases, and unemployment declines.

No additional economic control measures are imposed upon import/export of coal, on importation of oil, or the utilities, or upon the development of nuclear power.

Future Scenario II - Expansion of Nuclear Power - 1990

The essential premise of this scenario, and of all the alternative scenarios except conservation, is that total energy consumption remains the same as in the Status Quo 1990 scenario, but is highly weighted toward consumption of one type of fuel, in this case nuclear powered electric energy. The amount of nuclear electric generation proposed in this scenario is the same magnitude as predictions in the 1970 National Power Survey⁵ and follows closely accelerated case development of the Project Independence Blueprint⁶ nuclear report. The proportion of nuclear MW_e in the PJM system goes from 7% in 1975, to 30% in 1980, to 67.7% in 1990, as opposed to 57% in the 1990 Status Quo scenario (which also revealed strong nuclear growth).

The change in fuel consumption is broken down by major consuming sectors. Consumption of coal from other regions is eliminated in the residential/commercial sector, and cut by half in the industrial and utility sectors. Industry use of local coal is cut by 1/3 while utilities consume the same amount as in the Status Quo (since total MW_e fossil remains the same, though its proportion to the total goes down).

Importation of foreign oil is virtually eliminated except in the transportation sector. Electrification is assumed to take over only a small portion of the transport load (39×10^{12} Btu or 1.4% difference from Status Quo). Consumption of domestic oil stays high in residences and commerce, but decreases 20% in industries and utilities due to fuel switching. Supply of natural gas is expected to remain tight, and so all sectors combined reduce gas consumption by 655×10^{12} Btu (30%) and electrical generation accepts the added load.

Overall electrical consumption goes up 45%, mostly accommodated by new nuclear capacity.

The increase has a positive impact on air quality, but negative on water consumption, and there is a 50% increase in the generation of nuclear wastes to be stored. The air quality index is at 150, above the 100 mark for Reference 1975 because of industrial and transport growth, but less than the 184 index for Status Quo 1990. The

water consumption index goes to 448, 20.75×10^{12} gallons/yr, forty points over the Status Quo because of the poorer heat rate for nuclear plants and the greater need for cooling towers and ponds. Effluent quality improves only marginally since regulations on fossil fuel power plants are already stringent.

Land use rate for coal mining remains the same - the total amount of fossil generation is about 33,000 MW_e in the Reference 1975, Status Quo 1990, and Nuclear 1990.

Environmental controls remain at the Status Quo 1990 level for oil and gas, but change for coal and nuclear under the Nuclear Scenario. A moderate increase in environmental pressure on coal mining partially accounts for the lack of growth in coal-fired generation. On the other hand, all environmental impediments to nuclear development are assumed to have been removed.

The thriving nuclear industry is assumed to have direct and indirect positive effects upon the regional economy. In the 15 year period the gross regional product (GRP) increases 5% over the Status Quo growth prediction because of the nuclear stimulus. Per capita GRP concomitantly increases to \$8420 for the 29.7×10^6 regional population. The unemployment rate decreases marginally (.3%) for the same reasons, relative to the Status Quo Scenario.

However, consumer and wholesale price indices rise slightly above Status Quo levels because of increased demand for consumer goods and because of indirect effects through the capital market burdened by nuclear investment demand.

Energy price indices generally decline. The cost of nuclear electrical generation is less than by any other method, and so the electricity index goes down 20 points (9% or 20¢/MBtu). In order to remain more competitive, and because demand has been lowered, the coal and oil industries must lower their prices somewhat, about 50 points each (11% and 7%, respectively). However, the price of natural gas is assumed to be deregulated because of its declining importance, so its price jumps over 33%.

The burgeoning growth of the nuclear industry requires tremendous construction investments which will greatly strain the local capital market. Even if regional

investments grow at 10% per year from 1975 - 1990 (historically, growth has been 8%/year) the nuclear generation will require an ever increasing proportion of the total. To achieve the predicted capacity, the number of nuclear plants must grow at 35% per year from 1975 to 1980, and at 12.6% from 1980 to 1990, with a corresponding increase in capital investment in constant 1975 dollars. The resultant nuclear investment in comparison to standard projections in capital requirements for all regional industry is absurd. Nuclear capital requirements may equal or exceed amounts that were once thought to be high for investment in the entire region. Obviously, total industrial investment will also grow at unheard of rates, consistent with the input-output structure of the regional economy. Without adjusting the regional growth rate, it appears that nuclear investments will require more than 50% of the available money in Status Quo 1990, but more than 80% in Nuclear 1990. Basically the same relation holds for cumulated investments. Investments in other energy industries are assumed to remain constant.

Economic regulations should change quite a bit under this scenario. Fossil electricity remains at status quo levels, controls over nuclear plants are considerably expedited. Greater controls over oil are assumed because of the Project Independence effort to minimize reliance on foreign supplies, and because of the implied support of nuclear over oil sources. Regional development should encourage the use of Pennsylvania coal over regional imports.

In sum, it is fairly clear where the energy is coming from and who it is going to, but the impact of the Nuclear 1990 scenario upon the region is quite unclear.

Future Scenario III - Extensive Energy Conservation 1990

Energy consumption in this conservation scenario has been reduced from the Status Quo 1990 levels according to the "Technical Fix" scenario written by the Energy Policy Project of the Ford Foundation, published in A Time to Choose.⁷ According to the authors, only those conservation technologies that are presently understood and economically justified were considered. Much of the conservation effort depends not on new technology, but on federal policies that encourage energy savings - tax credits for adding insulation to buildings, higher taxes on gasoline consumption, a high energy price policy in general, and so on.

With these assumptions, residential and commercial sector energy consumption can be cut by 14%, or 560×10^{12} Btu. The energy saving measures include insulation against heat loss, more efficient furnaces, heat pumps and solar heating, especially of water. These savings enable the region to stop burning coal in the home, and to cut back 70% of oil imports and 20% of natural gas consumption for the residential/commercial sector.

Improving auto economy to 20 mpg will substantially reduce transportation energy consumption (680×10^{12} Btu out of 2840×10^{12} beforehand). Additional conservation measures include increasing load factors on airplanes from 54 to 67%, shifting 30% of intercity truck traffic to rail, and shifting 30% of auto traffic to mass transit. These savings add up to nearly 30% of Status Quo projections or 870×10^{12} Btu.

The potential energy savings in industry amounts to 1240×10^{12} Btu. Though this amount is only 13% of the projected consumption, it is nearly as much as the other two sectors combined because industrial energy use is so massive. Use of extraregional coal is cut in half (to 160×10^{12} Btu) and intraregional coal cut by 1/3 (to 620×10^{12} Btu). Foreign oil consumption is eliminated and domestic oil reduced by 20% to 400×10^{12} Btu. Natural gas consumption goes from 866 to 500×10^{12} Btu, and electrical consumption is cut by over 1/3 to 450×10^{12} Btu. Most of the energy savings come from more efficient production processes in the five most energy intensive industries - paper, steel, aluminum, plastics, and

cement manufacture. Additional savings come from heat recuperation, direct use of fuels instead of electricity, and materials recycling.

No savings over the Status Quo have been listed in the utilities column because the saving in primary fuels has already been reflected into the other sectors' savings. Overall electricity production will decline, although it increases in some spots, as in transportation. The mix of electrical generation has been kept the same as in Status Quo 1990.

As expected, there is an across-the-board improvement in environmental indicators. Particulate emissions increase is reduced 60% over the Status Quo, and SO_x emissions go down 10% from the 1975 Reference level. Utility water consumption grows at only 7%/year instead of 9.4%, and so the index decreases by 1/4 from 409 to 316% of the 1975 Reference level. Coal mining land use goes down to 4600 acres/year or 80% of the 1975 Reference. Only 3/4 as much nuclear energy is needed, and only 3/4 as much wastes are generated.

Because of the lowered consumption rates, the Nation will have the breathing space needed to study and more carefully regulate environmental damage. It is hard to assess whether environmental concern should be considered as a cause or an effect in the energy conservation scenario, but in any case all environmental regulatory control levels are expected to approach their maximum. Natural gas control alone stays at Status Quo levels - at present it is the most clean burning fuel, and supply and demand are projected to remain low, even though the gas price may be deregulated.

No large changes in economic indicators are predicted. The gross regional product decreases by $\$7 \times 10^9$ /year because of lower energy consumption, but unemployment remains at 5%. Since the increasing price of energy is used to spur energy conservation strategies, consumer and wholesale price indices go up as well as the fuel prices themselves. Compared to Status Quo 1990, the consumer price index is up 13% to 280, and the wholesale price index is 200, up 10%.

The energy price indices are expressed in $\text{¢}/10^6$ Btu and are listed below for easy comparison:

<u>Fuel</u>	<u>1975</u>	<u>Status Quo</u> <u>1990</u>	<u>1975-1990 SQ</u> <u>% Δ</u>	<u>Conservation</u> <u>1990</u>	<u>SQ $\rightarrow$ Cons.</u> <u>% Δ</u>
Coal	118	471	400%	500	6%
Oil	219	807	370%	870	8%
Gas	68	290	425%	340	17%
Electricity	450	1000	220%	1200	20%

Two competing pressures on energy prices nearly balance off each other.

Federal conservation policy dictates that prices should be raised to curtail consumption. However, other conservation stimuli - primarily changes in technology - lower demand. Consequently, energy companies lower prices in order to sell more and maintain profits.

The Conservation 1990 scenario still requires a high amount of regional capital investment. Technology conversions in industry, re-tooling for smaller autos, and greater capital investment in building structures rather than in energy intensive heating/cooling devices, all contribute to a large need for investments. However, the resultant growth rate is much more in line with the present 8% norm than with the 12% per year growth used in Status Quo 1990. Investments in new plant and equipment reach $\$5 \times 10^9$ /year instead of $\$6.2/10^9$. Cumulated nuclear investment is at 60% of status quo, and though small in comparison, coal investment is at 80% of the reference prediction.

Economic regulatory control is correspondingly close to the Status Quo levels. Only in oil and gas are controls expected to increase, mainly because of the doubtful availability of future supplies of these fuels.

Future Scenario IV - Coal Expansion 1990

In the regional Coal Expansion 1990 scenario, coal-burning increases in much the same proportion as nuclear power expanded in Nuclear 1990, mostly through increased electrical generation. Expansion of coal use is accomplished by fuel switching from oil and gas to coal-fired electrical generation. Figures in parentheses are used to indicate changes from the Status Quo.

Through encouragement of "all electrical" houses, consumption of oil and gas goes down 25% from Status Quo levels, and the 825×10^{12} Btu are added in the electricity requirements (88% increase). Use of foreign oil is also eliminated in the transportation sector by greater electrification and use of mass transit. Electricity for transportation increases by 5000%, reflecting the very low number of Btu's assumed in Status Quo 1990 (11×10^{12} Btu). Industrial use of oil goes down 50%, while natural gas goes down 25%. The energy displaced from oil is assumed to be met half by direct use of coal (150×10^{12} Btu added to intraregional coal) and half by greater electrical consumption (150×10^{12} Btu for oil and 210×10^{12} Btu for gas).

As a result of the greater generation capacity needed, utility consumption of intraregionally supplied coal is increased over 40% (650×10^{12} Btu), which includes 280×10^{12} Btu displaced from oil and gas-fired generators. Total generation capacity increases 30%, from 102,000 MW_e to 131,000 MW_e in PJM. Nuclear and hydro sources stay at the Status Quo levels, while fossil generation expands from 33,000 to 64,000 MW_e, or 48% of Coal 1990 generation.

Environmental indicators predictably decline. Particulate and SO_x emissions rise to nearly 13×10^6 tons/year for the region, a 260% increase for particulates over 1975, and 140% for SO_x. The change from Status Quo 1990 levels is 75 points for particulates and 40 points for SO_x emissions.

Water consumption for coal-fired power plant cooling is nearly as great as for Nuclear 1990, at 25×10^{12} gal/year, it is 360% over the Reference 1975, but 50 points under Nuclear 1990. Since the production of particulates and chemical wastes from mining and coal burning increase by 40%, water pollution increases, and effluent

quality degrades to 140% of 1975 Reference levels. Similarly the coal mining land use rate increases 40% from 5710 acres/year to 9290 acres/year in Western Pennsylvania, but nuclear wastes generation stays at the Status Quo 1990 level, or $166 \text{ m}^3/\text{year}$ (19 times 1975 levels).

The environmental regulatory control level must necessarily be relaxed for both coal mining and coal burning. Stringent emissions standards may be relaxed, or postponed until better technology is available. Strip-mining must be permitted, although more land reclamation may be mandated. The declining supply and use of oil and gas may reflect greater environmental controls on exploration for these fuels, particularly on the OCS. Nuclear generation capacity remains at Status Quo levels, and so must the amount of environmental regulation applied to nuclear plants.

The gross regional product increases $\$10 \times 10^9$ over Nuclear 1990, and $\$23 \times 10^9$ over Status Quo 1990 (10%) mainly because of the huge increase in Pennsylvania coal production that is assumed. The great need for coal miners lowers employment by 0.5%. A booming economy generates positive pressure on prices, so both the consumer and wholesale price indices increase 10 points, to 256 and 192 respectively.

The higher market price of coal (four times the 1975 Reference and 30¢/MBtu over the Status Quo 1990) acts as a stimulus to the higher production levels required. The price of oil declines somewhat (37¢/MBtu to an index of 770) as does its importance. The price of gas rises as short supplies and still-great demand have their effect. Overall, the price of electricity may decline 10% to 900, from 1000 in the Status Quo prediction or double the 1975 Reference, because of continued use of nuclear generation and because of utility expansion around mine-mouth plants.

In the Status Quo 1990 scenario, fossil generation capacity grew only 2000 MW_e , or 3.3% of total growth in the 15 year period, and the capital investment required was insignificant compared to the nuclear money requirements. Nuclear investments still dominate fossil investments, since nuclear capacity goes up 50,000 MW_e while fossil goes up 34,000 from 33,000 MW_e , but the money required for new fossil plants and equipment is significant in Coal 1990. Although fossil plants are

not nearly as capital intensive as nuclear plants (say, \$300/KW_e vs \$450 KW_e for comparative figures) the required yearly investment in 1990 is $\$1.4 \times 10^9$ for coal mining and generation vs $\$3.8 \times 10^9$ for nuclear generation and fuel processing. Six times the Status Quo requirements for non-nuclear generation have accumulated by 1990, or $\$9 \times 10^9$ (vs $\$20 \times 10^9$ for nuclear). Because of the additional generation required, Coal 1990 is also a capital-intensive scenario, and energy investments approach absurd fractions of total regional industrial investment, even at accelerated capital expansion rates. The energy fractions are 60% of cumulated investments and 80% of 1990 money demands.

Economic regulatory control will remain at Status Quo levels for oil, gas, and nuclear fuels, but positive support of the coal industry and utilities must be applied if supplies of coal and generation capacity are to meet the expected demand.

Future Scenario V - Breakthrough in Oil and Gas 1990

In this scenario the basic assumption is that greatly expanded oil and natural gas supplies become available (whether through peace in the Middle East, offshore drilling or other new discoveries cannot be determined here). Lower prices of these commodities stem the rush toward nuclear power and even fuel a growth in oil consumption beyond Status Quo 1990 levels.

Electrification of homes and commercial establishments proceeds slightly more slowly, while use of oil burners expands 65×10^{12} Btu (3.5%). Transportation remains the same as in Status Quo 1990 - i.e., almost exclusively petroleum fueled. Industry uses less coal (310×10^{12} Btu or 25%), but the same amount of electricity, and the difference is made up largely in oil consumption (290×10^{12} Btu or a 50% increase). Coal consumption and nuclear capacity of PJM utilities goes down (330×10^{12} Btu (25%) and 17,000 MW_e (30%)) and is replaced by oil-fired capacity (2690×10^{12} Btu burned by 51,000 MW_e capacity) plus natural gas consumption which has more than tripled (from 60 to 200×10^{12} Btu). Notably, consumption of imported oil by utilities increases nearly 6 times over Status Quo levels, and nearly matches consumption of domestic oil.

The overall generation mix is 50% fossil, 40% nuclear (down from 57% in the Status Quo), and 10% other (hydro and gas turbines). It must be recognized that within the fossil there is also a trend from coal-fired to oil-fired plants. The Status Quo mix is nearly 50-50, but Oil and Gas 1990 is 3-1 oil to coal in terms of Btu input.

Oil burns cleaner than coal, especially with respect to particulates and SO_x, and thus the air quality indicators improve. Particulates from stationary sources only go to 146 instead of 184% over Reference 1975 (a large amount of pollution from automobiles is neglected here) and SO_x emissions only increase 10% - although the sulphur content in oil is low, there is an increasing amount of it being burned. At 17×10^{12} gals/yr, utility water consumption is lower by 50% (248 vs 300 over Reference 1975) because of the lowered proportion of nuclear generation. Similarly coal mining decreases to 40% of its Status Quo value, or only 2300 acres/year. Nuclear waste generation declines by nearly 20% or 1520 vs 1940 over Reference 1975 levels.

To promote such large oil and gas supplies, environmental regulatory control on exploration and use of these fuels will have to be the absolute minimum. Coal and nuclear power will be regulated more closely since the slowed pace of their development allows more caution.

The region prospers with the influx of oil and gas, and so the GRP goes up slightly, $\$8 \times 10^9$ (3.4%), equivalent to a GRP per capita of \$8250. With prosperity, unemployment declines to 4.5%, but again consumer demand pushes up consumer and wholesale price indices. The CPI goes up 19 points or 7.2% over Status Quo 1990; WPI is up 16 points or 8.1%.

Although rising oil and gas prices first stimulate the necessary exploration, eventually the predicted abundant supply brings energy prices down below Status Quo levels. Oil is down 59¢/MBtu, a 7% decline from 807. To remain competitive, the price of coal also declines 50¢/MBtu, or 10,6%. Natural gas is presumed to be deregulated, and its price soars, doubling the Status Quo value at 573¢/MBtu, due to the restrained demand of past years. The price of electricity rises an additional 10% because of the greater use of the more expensive fuels, and because of lowered demand.

Capital requirements for new plants and equipment are not nearly as severe as in the Status Quo scenario. Some investment in drilling off the Jersey shore will be made, and the large PJM refinery may well be expanded to meet new load, but most exploration and extraction costs will be borne by other regions. Petroleum investments increase 6-fold ($\$1.5$ to $\$12 \times 10^9$) but the difference is half made up by a 30% decline in accumulated nuclear capital ($\$6 \times 10^9$). Coal mining costs decline 60% to $\$.4 \times 10^9$, but non-nuclear generation will require $\$5.5 \times 10^9$ additional (1975) dollars, a 467% increase. If the capital market expands at slightly greater than normal rates (10% vs 8% per year), the energy industry must again dominate 80% of the market in 1990, and 3/4 of the cumulative 15 years of investments.

Economic regulatory control of the oil and gas industries must be minimal, or very positive in its exercise. Control of foreign imports will decline

slightly. Regulation of the electric utilities closely follows the present day pattern, and therefore remains at Status Quo levels. Intraregional coal mining is still promoted, but importation of coal from other regions is more greatly constrained by taxes, transportation costs, etc.

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Scenario: Reference Scenario (1990)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	5	100%	0	100%	309	100%	348	100%
Intraregional coal	14	100%	0	100%	911	100%	941	100%
Foreign oil	760	100%	525	100%	113	100%	221	100%
Domestic oil	1548	100%	2314	100%	499	100%	974	100%
Natural Gas	1151	100%	48	100%	867	100%	60	100%
Electricity	934	100%	11	100%	619	100%	0	100%

Electrical generation mix: 33 % fossil, 57 % nuclear, 10 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions 9.2×10^6 tons/yrSO_x emissions 9.03×10^6 tons/yr

Water quality:

Utility consumption rate 20.75×10^{12} gals/yrEffluent quality 100 index

Land use:

Coal mining land use rate 5750 acres/yrNuclear waste generation rate 166 m³/yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal		5	
Oil		5	
Natural gas		5	
Fossil electricity		5	
Nuclear electricity		5	

Table 6-1

Economic indicators

Gross regional product:	236.8 x 10 ⁹	\$
Gross regional product per capita:	7973	\$/person
Unemployment rate:	5	%
Consumer price index:	246	index
Wholesale price index:	187	index
Energy price indices:		
Coal	471	index
Oil	807	"
Natural gas	290	"
Electricity	1000	"

Capital investments:

	Cumulative		Current year	
All non-energy industry	45,000	\$	6,200	\$
Coal mining	1,000	\$	105	\$
Petroleum extraction & refining	1,500	\$	100	\$
Non-nuclear generation	1,500	\$	100	\$
Nuclear generation	20,000	\$	3,600	\$
Nuclear fuel processing	1,200	\$	184	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal	5		
Intraregional coal	5		
Domestic oil	5		
Foreign oil	5		
Natural gas	5		
Fossil electricity	5		
Nuclear electricity	5		

Reference 1990

Scenario: Nuclear (1990)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	0	100%	0	0%	160	51%	225	64%
Intraregional coal	3	18%	0	0%	620	68%	941	100%
Foreign oil	0	0%	650	123%	0	0%	0	0%
Domestic oil	1,500	96%	2,150	92%	400	80%	800	82%
Natural Gas	790	68%	20	41%	600	69%	60	100%
Electricity	1,715	183%	80	707%	1,510	243%	0	0%

Electrical generation mix: 25 % fossil, 67 % nuclear, 8 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions

 7.5×10^6 tons/yrSO_x emissions 9.05×10^6 tons/yr

Water quality:

Utility consumption rate

 28.0×10^{12} gals/yr

Effluent quality

95 index

Land use:

Coal mining land use rate

5,710 acres/yr

Nuclear waste generation rate

195 m³/yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			7
Oil		5	
Natural gas		5	
Fossil electricity		5	
Nuclear electricity	1		

Table 6-2

Economic indicators

Gross regional product:	250.0 x 10 ⁹	\$
Gross regional product per capita:	8417	\$/person
Unemployment rate:	4.7	%
Consumer price index:	250	index
Wholesale price index:	200	index
Energy price indices:		
Coal	420	index
Oil	750	"
Natural gas	400	"
Electricity	800	"

Capital investments:

	Cumulative		Current year	
All non-energy industry	60,000	\$	7,000	\$
Coal mining	983	\$	105	\$
Petroleum extraction & refining	1,500	\$	100	\$
Non-nuclear generation	1,500	\$	100	\$
Nuclear generation	35,000	\$	4,200	\$
Nuclear fuel processing	1,900	\$	213	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			7
Intraregional coal		5	
Domestic oil			7
Foreign oil			9
Natural gas	4		
Fossil electricity		5	
Nuclear electricity	2		

Nuclear 1990

Scenario: Conservation 1990Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	0	0%	0	0%	160	51%	350	100%
Intraregional coal	0	0%	0	0%	620	68%	940	99%
Foreign oil	125	16%	0	0%	0	0%	220	99%
Domestic oil	1550	100%	2000	86%	400	80%	975	100%
Natural Gas	925	80%	30	62%	600	69%	60	100%
Electricity	760	81%	50	442%	1510	243%	0	0%

Electrical generation mix: 33 % fossil, 57 % nuclear, 10 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions 7.3×10^6 tons/yrSO_x emissions 8.0×10^6 tons/yr

Water quality:

Utility consumption rate 13.4×10^{12} gals/yrEffluent quality 80 index

Land use:

Coal mining land use rate 4582 acres/yrNuclear waste generation rate 120 m³/yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			9
Oil			8
Natural gas		5	
Fossil electricity			8
Nuclear electricity			7

Table 6-3

Economic indicators

Gross regional product:	<u>230.0 x 10⁹</u>	\$
Gross regional product per capita:	<u>7744</u>	\$/person
Unemployment rate:	<u>5</u>	%
Consumer price index:	<u>280</u>	index
Wholesale price index:	<u>200</u>	index
Energy price indices:		
Coal	<u>500</u>	index
Oil	<u>870</u>	"
Natural gas	<u>340</u>	"
Electricity	<u>1200</u>	"
Capital investments: (10 ⁶ dollars)		

	Cumulative		Current year	
All non-energy industry	<u>41,000</u>	\$	<u>5,000</u>	\$
Coal mining	<u>786</u>	\$	<u>80</u>	\$
Petroleum extraction & refining	<u>1,500</u>	\$	<u>100</u>	\$
Non-nuclear generation	<u>1,500</u>	\$	<u>100</u>	\$
Nuclear generation	<u>12,050</u>	\$	<u>2,000</u>	\$
Nuclear fuel processing	<u>1,000</u>	\$	<u>130</u>	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal		5	
Intraregional coal		5	
Domestic oil		5	
Foreign oil			8
Natural gas			8
Fossil electricity		5	
Nuclear electricity		5	

Conservation 1990

Scenario: Coal 1990Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	5	100%	0	0%	308	99%	350	100%
Intraregional coal	14	100%	0	0%	1061	116%	1590	168%
Foreign oil								
Domestic oil	0	0%	530	-100%	0	0%	170	76%
Natural Gas	1425	92%	2310	99%	305	61%	751	77%
Electricity	890	77%	48	100%	650	75%	52	86%
	1755	187%	545	4823%	940	151%	0	0%

Electrical generation mix: 48 % fossil, 44 % nuclear, 8 % otherEnvironmental Indicators

Air quality (stationary sources):

Particulate emissions 12.9×10^6 tons/yrSO_x emissions 12.7×10^6 tons/yr

Water quality:

Utility consumption rate 25×10^{12} gals/yrEffluent quality 140 index

Land use:

Coal mining land use rate 9,290 acres/yrNuclear waste generation rate 166 m³/yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal	2		
Oil			7
Natural gas			7
Fossil electricity	1		
Nuclear electricity		5	

Table 6-4

Economic indicators

Gross regional product:	<u>260 x 10⁹</u>	\$
Gross regional product per capita:	<u>8750</u>	\$/person
Unemployment rate:	<u>4.5</u>	%
Consumer price index:	<u>256</u>	index
Wholesale price index:	<u>192</u>	index
Energy price indices:		
Coal	<u>500</u>	index
Oil	<u>770</u>	"
Natural gas	<u>330</u>	"
Electricity	<u>900</u>	"

Capital investments:

	Cumulative		Current year	
All non-energy industry	<u>50,000</u>	\$	<u>6,500</u>	\$
Coal mining	<u>1,600</u>	\$	<u>170</u>	\$
Petroleum extraction & refining	<u>1,500</u>	\$	<u>70</u>	\$
Non-nuclear generation	<u>9,000</u>	\$	<u>1,200</u>	\$
Nuclear generation	<u>20,000</u>	\$	<u>3,600</u>	\$
Nuclear fuel processing	<u>1,200</u>	\$	<u>184</u>	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal	2		
Intraregional coal	1		
Domestic oil		5	
Foreign oil		5	
Natural gas		5	
Fossil electricity	2		
Nuclear electricity		5	

Coal 1990

Scenario: Oil and Gas 1990

Energy Indicators

Energy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	4	74%	0	0%	230	74%	260	74%
Intraregional coal	10	74%	0	0%	680	74%	700	74%
Foreign oil	415	54%	596	113%	189	166%	1290	583%
Domestic oil	1562	100%	2244	96%	711	142%	1400	143%
Natural Gas	1152	100%	50	104%	890	102%	200	333%
Electricity	900	96%	15	132%	620	100%	0	0%

Electrical generation mix: 50 % fossil, 40 % nuclear, 10 % other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{7.3 \times 10^6}{}$ tons/yr

SO_x emissions $\frac{10.05 \times 10^6}{}$ tons/yr

Water quality:

Utility consumption rate $\frac{17 \times 10^{12}}{}$ gals/yr

Effluent quality $\frac{95}{}$ index

Land use:

Coal mining land use rate $\frac{2,300}{}$ acres/yr

Nuclear waste generation rate $\frac{130}{}$ m³/yr

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			7
Oil	1		
Natural gas	1		
Fossil electricity			6
Nuclear electricity			7

Table 6-5

Economic indicators

Gross regional product:	<u>245 x 10⁶</u>	\$
Gross regional product per capita:	<u>8249</u>	\$/person
Unemployment rate:	<u>4.5</u>	%
Consumer price index:	<u>265</u>	index
Wholesale price index:	<u>198</u>	index
Energy price indices:		
Coal	<u>420</u>	index
Oil	<u>750</u>	"
Natural gas	<u>573</u>	"
Electricity	<u>1100</u>	"
Capital investments: (10 ⁶ dollars)		

	Cumulative		Current year	
All non-energy industry	<u>40,000</u>	\$	<u>5,163</u>	\$
Coal mining	<u>400</u>	\$	<u>50</u>	\$
Petroleum extraction & refining	<u>12,000</u>	\$	<u>900</u>	\$
Non-nuclear generation	<u>7,000</u>	\$	<u>1,000</u>	\$
Nuclear generation	<u>14,000</u>	\$	<u>2,920</u>	\$
Nuclear fuel processing	<u>800</u>	\$	<u>158</u>	\$

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			8
Intraregional coal			6
Domestic oil	1		
Foreign oil	4		
Natural gas	1		
Fossil electricity		5	
Nuclear electricity			6

Scenario: Preferred Scenario for Electric Utility (A1)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com % ref	Transport % ref	Industry % ref	Utilities % ref
Extraregional coal	3 50	0 100	230 74	287 82
Intraregional coal	8 58	0 100	796 87	1111 118
Foreign oil	145 19	251 47	33 29	212 95
Domestic oil	1492 96	2222 96	414 83	873 89
Natural Gas	908 78	35 73	674 77	71 118
Electricity	1506 161	202 1785	1094 176	0 100

Electrical generation mix:

35.1 % fossil, 58.2 % nuclear, 8.5 % other
(106%) (99%) (85%)

Environmental Indicators

			% Ref
Air quality (stationary sources):			
Particulate emissions	9.3×10^6	tons/yr	(101%)
SO _x emissions	10.1×10^6	tons/yr	112
Water quality:			
Utility consumption rate	24.5×10^{12}	gals/yr	118
Effluent quality	108.4	index	108
Land use:			
Coal mining land use rate	6408	acres/yr	111
Nuclear waste generation rate	174.	m ³ /yr	104

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			5.4
Oil			5.3
Natural gas			5.2
Fossil electricity	4.1		
Nuclear electricity	3.4		

Table 6-6

Economic indicators% Ref

Gross regional product:	249.9 x 10 ⁹	\$	(105%)
Gross regional product per capita:	8414	\$/person	105
Unemployment rate:	4.7	%	93
Consumer price index:	245	index	103
Wholesale price index:	196	index	104
Energy price indices:			
Coal	454	index	96
Oil	768	"	95
Natural gas	379	"	130
Electricity	901	"	90

Capital investments:

	Cumulative		Current year	
All non-energy industry	52350	\$	6488	\$ 112
Coal mining	1105	\$	118	\$
Petroleum extraction & refining	2504	\$	168	\$ 167
Non-nuclear generation	4253	\$	513	\$ 513
Nuclear generation	25600	\$	3729	\$ 103
Nuclear fuel processing	1437	\$	192	\$ 105

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.3
Intraregional coal	3.9		
Domestic oil			5.5
Foreign oil			6.8
Natural gas	4.3		
Fossil electricity	4.1		
Nuclear electricity	3.8		

Table 6-7

Scenario: Preferred Composite Scenario for Residential Consumer (A2)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com	% ref	Transport	% ref	Industry	% ref	Utilities	% ref
Extraregional coal	2	36	0	100	210	68	289	82
Intraregional coal	6	44	0	100	725	79	981	104
Foreign oil	211	27	377	71	41	36	235	106
Domestic oil	1518	98	2178	94	441	88	924	94
Natural Gas	932	80	33	69	666	76	74	122
Electricity	1303	139	101	896	988	159	0	100

Electrical generation mix: $\frac{33.0}{99\%}$ % fossil, $\frac{58.1}{(101\%)}$ % nuclear, $\frac{9.}{(89\%)}$ % other

Environmental Indicators

% Ref

Air quality (stationary sources):

Particulate emissions	$\frac{8.3 \times 10^6}{9.3 \times 10^6}$	tons/yr	10%
SO _x emissions		tons/yr	103

Water quality:

Utility consumption rate	$\frac{22.37 \times 10^{12}}{97.6}$	gals/yr	107
Effluent quality		index	97

Land use:

Coal mining land use rate	$\frac{5507}{188.6}$	acres/yr	95
Nuclear waste generation rate		m ³ /yr	113

Environmental regulatory control level:

Less than SQ   Status Quo   More than SQ

Coal		6.5
Oil		5.4
Natural gas	4.8	
Fossil electricity		5.3
Nuclear electricity	3.9	

Table 6-7

Economic indicators% Ref

Gross regional product:	244.1 x 10 ⁹	\$	103%
Gross regional product per capita:	8219	\$/person	103
Unemployment rate:	4.8	%	95
Consumer price index:	257	index	104
Wholesale price index:	197	index	105
Energy price indices:			
Coal	453	index	96
Oil	786	"	97
Natural gas	379	"	130
Electricity	956	"	95

Capital investments:

	Cumulative		Current year		
All non-energy industry	50420	\$	6222	\$	100
Coal mining	950	\$	101	\$	96
Petroleum extraction & refining	2590	\$	180	\$	179
Non-nuclear generation	2823	\$	304	\$	303
Nuclear generation	24050	\$	3469	\$	96
Nuclear fuel processing	1410	\$	136	\$	73

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.8
Intraregional coal	4.7		
Domestic oil			5.4
Foreign oil			7.1
Natural gas	4.8		
Fossil electricity	4.7		
Nuclear electricity	3.9		

Table 6-8

Scenario: Preferred Composite Scenario for Industrial Consumer (A3)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com % ref	Transport % ref	Industry % ref	Utilities % ref
Extraregional coal	3 62	0 100	241 78	295 84
Intraregional coal	9 66	0 100	803 88	1070 113
Foreign oil	208 27	218 41	66 58	456 206
Domestic oil	1503 97	2233 96	470 94	986 101
Natural Gas	971 84	41 84	719 83	97 162
Electricity	1348 144	194 1715	917 148	0 100

Electrical generation mix: 40.5 % fossil, 50.6 % nuclear, 8.9 % other
 122% 88% (89%)

Environmental Indicators

			% Ref
Air quality (stationary sources):			
Particulate emissions	9.26×10^6	tons/yr	100%
SO _x emissions	10.37×10^6	tons/yr	114
Water quality:			
Utility consumption rate	22.21×10^{12}	gals/yr	107
Effluent quality	108.2	index	108
Land use:			
Coal mining land use rate	5762	acres/yr	100
Nuclear waste generation rate	173	m ³ /yr	104

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			5.4
Oil	4.7		
Natural gas	4.5		
Fossil electricity	4.3		
Nuclear electricity	4.8		

Table 6-8

Economic indicators

			% Ref
Gross regional product:	248.9 x 10 ⁹	\$	105%
Gross regional product per capita:	8378	\$/person	105
Unemployment rate:	4.6	%	92
Consumer price index:	258	index	104
Wholesale price index:	196	index	104
Energy price indices:			
Coal	455	index	96
Oil	770	"	95
Natural gas	412	"	142
Electricity	964	"	96

Capital investments:

	Cumulative		Current year		
All non-energy industry	48400	\$	6107	\$	98
Coal mining	994	\$	108	\$	102
Petroleum extraction & refining	4475	\$	318	\$	317
Non-nuclear generation	5134	\$	690	\$	690
Nuclear generation	21330	\$	3442	\$	95
Nuclear fuel processing	1239	\$	153	\$	83

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.4
Intraregional coal	4.1		
Domestic oil	4.3		
Foreign oil			5.9
Natural gas	3.8		
Fossil electricity	4.1		
Nuclear electricity	4.6		

Scenario: Preferred Composite Scenario for Environmentalist (A4)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	1	22	0	100	191	61	308	88
Intraregional coal	4	27	0	100	681	74	945	100
Foreign oil	198	25	294	54	29	25	225	101
Domestic oil	1532	98	2115	91	432	86	945	97
Natural Gas	933	81	32	66	612	70	69	114
Electricity	1099	117	66	587	804	129	0	100

Electrical generation mix: $\frac{32.3}{97\%}$ % fossil, $\frac{58.3}{102\%}$ % nuclear, $\frac{9.4}{93\%}$ % other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{7.8 \times 10^6}{\text{tons/yr}}$ 84%

SO_x emissions $\frac{8.7 \times 10^6}{\text{tons/yr}}$ 96

Water quality:

Utility consumption rate $\frac{19.25 \times 10^{12}}{\text{gals/yr}}$ 92

Effluent quality $\frac{90.1}{\text{index}}$ 90

Land use:

Coal mining land use rate $\frac{5079}{\text{acres/yr}}$ 88

Nuclear waste generation rate $\frac{166}{\text{m}^3/\text{yr}}$ 100

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			7.5
Oil			6.2
Natural gas	4.8		
Fossil electricity			6.4
Nuclear electricity	4.9		

Table 6-9

Economic indicators

Gross regional product:	238.6 x 10 ⁹	\$	100%
Gross regional product per capita:	8034	\$/person	100
Unemployment rate:	4.9	%	97
Consumer price index:	265	index	107
Wholesale price index:	198	index	105
Energy price indices:			
Coal	468	index	99
Oil	816	"	101
Natural gas	364	"	125
Electricity	1040	"	103

Capital investments:

	Cumulative		Current year	
All non-energy industry	47230	\$	5805	\$ 93
Coal mining	875	\$	92	\$ 87
Petroleum extraction & refining	2177	\$	151	\$ 150
Non-nuclear generation	2094	\$	193	\$ 193
Nuclear generation	20140	\$	2973	\$ 82
Nuclear fuel processing	1280	\$	133	\$ 72

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.7
Intraregional coal	4.9		
Domestic oil			5.3
Foreign oil			7.5
Natural gas			5.9
Fossil electricity	4.9		
Nuclear electricity	4.2		

Scenario: Preferred Composite Scenario for Environmental Regulator (A5)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	2	29	0	100	201	65	315	90
Intraregional coal	5	33	0	100	701	76	950	100
Foreign oil	241	31	275	52	36	31	240	108
Domestic oil	1534	99	2127	91	437	87	955	98
Natural Gas	954	82	33	69	630	72	69	115
Electricity	1060	113	66	580	756	122	0	100

Electrical generation mix: $\frac{32.9}{99\%}$ % fossil, $\frac{57.6}{101\%}$ % nuclear, $\frac{9.5}{94\%}$ % other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{7.95 \times 10^6}{8.77 \times 10^6}$ tons/yr 86%
 SO_x emissions tons/yr 97

Water quality:

Utility consumption rate $\frac{18.91 \times 10^{12}}{90.8}$ gals/yr 91
 Effluent quality index 90

Land use:

Coal mining land use rate $\frac{5107}{161.6}$ acres/yr 88
 Nuclear waste generation rate m^3/yr 97

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			7.3
Oil			6.2
Natural gas	4.8		
Fossil electricity			6.3
Nuclear electricity			5.1

Table 6-10

Economic indicators

Gross regional product:	238.1 x 10 ⁹	\$	100%
Gross regional product per capita:	8016	\$/person	100
Unemployment rate:	4.9	%	97
Consumer price index:	264	index	107
Wholesale price index:	197	index	105
Energy price indices:			
Coal	471	index	99
Oil	818	"	101
Natural gas	359	"	123
Electricity	1050	"	104

Capital investments:

	Cumulative		Current year	
All non-energy industry	46420	\$	5769	\$ 93
Coal mining	880	\$	92	\$ 87
Petroleum extraction & refining	2198	\$	152	\$ 151
Non-nuclear generation	2155	\$	202	\$ 202
Nuclear generation	19330	\$	2950	\$ 81
Nuclear fuel processing	1240	\$	138	\$ 75

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.5
Intraregional coal	4.9		
Domestic oil			5.2
Foreign oil			7.2
Natural gas			5.9
Fossil electricity	4.9		
Nuclear electricity	4.4		

Table 6-11

Scenario: Preferred Composite Scenario for Executive (A6)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	3	99%	0	100%	226	73	282	81
Intraregional coal	8	57	0	100	779	85	1085	115
Foreign oil	133	17	250	47	43	37	320	145
Domestic oil	1496	96	2216	95	437	87	920	94
Natural Gas	918	79	36	75	681	78	84	140
Electricity	1470	157	198	1750	1059	171	0	100

Electrical generation mix: $\frac{37.4}{(113\%)}\%$ fossil, $\frac{54.0}{(94\%)}\%$ nuclear, $\frac{8.6}{(86\%)}\%$ other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{9.14 \times 10^6}{\text{tons/yr}}$ (99%)

SO_x emissions $\frac{10.25 \times 10^6}{\text{tons/yr}}$ (113)

Water quality:

Utility consumption rate $\frac{23.76 \times 10^{12}}{\text{gals/yr}}$ (114)

Effluent quality $\frac{107.6}{\text{index}}$ (107)

Land use:

Coal mining land use rate $\frac{6050}{\text{acres/yr}}$ (105)

Nuclear waste generation rate $\frac{190.5}{\text{m}^3/\text{yr}}$ (114)

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			5.5
Oil		5.0	
Natural gas	4.8		
Fossil electricity	4.2		
Nuclear electricity	3.9		

Table 6-11

Economic indicators

Gross regional product:	250 x 10 ⁹	\$	(105%)
Gross regional product per capita:	8417	\$/person	(105)
Unemployment rate:	4.6	%	(92)
Consumer price index:	256	index	(104)
Wholesale price index:	197	index	(105)
Energy price indices:			
Coal	451	index	(95)
Oil	766	"	(94)
Natural gas	402	"	(138)
Electricity	921	"	(92)

Capital investments:

	Cumulative		Current year		
All non-energy industry	51280	\$	6343	\$	(102)
Coal mining	1043	\$	112	\$	(100)
Petroleum extraction & refining	3494	\$	243	\$	(243)
Non-nuclear generation	4740	\$	530	\$	(592)
Nuclear generation	24400	\$	3621	\$	(100)
Nuclear fuel processing	1392	\$	143	\$	(77)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.5
Intraregional coal	4.0		
Domestic oil		5.0	
Foreign oil			6.6
Natural gas	4.0		
Fossil electricity	4.1		
Nuclear electricity	4.0		

Table 6 -12

Scenario: Preferred Composite Scenario for Legislator (A7)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	3	52%	0	100%	230	74%	291	83%
Intraregional coal	8	58	0	100	792	86	1109	117
Foreign oil	130	17	180	34	42	36	334	151
Domestic oil	1494	96	214	95	433	86	924	94
Natural Gas	923	80	37	77	675	77	84	140
Electricity	1440	154	215	1899	1004	162	0	100

Electrical generation mix: $\frac{38.5}{(116\%)}\%$ fossil, $\frac{52.8}{(92\%)}\%$ nuclear, $\frac{8.7}{(861)}\%$ other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{9.31 \times 10^6}{\text{tons/yr}}$ (101%)

SO_x emissions $\frac{10.34 \times 10^6}{\text{tons/yr}}$ (114)

Water quality:

Utility consumption rate $\frac{23.12 \times 10^{12}}{\text{gals/yr}}$ (111)

Effluent quality $\frac{108.6}{\text{index}}$ (108)

Land use:

Coal mining land use rate $\frac{6134}{\text{acres/yr}}$ (106)

Nuclear waste generation rate $\frac{182.3}{\text{m}^3/\text{yr}}$ (110)

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			5.4
Oil			5.2
Natural gas	4.9		
Fossil electricity	4.2		
Nuclear electricity	4.3		

Table 6-12

Economic indicators

Gross regional product:	249.7 x 10 ⁹	\$	(105%)
Gross regional product per capita:	8406	\$/person	(105)
Unemployment rate:	4.6	%	(92)
Consumer price index:	258	index	(104)
Wholesale price index:	196	index	(104)
Energy price indices:			
Coal	456	index	(96)
Oil	771	"	(95)
Natural gas	398	"	(137)
Electricity	939	"	(93)

Capital investments:

	Cumulative		Current year		
All non-energy industry	50270	\$	6249	\$	(100)
Coal mining	1057	\$	114	\$	(108)
Petroleum extraction & refining	3497	\$	242	\$	(242)
Non-nuclear generation	5022	\$	634	\$	(634)
Nuclear generation	23040	\$	3512	\$	(97)
Nuclear fuel processing	1336	\$	146	\$	(79)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			5.2
Intraregional coal	3.9		
Domestic oil	4.9		
Foreign oil			6.4
Natural gas	4.2		
Fossil electricity	4.0		
Nuclear electricity	4.2		

Table 6-13

Scenario: Preferred Composite Scenario for Oil & Gas Suppliers (A8)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	4	73%	0	100%	242	78	282	81
Intraregional coal	10	74	0	100	745	81	847	90
Foreign oil	385	50	452	86	742	125	917	414
Domestic oil	1542	99	2246	97	611	122	1225	125
Natural Gas	1096	95	47	98	832	95	153	254
Electricity	1035	110	75	659	699	112	0	100

Electrical generation mix: $\frac{45.4}{(137\%)}\%$ fossil, $\frac{44.9}{(78\%)}\%$ nuclear, $\frac{9.7}{(96\%)}\%$ other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{8.15 \times 10^6}{10.06 \times 10^6}$ tons/yr (88%)

SO_x emissions tons/yr (111)

Water quality:

Utility consumption rate $\frac{18.85 \times 10^{12}}{99.8}$ gals/yr (90)

Effluent quality index (99)

Land use:

Coal mining land use rate $\frac{3771}{145.3}$ acres/yr (65)

Nuclear waste generation rate $\frac{145.3}{m^3/yr}$ (125)

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			6.3
Oil	2.6		
Natural gas	2.5		
Fossil electricity			5.4
Nuclear electricity			6.2

Table 6-13

Economic indicators

Gross regional product:	245 x 10 ⁹	\$	(103%)
Gross regional product per capita:	8255	\$/person	(103)
Unemployment rate:	4.6	%	(91)
Consumer price index:	261	index	(106)
Wholesale price index:	196	index	(104)
Energy price indices:			
Coal	438	index	(92)
Oil	764	"	(94)
Natural gas	491	"	(169)
Electricity	1052	"	(105)

Capital investments:

	Cumulative		Current year		
All non-energy industry	42910	\$	5540	\$	(89)
Coal mining	6533	\$	74	\$	(70)
Petroleum extraction & refining	8509	\$	630	\$	(630)
Non-nuclear generation	5950	\$	815	\$	(814)
Nuclear generation	16580	\$	3135	\$	(86)
Nuclear fuel processing	966	\$	160	\$	(86)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			6.8
Intraregional coal			5.3
Domestic oil	2.4		
Foreign oil	4.7		
Natural gas	2.4		
Fossil electricity	4.7		
Nuclear electricity			5.5

Table 6 -14

Scenario: Preferred Composite Scenario for Coal Suppliers (A9)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com		Transport		Industry		Utilities	
Extraregional coal	5	88%	0	100%	287	92	333	95%
Intraregional coal	13	89	0	100	959	105	1340	142
Foreign oil	166	21	159	-30	36	31	270	122
Domestic oil	1466	94	2285	98	383	76	857	87
Natural Gas	951	82	46	95	699	80	68	112
Electricity	1511	161	363	3216	883	142	0	100

Electrical generation mix: $\frac{43.7}{(132\%)}\%$ fossil, $\frac{47.7}{(83\%)}\%$ nuclear, $\frac{8.6}{(85\%)}\%$ other

Environmental Indicators

Air quality (stationary sources):

Particulate emissions $\frac{11.26 \times 10^6}{11.47 \times 10^6}$ tons/yr (122%)

SO_x emissions tons/yr (127)

Water quality:

Utility consumption rate $\frac{23.44 \times 10^{12}}{124.6}$ gals/yr (112)

Effluent quality index (124)

Land use:

Coal mining land use rate $\frac{7695}{167.1}$ acres/yr (133)

Nuclear waste generation rate $\frac{167.1}{m^3/yr}$ (100)

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal	3.5		
Oil			6.0
Natural gas			5.9
Fossil electricity	2.6		
Nuclear electricity		5.0	

Table 6-14

Economic indicators

Gross regional product:	<u>253.3 x 10⁹</u>	\$	(106%)
Gross regional product per capita:	<u>8525</u>	\$/person	(106)
Unemployment rate:	<u>4.6</u>	%	(92)
Consumer price index:	<u>256</u>	index	(103)
Wholesale price index:	<u>193</u>	index	(102)
Energy price indices:			
Coal	<u>483</u>	index	(102)
Oil	<u>776</u>	"	(96)
Natural gas	<u>351</u>	"	(120)
Electricity	<u>937</u>	"	(93)

Capital investments:

	Cumulative		Current year		
All non-energy industry	<u>48690</u>	\$	<u>6320</u>	\$	(101)
Coal mining	<u>1327</u>	\$	<u>141</u>	\$	(134)
Petroleum extraction & refining	<u>2456</u>	\$	<u>153</u>	\$	(153)
Non-nuclear generation	<u>6864</u>	\$	<u>895</u>	\$	(895)
Nuclear generation	<u>20240</u>	\$	<u>3532</u>	\$	(98)
Nuclear fuel processing	<u>1205</u>	\$	<u>174</u>	\$	(94)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal	3.5		
Intraregional coal	2.5		
Domestic oil	4.8		
Foreign oil			5.3
Natural gas	4.7		
Fossil electricity	3.1		
Nuclear electricity	4.9		

Scenario: Preferred Composite Scenario for Nuclear Supplier (A10)Energy IndicatorsEnergy Consumption (10^{12} Btu)

	Res/Com	Transport	Industry	Utilities
Extraregional coal	2 30%	0	203	271
Intraregional coal	6 41	0	706	958
Foreign oil	195	500	35	158
Domestic oil	1515	2183	436	887
Natural Gas	906	30	667	69
Electricity	1413	82	1140	0 100

Electrical generation mix: 30.2 % fossil, 61.1 % nuclear, 8.7 % other
 (91%) (107%) (87%)

Environmental Indicators

Air quality (stationary sources):

Particulate emissions	<u>8.09×10^6</u>	tons/yr	(87%)
SO _x emissions	<u>9.19×10^6</u>	tons/yr	(101)

Water quality:

Utility consumption rate	<u>24.26×10^{12}</u>	gals/yr	(116)
Effluent quality	<u>96.9</u>	index	(96)

Land use:

Coal mining land use rate	<u>5571</u>	acres/yr	(96)
Nuclear waste generation rate	<u>209</u>	m ³ /yr	(125)

Environmental regulatory control level:

	Less than SQ	Status Quo	More than SQ
Coal			6.5
Oil			5.1
Natural gas	4.8		
Fossil electricity			5.1
Nuclear electricity	3		

Table 6-15

Economic indicators

Gross regional product:	245.6 x 10 ⁹	\$	(103%)
Gross regional product per capita:	8267	\$/person	(103)
Unemployment rate:	4.8	%	(95)
Consumer price index:	253	index	(102)
Wholesale price index:	197	index	(105)
Energy price indices:			
Coal	442	index	(93)
Oil	774	"	95
Natural gas	379	"	130
Electricity	904	"	90

Capital investments:

	Cumulative		Current year	
All non-energy industry	53320	\$	6502	\$ (104)
Coal mining	961	\$	102	\$ (97)
Petroleum extraction & refining	2172	\$	150	\$ (149)
Non-nuclear generation	2226	\$	213	\$ (212)
Nuclear generation	27630	\$	3755	\$ (104)
Nuclear fuel processing	1565	\$	128	\$ (69)

Economic regulatory control level:

	Less than SQ	Status Quo	More than SQ
Extraregional coal			6.2
Intraregional coal	4.9		
Domestic oil			5.9
Foreign oil			7.6
Natural gas	4.4		
Fossil electricity	4.9		
Nuclear electricity	3.3		

APPENDIX E

REEG SOURCE LISTINGS (APLSV)

REEG - PHASE II - VERSION 2 - RELEASE - 1

This appendix contains the APLSV source listings for the first release of the Phase II Regional Energy Environment Game. Subsequent releases of Version 2 are under development employing graphic display at this writing.

FUNCTION INDEX

Communicator

Director Workspace

CUS (also util)
GIVE
OFFER
RECEIVE
REFORM
SUS (also util)

Player Workspace

GET
GETS
RESGET
RETRACT
RETRIEVE

Monitor

Director Workspace

ACTIONS
ACTIVE

EXPROC
EXPROCX
EXTERNAL
INTERNAL
PASSIVE
PROCESS
RESET
RESULTA
START
STOP

Player Workspace

ADDITONAL
CHECK

Policy Implementation Module

Director Workspace

PASSIVE ACTORS
POLICY CHOOSE
REVIEW
STOP (Also M)
STRATCHOOSE

Player Workspace

ACTIVATE*   SUSET*
ACTION
DEACTIVATE*
PLAY*
POLICY CHOOSE
PROCEED*
RESET*
STOP*
STRATCHOOSE
STRATDEF*
SUPROC*
SUC*   * Management
                                 Programs

Player Analyzer Module

Director Workspace

DESCRIPTION

Player Workspace

REVIEW
ANALYSIS
DESCRIPTION
ENVREVIEW
NEWS
PRINT
RESREVIEW

Impact Analysis Module

Director Workspace 1

MATRIX   GUMAT
             IMPACT
             LPRICE
             SUBLPRICE
             VMAT

FIXBACK

FIXUP

Utility Functions

Director Workspace

ALL   SIZE
BPE   SOM
CHK   SORT
CHK 1   SVS (also Comm)
CVS (also Comm)
CWRITE
DIAG
ERROR

FIND
LIST
NLIST
QUEST
QUOTE

Player Workspace

Player Workspace

ALL
CVS
ERROR
FIND
LIST
NLIST
PLAYERERROR
QUEST
QUOTE
SOM
SORT
SVS

Director

Director Workspace

Player Workspace

DESCRIBE

SETDECISION

Game Step Library

Director Workspace

Player Workspace

FDELETE

SAVEGAME

BIOINTIAL

BIOSTART

BIOWRITE

SOURCE LISTINGS

DIRECTOR WORKSPACE:

[0] X←ACTIONS
[1] X←(FS[1;]≠0)/FS

[0] ACTIVE M
[1] AST[M]←1
[2] 'ACTOR ',(M), ' (' ,ACTORS[M;], ') IS NOW IN ACTIVE STATUS'

[0] ARG←ALL
[1] ARG←NL 3

[0] PKL AMATRIX P;LPXI;FAEI;MMI;ESΔEIS;MSΔMIS;LPPXI;XΔXI;XSΔXIS;EE;AE;EES;AES;M
[1] LPXI←PKL LPRICE P
[2] EΔEI←(ESΔEIS←('E' VMAT PE))×((LPEI)÷(PE))
[3] MMI←(MSΔMIS←('M' VMAT PM))×((LPMI)÷(PM))
[4] LPPXI←(4 9 ρLPXI)
[5] XΔXI←(XSΔXIS←(GVMAT LPX))×((LPPXI)÷(LPX))
[6] EE←(5 9 ρXΔXI[;3])
[7] EES←(5 9 ρXSΔXIS[;3])
[8] AE←EE×EΔEI
[9] AES←EES×ESΔEIS
[10] AM←(5 9 ρXΔXI[;4])
[11] MS←(5 9 ρXSΔXIS[;4])
[12] AM←AM×MMI
[13] AMS←MS×MSΔMIS
[14] AKLS←XSΔXIS[; 1 2]
[15] AKL←XΔXI[; 1 2]
[16] A←(AM,AE),AKL
[17] AS←(AMS,AES),AKLS
[18] A←((4 9)A),[1] 1θ((-8 -9)A)
[19] AS←((4 9)AS),[1] 1θ((-8 -9)AS)
[20] PO←LPXI
[21] AP←A
[22] EE←LEX 5 4 ρ'EΔEILPX LPXIPE PM

[0] DT←BPE DAT
[1] DAT←64ρ1+0ρDAT
[2] DT←WA
[3] DT←WA
[4] DAT←128ρDAT
[5] DT←0.015625×DT-WA

[0] Z←CHK N;Y
[1] Y←
[2] M←OUT×N=ρ,Y
[3] 'INCORRECT DIMENSION--PLEASE REENTER'
[4] Y←
[5] M
[6] OUT←Z+Y

```
[ 0] Z←N CHK1 Y
[ 1] M:→OUT×1N=p.Y
[ 2] 'INCORRECT DIMENSION--PLEASE REENTER'
[ 3] Y←[]
[ 4] →M
[ 5] OUT:Z←Y
```

```
[ 0] CVS
[ 1] 'DEF= ',(DEF),' DEF=1 FOR ALL DEFAULT OPTIONS'
[ 2] 'REV= ',(REV),' REV=1 FOR ALL REVIEW OPTIONS'
[ 3] 'FAST= ',(FAST),' FAST=1 FOR FAST OPTIONS'
[ 4] 'AST= ',(AST),' **=1 FOR ACTIVE (ACTOR STATUS)'
[ 5] 'LST= ',(LST),' **=1 FOR INTERNAL (ACTOR LOCATION STATUS)'
```

```
[ 0] X←CWRITE N;A;B
[ 1] B←(1,N)ρ' '
[ 2] L:→(0=ρA+[])/E
[ 3] B←B,[1](1,N)ρA,(N-1+ρA)ρ' '
[ 4] →L
[ 5] E:X← 1 0 +B
[ 6] →0
```

```
[ 0] N DESCRIBE M
[ 1] 'ENTER DECISION ENVIRONMENT DESCRIPTION-+GAME= ',(N),' STEP= ',STEP
[ 2] 'WHEN DESCRIPTION IS COMPLETED ENTER CARRIAGE RETURN'
[ 3] LAV[160]
[ 4] DESCRIPT←CWRITE 100
[ 5] DESCRIPT←((10 0 N,M),80ρ' '),[1] DESCRIPT
```

```
[ 0] DESCRIPTION;N
[ 1] LAV[160]
[ 2] N←2DESCRIPT[1;120]
[ 3] LAV[160]
[ 4] 'DECISION ENVIRONMENT DESCRIPTION'
[ 5] 'GAME= ',(N[1]),' STEP= ',N[2]
[ 6] LAV[160]
[ 7] 1 0 +DESCRIPT
[ 8] LAV[160]
```

```
[ 0] Z←DIAG X;T;I
[ 1] Z←I×(((ρT).1)ρT)+.×(I+((1ρT)°. =1ρ(T+X)))
```

```
[ 0] C←A ERROR B;N;C
[ 1] →3×10=ρB
[ 2] →L×10→/(B+,B)[1]εA
[ 3] LAV[160]
[ 4] 'INCORRECT RESPONSE****'
[ 5] 'MUST BEGIN WITH: ',1+,2,N)ρA,(N+ρA)ρ'.'
[ 6] ' PLEASE REENTER '
[ 7] LAV[160]
[ 8] C←2
[ 9] →0
[10] L:C←1
[11] →0
```

```
[ 0] EXPROC I;X
[ 1] DEC+1
[ 2] GIVE I
[ 3] SAVE+SAVE,X+RECEIVE I
```

```
[ 0] S+EXPROCX SAVE;N;Y;X;I
[ 1] N+1+ρSAVE
[ 2] I+1
[ 3] Y+ 2 1 ρ0
[ 4] L:Y+Y,X+RECEIVE SAVE[1;I]
[ 5] →L×1N≥I+I+1
[ 6] S+Y
```

```
[ 0] N EXTERNAL M;X
[ 1] '-----SV OFFER STATUS'
[ 2] N [SVO X+(4 3 ρ'SVCSVDSVNSVM'),(4 1 ρM)
[ 3] '-----ACV STATUS'
[ 4] (4 4 ρ0) [SVC X
[ 5] AST[M]+1+LST[M]+0
[ 6] 'ACTOR',(M),' MADE EXTERNAL ('ACTORS[M;],')'
[ 7] GIVE M
```

```
[ 0] FDELETE FILE;X
[ 1] CTL1+'DELETE DSN=',FILE,',CODE=E'
[ 2] →L×10≠+0≠X+CTL1
[ 3] FILE,' DELETED FROM OLS'
[ 4] CTL1+' '
[ 5] →0
[ 6] L:'ERROR IN TSIO: CODE= ',X
[ 7] CTL1+' '
```

```
[ 0] X+FIND;N
[ 1] →0×10=1+ρSVS
[ 2] N+ρX+SVS[;4]
[ 3] X+((19)ε1, 2,N)ρX,Nρ' ')/19
```

```
[ 0] FIXBACK N;A;B;C
[ 1] →TWO×12=N
[ 2] A+AP
[ 3] AP+A[19;], 9 2 ρ0
[ 4] B+A[10 11 12 ;], 3 2 ρ0
[ 5] AP+AP,[1](2 11 ρ0).[1] B
[ 6] a FIXUP AS
[ 7] A+AS
[ 8] AS+A[19;], 9 2 ρ0
[ 9] B+A[10 11 12 ;], 3 2 ρ0
[10] AS+AS,[1](2 11 ρ0).[1] B
[11] a FIXUP PO
[12] PO+PO,5ρ0
[13] →0×11=N
[14] TWO:XF+XF,2ρ0
[15] XS+XS,2ρ0
[16] A+TS
[17] TS+A, 9 2 ρ0
[18] TS+TS,[1] 2 11 ρ0
[19] QX+QX, 5 2 ρ0
```



```
[ 0] FIXUP
[ 1] AP← 9 9 +AP
[ 2] AS← 9 9 +AS
[ 3] YF← 9 4 +YF
[ 4] Q← 5 9 +Q
[ 5] PO←PO[19]
```

```
[ 0] GIVE N
[ 1] 1'SVC',(NM),'+STEP,DEC,RES,NEW,MES,POL,STRAT,AST,LST'
```

```
[ 0] R←GVMAT LPX;LPPPX
[ 1] LPPPX← 2 1 3 Q(4 9 4 ρ(,LPX))
[ 2] R←(+/GBETA×LPPPX)+(0 1 +GALPHA)
```

```
[ 0] T←STEP IMPACT F
[ 1] REFORM F
[ 2] AREFORMED AP AS PO --YF Q REGS--TO FORM XF XS TS QX
[ 3] FIXUP
[ 4] XF←(+/YF)E((1(1+ρAP))•≡ 1+ρAP)-AP
[ 5] XS←XF×PO
[ 6] TS←AS+•DIAG XS
[ 7] QX←Q×(5,(ρXS))ρXS
[ 8] FIXBACK 2
[ 9] T←(,XF),(,XS),(,TS),(,QX)
[10] T← 2 198 ρT
```

```
[ 0] INTERNAL M;X
[ 1] LST[M]←1
[ 2] 'ACTOR',(NM),' MADE INTERNAL ('.ACTORS[M;],')'
[ 3] USVR X←(4 3 ρ'SVCSVDSVMSVN'), 4 1 ρNM
[ 4] UEX X
```

```
[ 0] LIST J;I;OUT
[ 1] J←SORT J
[ 2] I←1
[ 3] I←I+1×((+/ρCR J[I;])=0)
[ 4] '[', Q 0 ρ (ρOUT)[1],1)ρ0.1(ρOUT)[1]-1),']',' ',[2] OUT←CR J[I;]
[ 5] 2ρAV[160]
[ 6] I←I+1
[ 7] →3×I≤ρJ
```

```
[ 0] R←PKL LPRICE P;LPR;LPKL;LPX;LP1;LPR;LP2
[ 1] LPR← 9 4 4 ρ1
[ 2] LPKL←PKL
[ 3] PE←5+(4+P)
[ 4] PM←(4+P),P[10]
[ 5] LPEI←'E' SUBLPRICE PE
[ 6] LPMI←'M' SUBLPRICE PM
[ 7] LPX←(LPKL,LPEI),LPMI
[ 8] LPX←(9 1 ρ1),LPX
[ 9] LP1←+/(GALPHA×LPX)
[10] LPR[;1;]←LPX×Q(4 9 ρLPKL[;1])
[11] LPR[;2;]←LPX×Q(4 9 ρLPKL[;2])
[12] LPR[;3;]←LPX×Q(4 9 ρLPEI)
[13] LPR[;4;]←LPX×Q(4 9 ρLPMI)
[14] LP2←+//+0.5×(GBETA×LPR)
[15] R←LP1+LP2
```

```
[ 0] LST N;M;X
[ 1] ' ACT      PLAYER      VAR      VALUE'
[ 2] X←ACTIONS
[ 3] M←1+pX
[ 4] (5 0 M,1)p(M),((M,1)p' '), 10 1 10 1 15 -4 X
```

```
[ 0] NLIST ARG;MAT;LEN;L;ROWNUM;NUM
[ 1] MAT←(SORT ARG), ' '
[ 2] LEN←1+pMAT
[ 3] L←-1+pMAT
[ 4] NUM←[PW÷L
[ 5] ROWNUM←1+[LEN÷NUM
[ 6] (ROWNUM,L×NUM)pMAT,[1](NUM,L)p' '

```

```
[ 0] OFRN OFFER SVN;I
[ 1] I←1
[ 2] →(OFRNΛ,=370 [SVO.SVN])/0
[ 3] →(10≥I+I+0!DL 1)/2
[ 4] 'TSIO UNAVAILABLE. TRY AGAIN LATER'
[ 5] →

```

```
[ 0] PASSIVE M
[ 1] LST[M]←1+AST[M]←0
[ 2] 'ACTOR ',(M), ' (',ACTORS[M;],') IS NOW IN PASSIVE STATUS'

```

```
[ 0] PS+TS PASSIVEACTORS N;M;L;AT;AS;Q;P;S
[ 1] M←IMP[N;1;]
[ 2] L←IMP[N;4;]/16
[ 3] AT←(AS+MF[;M]-IMP[N; 2 3 ;])<IMP[N; 5 6 ;]
[ 4] AT[;L]←(AS>IMP[N; 5 6 ;])[;L]
[ 5] AT[;6]← 1 1
[ 6] COMPUTE POLICY INDEX-----
[ 7] P←((Q+AT)>0),1
[ 8] COMPUTE STRATEGY INDEX-----
[ 9] S←1+/(|AS[;P]-IMP[N; 5 6 ;P])>IMP[N; 5 6 ;P]
[10] PS+P,S

```

```
[ 0] Q←POLICYCHOOSE M;X
[ 1] →OUT×1DEF=1
[ 2] LAV[160]
[ 3] 'POLICY FOR ',ACTORS[M;], ' (ACTOR ',(M), ' )'
[ 4] →L×1FAST=1
[ 5] '(PRESENT POLICY: ',POLICY[M;POL[M];], ' )'
[ 6] '(DEFAULT POLICY: ',POLICY[M;DEFPOL[M];], ' )'
[ 7] LAV[160]
[ 8] P←X+QUOTE 'WOULD YOU LIKE YOUR POLICY OPTIONS? (Y OR N): '
[ 9] →Q←'Q'['YN' ERROR X]
[10] Q←L×10=pX
[11] →L×1'N'=X[1]
[12] (10 1 p,10)),(10 1 p' '),POLICY[M;;]
[13] L:LAV[160]
[14] 1 REVIEW'[1+16×(REV=1)^(FAST=0)]
[15] R←X+QUOTE 'ENTER POLICY CHOICE (DEF=0): '
[16] →S←'SR'['0123456789' ERROR X]
[17] S←OUT×10=pX
[18] →OUT×10=X+2X
[19] Q←POL[M]←X
[20] →0
[21] OUT:Q←POL[M]←DEFPOL[M]
```

```

[ 0] PROCESS;I;SAVE;A;X
[ 1] [AV[160]
[ 2] 'ENERGY ENVIRONMENT GAME: STEP= ';STEP
[ 3] [AV[160]
[ 4] '*****DECISION ENVIRONMENT SETUP *****'
[ 5] SETDECISION
[ 6] '*****DECISION ENVIRONMENT COMPLETED ****'
[ 7] RES←0
[ 8] FS← 3 500 ρ0
[ 9] SAVE← 2 1 ρ0
[10] I←DEC+1+RES←0
[11] [AV[160]
[12] '***** BEGIN ACTOR PROCESSING *****'
[13] [AV[160]
[14] L1:→L2×1AST[I]=1
[15] *PASSIVE ACTOR PROCESSING
[16] A←TS PASSIVEACTORS I
[17] POL[I]←A[1]
[18] STRAT[I]←A[2]
[19] →L1×110≥I+I+1
[20] →FIN
[21] *ACTIVE ACTOR PROCESSING
[22] L2:→L3×1LST[I]=0
[23] *-----INTERNAL ACTOR PROCESSING
[24] '***** INTERNAL ACTOR PROCESSING *****'
[25] STRAT[I]←I STRATCHOOSE POL[I]←POLICYCHOOSE I
[26] '*****'
[27] →L1×110≥I+I+1
[28] →FIN
[29] *-----EXTERNAL ACTOR PROCESSING
[30] L3:[AV[160]
[31] 'EXTERNAL ACTOR PROCESSED AT REMOTE TERMINAL--ACTOR ';I
[32] EXPROC I
[33] [AV[160]
[34] →L1×110≥I+I+1
[35] →FIN
[36] *CHECK IF ALL ACTION PLAYS ARE IN
[37] [AV[160]
[38] FIN:'***** ALL ACTORS PROCESSED *****'
[39] [AV[160]
[40] →IMP×10=+/SAVE[2;]
[41] SAVE←(SAVE[2;]≠0)/SAVE
[42] SGO:[AV[160]
[43] '***** RETURNED TO GAME MONITOR MODE *****'
[44] [AV[160]
[45] 'ACTION NOT COMPLETED BY PLAYERS ';SAVE[1;]
[46] P:X←QUOTE 'WILL YOU WAIT FOR RESULTS? (WAIT STOP OR NOTIFY): '
[47] →2'QP'['WSN' ERROR X]
[48] Q:→2'LMN'[(X[1]='WSN')/13]
[49] *WAIT SEQUENCE
[50] L:SAVE←EXPROCX SAVE
[51] SAVE←(SAVE[2;]≠0)/SAVE
[52] →LL×10≠1↑ρSAVE
[53] 'ALL ACTION STEPS NOW COMPLETED FOR STEP ';STEP
[54] [AV[160]
[55] →IMP

```

```

[56] LL:-L,DDL 10
[57] M:STOP
[58] -SGO
[59] N:'NOTIFY SEQUENCE NOT AVAILABLE--STOP ENACTED'
[60] STOP
[61] -SGO
[62] *IMPACT ANALYSIS SEQUENCE
[63] IMP:'IMPACT ANALYSIS EXECUTION SEQUENCE UNDER DEVELOPMENT'
[64] FS-ACTIONS
[65] S+ρSAVE+(LST=0)/110
[66] T+STEP IMPACT F
[67] +OUT×110=+/LST≠0
[68] RES+1+DEC+0
[69] *MAKE RESULTS AVAIL TO EXTERNAL ACTORS
[70] I+1
[71] I1:GIVE SAVE[I]
[72] *SVD',(ρSAVE[I]),'+T'
[73] +I1×1S≥I+I+1
[74] RESULTX
[75] *RESET EXT ACTORS FOR NEXT STEP
[76] STEP+STEP+1
[77] I+1
[78] I2:GIVE I
[79] +I2×1S≥I+I+1
[80] OUT:DAV[160]
[81] 'GAME STEP COMPLETED ,SYSTEM RESET FOR STEP ':STEP
[82] DAV[160]

```

```

[ 0] X+Z QUEST MES
[ 1] P:X+QUOTE MES
[ 2] +*QP'[Z ERROR X]
[ 3] Q:+0

```

```

[ 0] X+QUOTE MES;Y
[ 1] Y+,0,0+MES
[ 2] Y+(-ρMES)+Y
[ 3] X+(Y≠' ')/Y

```

```

[ 0] X+RECEIVE I;Y;NN;MM
[ 1] X+*SVD',(ρI),'[ 1]'
[ 2] +GO×12=+/X=STEP,1
[ 3] X+ 2 1 ρI,1
[ 4] +0
[ 5] GO:X+ 2 1 ρI,0
[ 6] *ACTION
[ 7] Y+ 0 1 +*SVD',ρI
[ 8] F[1;1+Y[1;]]+1+Y[2;]
[ 9] *SAVE ACTIONS FILE
[10] NN+ρMM+1+Y[1;]
[11] FS[;MM]+(3,NN)ρ(NNρI),MM,1+Y[2;]

```

```
[ 0] REFORM SV
[ 1] SV←SV[1;]
[ 2] PKL← 2 11 ρSV[122]
[ 3] PEN←SV[22+15]
[ 4] PMAT←SV[27+16]
[ 5] PO←SV[33+14]
[ 6] AS← 14 11 ρSV[47+1154]
[ 7] AP← 14 11 ρSV[201+1154]
[ 8] YF← 11 4 ρSV[355+144]
[ 9] Q← 5 11 ρSV[399+155]
[10] REGS←SV[454+111]
```

```
[ 0] RESET;N;I;S
[ 1] STEP←1+DEC←RES←MES←NEW←0
[ 2] N←ρS+(LST=0)/110
[ 3] →0×10=ρS
[ 4] I←1
[ 5] L:GIVE S[I]
[ 6] 2'SVD',(S[I]),'←T'
[ 7] →L×1N≥I+I+1
```

```
[ 0] RESULTX;I;X;Y;Z;A;B
[ 1] Y←ρX←FIND
[ 2] I←1
[ 3] Z←10
[ 4] L:Z←Z,2'SVC',(X[I]),'[5]'
[ 5] →L×1Y≥I+I+1
[ 6] A←(Z)/X
[ 7] →0×10=ρA
[ 8] [AV[160]
[ 9] 'RESULTS NOT ACCESSED BY ACTORS 'A
[10] Q:B←QUOTE 'WAIT STOP OR PROCEED WITH EXECUTION: '
[11] →2'ZQ'[C←'WSP' ERROR B]
[12] Z:→2'RST'[(WSP=B[1])/13]
[13] R:→1,[DL 20
[14] S:'EXECUTION STOPPED'
[15] 'TYPE ''→9'' TO PROCEED'
[16] [AV[160]
[17] T:[AV[160]
[18] 'PROCESSING RESUMED'
[19] [AV[160]
[20] I←1
[21] L2:2'SVC',(X[I]),'[5]←0'
[22] →L2×1Y≥I+I+1
```

```
[ 0] REVIEW;X
[ 1] P:X←QUOTE 'WOULD YOU LIKE A DECISION ENVIRONMENT REVIEW SESSION? (Y OR N): '
[ 2] →2'QP'['YN' ERROR X]
[ 3] Q:→L×1X[1]='N'
[ 4] 'PROCEED WITH REVIEW'
[ 5] 'TYPE ''→6'' TO RESUME'
[ 6] [AV[160]
[ 7] 'PROCESSING RESUMED'
[ 8] L:[AV[160]
```

```
[ 0] SAVEGAME;XY
[ 1] TSIOSTART
[ 2] TSIOWRITE STEP
[ 3] XY←LEX 4 4 ρ'CTL1CTL2DAT1DAT2'
```

```
[ 0] SETDECISION;X;Y;Z;N;I
[ 1] X←'YN' QUEST 'DO YOU WANT TO DEFAULT THE DECISION ENVIRONMENT SETUP: (Y OR N): '
[ 2] N←(('YN'=X[1])/12)
[ 3] ADEFAULT OPTIONS
[ 4] A:PKL←PKLDEF
[ 5] PEN←PENDEF
[ 6] PMAT←PMATDEF
[ 7] Q←QDEF
[ 8] YF←YDEF
[ 9] REGS←REGSDEF
[10] DESCRIPT←((10 0 ▼GAME,STEP),(80ρ' ')),[1] DESDEF
[11] LAV[160]
[12] →TWO×1N=1
[13] B:LAV[160]
[14] →GO×10=REV
[15] 'DECISION ENVIRONMENT ELEMENTS:'
[16] ' 1 KLEM PRICES'
[17] ' 2 FINAL DEMANDS'
[18] ' 3 POLLUTION COEFFICIENTS'
[19] ' 4 ESTABLISHED REGULATIONS'
[20] ' 5 VERBAL DESCRIPTION OF DEC ENVIRONMENT'
[21] GO:ENTER THE INDICIES OF THE OPTIONS YOU WOULD LIKE TO SET:
[22] N←,N←[]
[23] O1:→O2×10=+/1=N
[24] 'ENTER CAPITAL PRICES (ρ=11)'
[25] Y←CHK 11
[26] 'ENTER LABOR PRICES (ρ=11)'
[27] Z←CHK 11
[28] PKL←Q 2 11 ρY,Z
[29] 'ENTER ENERGY PRICES (ρ=5)'
[30] PEN←CHK 5
[31] 'ENTER MATERIAL PRICES (ρ=6)'
[32] PMAT←CHK 6
[33] LAV[160]
[34] 'OPTIONED PRICES ENTERED'
[35] LAV[160]
[36] O2:→O3×10=+/2=N
```

```

[37] 'ENTER NEW FINAL DEMAND LEVELS'
[38] '    FINAL DEMAND SECTORS:'
[39] '    1 PERSONAL CONSUMPTION'
[40] '    2 GROSS PRIVATE DOMESTIC INVESTMENT'
[41] '    3 NET EXPORTS OF GOODS AND SERVICES'
[42] '    4 GOVERNMENT EXPENDITURES'
[43] 'ENTER SECTOR 1 VALUES (p=11 OR 0 FOR DEFAULT VALUES)'
[44] →Y2×11=pX+,X+[]
[45] YF[;1]+11 CHK1 X
[46] Y2:'ENTER SECTOR 2 VALUES (p=11 OR 0 FOR DEFAULT VALUES)'
[47] →Y3×11=pX+,X+[]
[48] YF[;2]+11 CHK1 X
[49] Y3:'ENTER SECTOR 3 VALUES(p=11 OR 0 FOR DEFAULT VALUES)'
[50] →Y4×11=pX+,X+[]
[51] YF[;3]+11 CHK1 X
[52] Y4:'ENTER SECTOR 4 VALUES (p=11 OR 0 FOR DEFAULT VALUES)'
[53] →Y5×11=pX+,X+[]
[54] YF[;4]+11 CHK1 X
[55] Y5:'ALL FINAL DEMANDS ENTERED'
[56] O3:→O4×10=+/3=N
[57] 'ENTER NEW POLLUTION COEFFICIENTS'
[58] '    ENTER MATRIX OF POLLUTION COEFFICIENTS (p=5×11)'
[59] Q+ 5 11 pX+[]
[60] 'ALL POLLUTION COEFFICIENTS ENTERED'
[61] O4:→O5×10=+/4=N
[62] 'ENTER NEWLY ESTABLISHED REGULATIONS'
[63] 'NOT AVAILABLE YET'
[64] [AV[160]]
[65] O5:→O6×10=+/5=N
[66] ADECISION ENVIRONMENT DESCRIPTION
[67] GAME DESCRIBE STEP
[68] O6:'ALL OPTIONS ENTERED'
[69] TWO:[AV[160]]
[70] ATEMPORARY FIXUP-----
[71] PKLX+PKL[19;]
[72] PEN+PEN
[73] PMATX+PMAT[14]
[74] PKLX AMATRIX PMATX,PEN,2
[75] FIXBACK 1
[76] AEND TEMPORARY FIXUP-----
[77] ASEND RESULTS TO ACTIVE ACTORS
[78] →SS×10=1+pSVS
[79] N+pX+FINF
[80] I+1
[81] L:1'SVN',(X[I]),'+(,PKL),PEN,PMAT,PO,(,AS),(,AP),(,YF),(,Q),,REGS'
[82] 1'SVM',(X[I]),'+DESCRIPT'
[83] →L×1N≥I+I+1
[84] ASAVE FOR TSIO
[85] SS:F+(,PKL),(PEN),PMAT,PO,(,AS),(,AP),(,YF),(,Q),,REGS
[86] MF+F+(2,pF)pF

```

```

[ 0] LEN+SIZE A
[ 1] LEN+(12+(4×ppA)).4×[0.25×(×/pA)×BPE 1+0pA

```

```

0] ARG←SOM;A1;MAX
1] 'FNS?'
2] ARG← 1 1 p' '
3] LOOP:→(0=ρA1←,[])/FINIS
4] →((¬1↑ρARG)=MAX+[(¬1↑ρARG),ρA1])/BELOW
5] ARG←ARG,(((ρARG)[1]),MAX-(ρARG)[2])ρ' '
6] →SET
7] BELOW:A1←A1,(MAX-ρA1)ρ' '
8] SET:ARG←ARG,[1] A1
9] →LOOP
10] FINIS:ARG← 1 0 →ARG

```

```

[ 0] R←SORT M;S
[ 1] S←A6610[AV[153,86+164]]M
[ 2] R←M[S;]

```

```

[ 0] START
[ 1] DEF←FAST←0
[ 2] REV←1
[ 3] AST← 1 0 0 0 0 0 0 0 0 1
[ 4] LST←10ρ1
[ 5] STEP←1
[ 6] DEC←0
[ 7] RES←0
[ 8] MES←0
[ 9] NEW←0
[10] →
[11] →
[12] →

```

```

[ 0] STATUS
[ 1] SAVE←EXPROCX SAVE
[ 2] SAVE←(SAVE[2;]≠0)/SAVE
[ 3] 1' SAVE←2 1ρ1 0'[1+13×(¬1↑ρSAVE)=0]
[ 4] SAVE

```

```

[ 0] STOP
[ 1] [AV[160]
[ 2] 'PLAY SUSPENDED UNTIL RESUMED'
[ 3] 'TYPE '←4' TO RESUME'
[ 4] [AV[160]
[ 5] 'PLAY RESUMED'
[ 6] [AV[160]

```



```
[ 0] Q←M STRATCHOOSE N;X
[ 1] →OUT×1DEF=1
[ 2] [AV[160]
[ 3] 'STRATEGY FOR ',ACTORS[M;]
[ 4] 'CURRENT POLICY: ',POLICY[M;N;]
[ 5] '(DEFAULT STRATEGY: ',(1'STRAT',(M ;'[N;DEFSTRAT[M;:]'))' )'
[ 6] →L×1FAST=1
[ 7] P:X←QUOTE 'WOULD YOU LIKE YOUR STRATEGY OPTIONS? (Y OR N): '
[ 8] →1'QP'['YN' ERROR X]
[ 9] Q:→L×10=ρX
[10] →L×1'N'=X[1]
[11] [AV[160]
[12] (9 9 1 ρ15)),(5 1 ρ' '), (1'STRAT',(M),'[N;:]')
[13] L:[AV[160]
[14] R:X←QUOTE 'ENTER STRATEGY CHOICE (DEF=0): '
[15] →1'SR'['012345' ERROR X]
[16] S:→OUT×10=ρX
[17] →OUT×10=X+1X
[18] Q←STRAT[M]+X
[19] →0
[20] OUT:Q←STRAT[M]+DEFSTRAT[M]
```

```
[ 0] R←NAME SUBLPRICE P;P;D1;D;PP;LP1;LPP;LPPP;DD;LP2
[ 1] P←(*1),P
[ 2] D1←ρP
[ 3] D←D1-1
[ 4] PP←(PP+9,D1)ρP
[ 5] LP1←+/(1NAME,'ALPHA','×PP')
[ 6] LPP←(PP)×(PP)
[ 7] LPPP←(DD+9,D,D)ρ,LPP
[ 8] LP2←1'+/+.5×(LPPP×',NAME','BETA)')
[ 9] R←LP1+LP2
```

```
[ 0] S←SVS
[ 1] S←((0≠SVO [NL 2])/[LIO] [NL 2])
```

```
[ 0] TSIOINITIAL STEP;X;ER
[ 1] X←'SW DSN=',(FILEREF),' STEP',STEP
[ 2] X←X,',DISP=NEW,RECFM=FB,CODE=E'
[ 3] X←X,',BLKSIZE=12000,LRECL=1000'
[ 4] X←X,',SPACE=(12000,(3,1))'
[ 5] CTL1←X
[ 6] →ERROR×10≠+/ER←CTL1
[ 7] 'FILE 'STEP',(STEP),' ' ALLOCATED TO OLS'
[ 8] CTL1←' '
[ 9] →0
[10] ERROR:[AV[160]
[11] 'ERROR IN TSIO: CODE= ',ER
[12] [AV[160]
[13] CTL1←' '
```

```
[ 0] TSIOSTART
[ 1] 2 1 OFFER 2 4 ρ'CTL1DAT1'
[ 2] 2 1 OFFER 2 4 ρ'CTL2DAT2'
[ 3] [AV[160]
[ 4] 'TSIO LINK SUCCESSFUL:'
[ 5] 'SV'S=CTL1,DAT1,CTL2,DAT2'
[ 6] [AV[160]
[ 7] →0
```

```

0] ARG←SQ1;A1;MAX
1] 'FMS?'
[ 2] ARG← 1 1 p' '
[ 3] LOOP:→(0=pA1+,□)/FINIS
[ 4] →((¬1+pARG)=MAX+[/ (¬1+pARG),pA1)/BELOW
[ 5] ARG←ARG,(((pARG)[1]),MAX-(pARG)[2])p' '
[ 6] →SET
[ 7] BELOW:A1+A1,(MAX-pA1)p' '
[ 8] SET:ARG←ARG,[1] A1
[ 9] →LOOP
[10] FINIS:ARG← 1 0 +ARG

```

```

[ 0] R←SORT M;S
[ 1] S←16610□AV[153,86+164]1M
[ 2] R←M[S;]

```

```

[ 0] START
[ 1] DEF←FAST+0
[ 2] REV←1
[ 3] AST← 1 0 0 0 0 0 0 0 0 1
[ 4] LST←10p1
[ 5] STEP←1
[ 6] DEC←0
[ 7] RES←0
[ 8] MES←0
[ 9] NEW←0
[10] →
[11] →
[12] →

```

```

[ 0] STATUS
[ 1] SAVE←EXPROCX SAVE
[ 2] SAVE←(SAVE[2;]≠0)/SAVE
[ 3] 1' SAVE+2 1p1 0'[1+13×(¬1+pSAVE)=0]
[ 4] SAVE

```

```

[ 0] STOP
[ 1] □AV[160]
[ 2] 'PLAY SUSPENDED UNTIL RESUMED'
[ 3] 'TYPE ''+4'' TO RESUME'
[ 4] □AV[160]
[ 5] 'PLAY RESUMED'
[ 6] □AV[160]

```

```

[ 0] TSIOWRITE STEP;N;M;X;Y;ER;I;MN;J
[ 1] X←'SW DSN='; FILEREF)' STEP',STEP
[ 2] X←X,' ,DISP=OLD,LRECL=1000,BLKSIZE=12000'
[ 3] X←X,' ,CODE=E,RECFM=FB'
[ 4] CTL1←X
[ 5] →ERROR×10÷+/ER←CTL1
[ 6] ADEC ENVR DESCRIPTION
[ 7] N←1↑pDESCRIPT
[ 8] CTL1← 10 0 W,99p0
[ 9] →ERROR×10÷+/ER←CTL1
[10] MN←pX←(1000-1000|p(,DESCRIPT))p' '
[11] 1' MN←pX←(1000-p,DESCRIPT)p' ' '[1+127×1000>p,DESCRIPT]
[12] M←pDESCRIPT←(,DESCRIPT),X
[13] I←0
[14] L1:CTL1←DESCRIPT[I+11000]
[15] →ERROR×10÷+/ER←CTL1
[16] →L1×1M>I←I+1000
[17] ARESTORE DESCRIPT
[18] DESCRIPT←(N,100)p(←MN)+DESCRIPT
[19] A ACTIONS SUMMARY
[20] N←1↑pFS
[21] CTL1← 10 0 W,99p0
[22] →ERROR×10÷+/ER←CTL1
[23] MN←pX←(100-100|p(,FS))p0
[24] 1' MN←pX←(100-p,FS)p0'[1+118×100>p,FS]
[25] M←pFS←(,FS),X
[26] I←0
[27] L3:CTL1← 10 -4 WFS[I+1100]
[28] →ERROR×10÷+/ER←CTL1
[29] →L3×1M>I←I+100
[30] ARESTORE TS
[31] FS←(3,N)p(←MN)+FS
[32] A MODELING FACTORS
[33] MF←MF, 2 35 p0
[34] I←1+J←0
[35] L4:CTL1← 10 -4 WMF[E J+1100]
[36] →ERROR×10÷+/ER←CTL1
[37] →L4×1400≥J←J+100
[38] →L4×12≥I←I+1+J←0
[39] ARESTORE MODELING FACTORS
[40] MF← 0 -35 WMF
[41] A RESULTS
[42] I←1+J←0
[43] T←T, 2 2 p0
[44] L5:CTL1← 10 -4 WT[I;J+1100]
[45] →ERROR×10÷+/ER←CTL1
[46] →L5×1100≥J←J+100
[47] →L5×12≥I←I+1+J←0
[48] ARESTORE RESULTS (T)
[49] T← 0 -2 WT
[50] CTL1←''
[51] →0
[52] ERROR:[AV[160]
[53] 'ERROR IN TSIO: CODE= ';ER
[54] CTL1←''

```

```

[ 0] R←NAME VMAT P;LP;D;DD;LPPP
[ 1] LP←P
[ 2] D←pP
[ 3] LPPP←(DD+9,D,D)pLP
[ 4] R←1'(+/(,NAME,'BETA×LPPP))+(0 1+',NAME,'ALPHA)'

```

PLAYER WORKSPACE:

```
[ 0] X←ACTION PS
[ 1] →DEF×,FUNIDX[PS[1];PS[2];PS[3]]=0
[ 2] →X←STRAT', 1 0 →PS
[ 3] X←(2 1 ρSTEP,1),X
[ 4] →0
[ 5] DEF:X←STRATDEF
[ 6] →0
```

```
[ 0] ACTIVATE N
[ 1] FUNIDX[N[1];N[2];N[3]]←1
```

```
[ 0] ADDITIONAL ID;X
[ 1] REV←1+FAST←DEF←0
[ 2] [AV[160]
[ 3] →HEADER
[ 4] 50ρ'★'
[ 5] 'REGIONAL ENERGY ENVIRONMENT GAME (PHASE II)'
[ 6] 'ADDITIONAL ACTOR SPECIFICATION'
[ 7] [AV[160]
[ 8] [AV[160]
[ 9] ACTORS[ID;],'- ACTIVE EXTERNAL PLAYER ':ID
[10] 'HOST COMMUNICATION STATUS (HOST USER NO.= ', →HOST) )'
[11] '-----SV OFFER STATUS'
[12] HOST [SVO X←(4 3 ρ'SVCSVDSVNSVM'),(4 1 ρID)
[13] '-----ACV STATUS'
[14] (4 4 ρ0) [SVC X
[15] '-----GAME STATUS'
[16] GET
[17] CVS
[18] 50ρ'★'
[19] [AV[160]
```

```
[ 0] ARG←ALL
[ 1] ARG←[NL 3
```

```
[ 0] ANALYSIS
[ 1] →DUMMY ANALYSIS FUNCTION
```

```
[ 0] CHECK ID;M
[ 1] →A×11→M→SVC 5
[ 2] □AV[160]
[ 3] 'MESSAGE: '
[ 4] →'SVM',→ID
[ 5] 5 SVSET 0
[ 6] A:→B×11→M→SVC 4
[ 7] □AV[160]
[ 8] 'LATEST NEWS: (STEP= ', →M→SVC 1), ' )'
[ 9] →'SVN',→ID
[10] 4 SVSET 0
[11] B:→C×11→M→SVC 2
[12] □AV[160]
[13] 'DECISION ENVIRONMENT SETUP NOW COMPLETED'
[14] C:→D×11→M→SVC 3
[15] 'RESULTS OF GAME STEP NOW AVAILABLE'
[16] D:□AV[160]
[17] NOT→0
```

```
[ 0] CVS
[ 1] 'DEF= ',(→DEF), ' DEF=1 FOR ALL DEFAULT OPTIONS'
[ 2] 'REV= ',(→REV), ' REV=1 FOR ALL REVIEW OPTIONS'
[ 3] 'FAST= ',(→FAST), ' FAST=1 FOR FAST OPTIONS'
[ 4] 'AST= ', →AST), ' **=1 FOR ACTIVE (ACTOR STATUS) '
[ 5] 'LST= ',(→LST), ' **=1 FOR INTERNAL (ACTOR LOCATION STATUS)'
```

```
[ 0] DEACIVATE
[ 1] FUNIDX[N1[];N[2];N[3]]→0
```

```
[ 0] DESCRIPTION;N
[ 1] □AV[160]
[ 2] N→→DESCRIPT[1;120]
[ 3] □AV[160]
[ 4] 'DECISION ENVIRONMENT DESCRIPTION'
[ 5] 'GAME= ',(→N[1]), ' STEP= ',→N[2]
[ 6] □AV[160]
[ 7] 1 0 →DESCRIPT
[ 8] □AV[160]
```

```
[ 0] ENVREVIEW;X;Y;Z;N;I
[ 1] [AV[160]
[ 2] 'THESE ARE YOUR REVIEW OPTIONS'
[ 3] [AV[160]
[ 4] ' 1 DECISION ENVIRONMENT VERBAL DESCRIPTION'
[ 5] ' 2 PRESENT CAPITAL AND LABOR PRICES'
[ 6] ' 3 PRESENT ENERGY PRICES'
[ 7] ' 4 PRESENT MATERIAL INPUT PRICES'
[ 8] ' 5 INDUSTRY OUTPUT PRICES'
[ 9] ' 6 INDUSTRY TECHNICAL COEFFICIENTS (PHYS UNITS)'
[10] ' 7 INDUSTRY TECHNICAL COEFFICIENTS ($ AT PROD PRICES)'
[11] ' 8 FINAL DEMANDS'
[12] ' 9 POLLUTION COEFFICIENTS'
[13] '10 ESTABLISHED REGULATORY STANDARDS'
[14] [AV[160]
[15] W:'LIST INDICIES OF THE OPTIONS YOU WOULD LIKE TO REVIEW: '
[16] X+,X+[]
[17] +Zx,0=+/X>10
[18] 'OPTION CHOICE TOO LARGE--PLEASE REENTER'
[19] +W
[20] Z:I+1
[21] N+pX
[22] L:1 PRINT X[I]
[23] +Lx,N>I+I+1
```

```
[ 0] C+A ERROR B;N
[ 1] +3x,0=pB
[ 2] +Lx,0+/(B+,B)[1]eA
[ 3] [AV[160]
[ 4] 'INCORRECT RESPONSE****'
[ 5] 'MUST BEGIN WITH: ',1+,q 2.N)pA,(N+pA)p',
[ 6] ' PLEASE REENTER '
[ 7] [AV[160]
[ 8] C+2
[ 9] +0
[10] L:C+1
[11] +0
```

```
[ 0] X+FIND;N
[ 1] +Lx,0=1+pSVS
[ 2] N+pX+SVS[;4]
[ 3] X+((19)e2,q 2.N)pX,Np' ')/19
[ 4] +0
[ 5] L:X+,0
```

```
[ 0] GET;SV
[ 1] SV+2'SVC',+ID
[ 2] STEPR+SV[1]
[ 3] DEC+SV[2]
[ 4] RES+SV[3]
[ 5] NEW+SV[4]
[ 6] MFS+SV[5]
[ 7] POL+SV[5+110]
[ 8] STRAT+SV[15+110]
[ 9] AST+SV[25+110]
[10] LST+SV[35+110]
```

```
[ 0] GETS ID;SV
[ 1] SV←2'SVC',▽ID
[ 2] STEP←SV[1]
[ 3] DEC←SV[2]
[ 4] RES←SV[3]
[ 5] NEW←SV[4]
[ 6] MES←SV[5]
[ 7] POL←SV[5+10]
[ 8] STRAT←SV[15+10]
[ 9] AST←SV[25+10]
[10] LST←SV[35+10]
```

```
[ 0] LIST J;I;OUT
[ 1] J←SORT J
[ 2] I←1
[ 3] I←I+1×((+ /ρ□CR J[I;])=0)
[ 4] '[' 2 0 ▽ (ρOUT)[1],1)ρ0.1(ρOUT)[1]-1).')'. ' ',[2] OUT←□CR J[I ]
[ 5] 2ρ□AV[160]
[ 6] I←I+1
[ 7] →3×I≤ρJ
```

```
[ 0] NEWS
[ 1] □AV[160]
[ 2] 'NEWSPAPER: STEP= ' ;STEP
[ 3] □AV[160]
[ 4] ▽ LASTNEWS←2'SVN',▽ID
[ 5] NEW←0
```

```
[ 0] NLIST ARG;MAT;LEN;L;ROWNUM;NUM
[ 1] MAT←(SORT ARG), ' '
[ 2] LEN←1+ρMAT
[ 3] L←1+ρMAT
[ 4] NUM←[□PW÷L
[ 5] ROWNUM←1+[LEN÷NUM
[ 6] (ROWNUM,L×NUM)ρMAT.[1](NUM,L)ρ' '
```

```
[ 0] PLAY ID;M;N;X;Y;I
[ 1] →2'YZ'[1+PLAYERERROR ID]
[ 2] ▽ →G×10→2'ZIP',(▽ID)
[ 3] GET LATEST INFORMATION
[ 4] GET
[ 5] ADECISION ENVIRONMENT STATUS CHK-----
[ 6] G:→2'ABC'[1+2'ZIP',▽ID]
[ 7] A:→B×11→ 2'SVC',▽ID)[2]
[ 8] 'DECISION ENVIRONMENT SETUP FOR STEP ',(▽STEP),' NOT COMPLETED'
[ 9] P:X←QUOTE 'WAIT STOP OR NOTIFY? :'
[10] →2'QP'['WSN' ERROR X]
[11] Q:→2'ABC'[( 'WSN'=X[1])/13]
[12] AWAIT SEQUENCE
[13] A:→A1×11→(2'SVC',▽ID)[2]
[14] □AV[160]
[15] 'DECISION ENVIRONMENT SETUP COMPLETED (STEP= ', ▽STEP),' )'
[16] →B
[17] □AV[160]
```

```

[18] A1:→A,DL 10
[19] ASTOP SEQUENCE
[20] B:STOP 0
[21] →0
[22] ANOTIFY SEQUENCE
[23] C:NOT←1
[24] [AV[160]
[25] 'YOU WILL BE NOTIFIED WHEN'
[26] 'DECISION ENVIRONMENT SETUP IS COMPLETE'
[27] [AV[160]
[28] STOP 0
[29] →0
[30] APOLICY STRATEGY ACTION PROCESSING-----
[31] [AV[160]
[32] B:→C×12=1'ZIP',ID
[33] 'DECISION ENVIRONMENT SETUP COMPLETE--STEP ':STEP
[34] 'ACTOR PROCESSING UNDERWAY'
[35] RETRIEVE ID
[36] 1'ZIP',(ID),'+2'
[37] [AV[160]
[38] STRAT[ID]←ID STRATCHOOSE POL[ID]←POLICYCHOOSE ID
[39] [AV[160]
[40] 'STRATEGY EXECUTION ****STEP ':STEP
[41] 1'SVD',(ID),'+ ACTION X←ID,POL[ID],STRAT[ID]'
[42] [AV[160]
[43] C:→D×11=4←SVC 3
[44] 'STRATEGY EXECUTED-GAME STEP ',(ID),' RESULTS BEING PROCESSED'
[45] X←'WSN' QUEST 'WILL YOU WAIT FOR RESULTS? (WAIT,STOP, OR NOTIFY): '
[46] →1'DEF'[( 'WSN'=X[1])/13]
[47] AWAIT SEQUENCE
[48] D:→D1×11=(1'SVC',ID)[3]
[49] 'RESULTS OF GAME STEP AVAILABLE--STEP ':STEP
[50] [AV[160]
[51] 'TYPE 'PROCEED ',(ID),' TO NOTIFY CONTROL'
[52] 'THAT YOU ARE READY FOR THE NEXT GAME STEP'
[53] [AV[160]
[54] STOP 2
[55] →END
[56] D1:→D,DL 20
[57] ASTOP SEQUENCE
[58] E:STOP 2
[59] →0
[60] ANOTIFY SEQUENCE
[61] F:NOT←1
[62] 'YOU WILL BE NOTIFIED WHEN'
[63] 'GAME STEP RESULTS ARE AVAILABLE'
[64] [AV[160]
[65] 'TYPE PROCEED ',(ID),' TO NOTIFY CONTROL'
[66] 'THAT YOU ARE READY TO PROCEED TO THE NEXT GAME STEP'
[67] [AV[160]
[68] →0
[69] END:[AV[160]
[70] 2 SVSET 0
[71] 3 SVSET 1
[72] →0
[73] Y:→0

```



```
[ 0] X←PLAYERERROR ID
[ 1] →L×1ID←FIND
[ 2] '***PLAYER ',(ID),' NOT IN ACTIVE EXTERNAL STATUS'
[ 3] X←0
[ 4] →0
[ 5] L:X←1
```

```
[ 0] Q←POLICYCHOOSE M;X
[ 1] →OUT×1DEF=1
[ 2] [AV[160]
[ 3] 'POLICY FOR ',ACTORS[M;],' (ACTOR ',(M),' )'
[ 4] →L×1FAST=1
[ 5] '(PRESENT POLICY: ',POLICY[M;POL[M;],' )'
[ 6] '(DEFAULT POLICY: ',POLICY[M;DEFPOL[M;],' )'
[ 7] [AV[160]
[ 8] P:X←QUOTE 'WOULD YOU LIKE YOUR POLICY OPTIONS? (Y OR N): '
[ 9] →P'QP'['YN' ERROR X]
[10] Q:→L×10=PX
[11] →L×1'N'=X[1]
[12] (P 10 1 p 10),(10 1 p' '),POLICY[M;]
[13] L:[AV[160]
[14] P' REVIEW'[1+16×(REV=1)^(FAST=0)]
[15] R:X←QUOTE 'ENTER POLICY CHOICE (DEF=0): '
[16] →P'SR'['0123456789' ERROR X]
[17] S:→OUT×10=PX
[18] →OUT×10=X+PX
[19] Q←POL[M]←X
[20] →0
[21] OUT:Q←POL[M]←DEFPOL[M]
```

```
[ 0] N PRINT M;X;Y;Z;LABS;S
[ 1] [AV[160]
[ 2] S←[AV[160]
[ 3] LABS←'ABCDEFGHJKLMNOP'
[ 4] →LABS[M+10×N=2]
[ 5] S←[AV[160]
[ 6] A:S
[ 7] DESCRIPTION
[ 8] 2pS
[ 9] →0
[10] B:'CAPITAL AND LABOR PRICES'
[11] X←LAB14[11;]
[12] ' INDUSTRY
[13] '
[14] X,(11 2 p' '), 15 5 PKL
[15] 2pS
[16] →0
[17] C:'ENERGY PRICES'
[18] X←LAB14[5 6 7 8 9 ;]
[19] 'ENERGY OUTPUT PRICE($)/UNIT'
[20] X,(((1+pX),2)p' '), 15 5 5 1 pPEN
[21] 2pS
[22] →0
[23] D:'MATERIAL INPUT PRICES'
[24] X←LAB14[(14). 10 11 ;]
[25] 'INDUSTRY PRICE($)/UNIT'
[26] X,(((1+pX),2)p' '), 15 5 6 1 pPMAT
[27] 2pS
[28] →0
[29] E:'INDUSTRY OUTPUT PRICES'
```

PRICE(\$)/UNIT'
CAPITAL LABOR'

PRICE(\$)/UNIT'

[30] X+LAB14
 [31] X,(((1+pX),2)p' '), 15 5 ▽ 14 1 pPO
 [32] 2pS
 [33] →0
 [34] F:'TECHNICAL COEFFICIENTS (PHYS UNITS)'
 [35] [AV[160]
 [36] LAB14, 8 5 ▽AP
 [37] 2pS
 [38] →0
 [39] G:'TECHNICAL COEFFICIENTS (\$ AT PROD PRICES)'
 [40] [AV[160]
 [41] LAB14, 8 5 ▽AS
 [42] 2pS
 [43] →0
 [44] H:'FINAL DEMANDS'
 [45] [AV[160]
 [46] X+LAB14[111;]
 [47] 'INDUSTRY PERS CONS GOVT
 [48] X,(((1+pX),2)p' '), 15 5 ▽YF
 [49] 2pS
 [50] →0
 [51] I:[AV[160]
 [52] 'POLLUTION COEFFICIENTS'
 [53] [AV[160]
 [54] 'INDUSTRY SO2 NOX HC
 [55] X+LAB14[111;]
 [56] X,(((1+pX),2)p' '), 15 5 ▽Q
 [57] 2pS
 [58] →0
 [59] J:'EXISTING REGULATIONS'
 [60] [AV[160]
 [61] 'THIS OPTION NOT AVAILABLE YET'
 [62] 2pS
 [63] →0
 [64] K:'RESULTS: TOTAL OUTPUTS (PHYSICAL UNITS)'
 [65] [AV[160]
 [66] 'INDUSTRY OUTPUT'
 [67] LAB14[111;], 15 5 ▽ 11 1 pXF
 [68] [AV[160]
 [69] 2pS
 [70] →0
 [71] L:'RESULTS: TOTAL OUTPUTS (CURRENT DOLLARS)'
 [72] [AV[160]
 [73] 'INDUSTRY VALUE OF OUTPUT(\$)'
 [74] LAB14[111;], 15 5 ▽ 11 1 pXS
 [75] 2pS
 [76] →0
 [77] M:'INTERINDUSTRY TRANSACTIONS (CURRENT DOLLARS)'
 [78] [AV[160]
 [79] LAB14[111;], 8 5 ▽TS
 [80] 2pS
 [81] →0
 [82] N:'POLLUTION LEVELS'
 [83] [AV[160]
 [84] 'INDUSTRY XX XX XX XX XX
 [85] 'OPTION NOT AVAILABLE YET'
 [86] 2pS
 [87] →0
 [88] O:'NON EXISTENT OPTION'
 [89] →0
 [90] P:'NON EXISTENT OPTION'
 [91] →0

```

[ 0] PROCEED I;N
[ 1]  $\mathbf{z} \leftarrow \mathbf{SVC}', (\mathbf{vF}), '[5] \leftarrow 1'$ 
[ 2]  $\mathbf{z} \leftarrow \mathbf{ZIP}', (\mathbf{vF}), '\leftarrow 0'$ 
[ 3]  $\mathbf{N} \leftarrow \rho \mathbf{FIND}$ 
[ 4]  $\mathbf{STEP} \leftarrow \mathbf{STEP} + 1 * \mathbf{N} = + / \mathbf{STP}[\mathbf{FIND}] = \mathbf{STP}[\mathbf{I}] + \mathbf{STP}[\mathbf{I}] + 1$ 

```

```

[ 0]  $\mathbf{X} \leftarrow \mathbf{Z} \text{ QUEST MES}$ 
[ 1]  $\mathbf{P} \leftarrow \mathbf{X} \leftarrow \mathbf{QUOTE MES}$ 
[ 2]  $\rightarrow \mathbf{z} \leftarrow \mathbf{QP}'[\mathbf{Z} \text{ ERROR } \mathbf{X}]$ 
[ 3]  $\mathbf{Q} \leftarrow 0$ 

```

```

[ 0]  $\mathbf{X} \leftarrow \mathbf{QUOTE MES}; \mathbf{Y}$ 
[ 1]  $\mathbf{Y} \leftarrow \mathbf{U}, \mathbf{U} \leftarrow \mathbf{MES}$ 
[ 2]  $\mathbf{Y} \leftarrow (-\rho \mathbf{MES}) + \mathbf{Y}$ 
[ 3]  $\mathbf{X} \leftarrow (\mathbf{Y} \neq ' ') / \mathbf{Y}$ 

```

```

[ 0] RESET
[ 1]  $\mathbf{STEP} \leftarrow 1$ 
[ 2]  $\mathbf{ZIP1} + \mathbf{ZIP2} + \mathbf{ZIP3} + \mathbf{ZIP4} + \mathbf{ZIP5} + \mathbf{ZIP6} + \mathbf{ZIP7} + \mathbf{ZIP8} + \mathbf{ZIP9} \leftarrow 0$ 
[ 3]  $\mathbf{X} \leftarrow \rho \mathbf{Y} + \mathbf{FIND}$ 
[ 4]  $\mathbf{I} \leftarrow 1$ 
[ 5]  $\mathbf{L} \leftarrow \mathbf{z} \leftarrow \mathbf{SVD}', (\mathbf{vY}[\mathbf{I}]), '\leftarrow (2 \rho \mathbf{STEP}, 0), 2 \ 70 \rho 99'$ 
[ 6]  $\rightarrow \mathbf{L} \times \mathbf{X} \geq \mathbf{I} + \mathbf{I} + 1$ 
[ 7]  $\mathbf{STP} \leftarrow 9 \rho 1$ 

```

```

[ 0] RESGET;N
[ 1]  $\mathbf{N} \leftarrow \mathbf{FIND}$ 
[ 2]  $\mathbf{XF} \leftarrow \mathbf{z} \leftarrow \mathbf{SVD}', (\mathbf{vN}), '[1;11]'$ 
[ 3]  $\mathbf{XS} \leftarrow \mathbf{z} \leftarrow \mathbf{SVD}', (\mathbf{vN}), '[1;11+11]'$ 
[ 4]  $\mathbf{TS} \leftarrow 11 \ 11 \ \rho \mathbf{z} \leftarrow \mathbf{SVD}', (\mathbf{vN}), '[1;22+1121]'$ 
[ 5]  $\mathbf{QX} \leftarrow 5 \ 11 \ \rho \mathbf{z} \leftarrow \mathbf{SVD}', (\mathbf{vN}), '[1;143+155]'$ 

```

```

[ 0] RESREVIEW;X;Y;Z;I;N
[ 1] RESGET
[ 2]  $\mathbf{AV}[\mathbf{160}]$ 
[ 3] 'THESE ARE YOUR RESULT REVIEW OPTIONS: '
[ 4]  $\mathbf{AV}[\mathbf{160}]$ 
[ 5] '1 INDUSTRIAL OUTPUTS IN PHYSICAL UNITS'
[ 6] '2 INDUSTRIAL OUTPUTS IN CURRENT DOLLARS'
[ 7] '3 INTERINDUSTRY TRANSACTIONS (CURRENT DOLLARS)'
[ 8] '4 POLLUTION LEVELS'
[ 9]  $\mathbf{W} \leftarrow$  'LIST THE INDICIES OF THE OPTION YOU WOULD LIKE TO REVIEW: '
[10]  $\mathbf{X} \leftarrow \mathbf{X} \leftarrow$ 
[11]  $\rightarrow \mathbf{Z} \times 10 = + / \mathbf{X} > 4$ 
[12] 'OPTION CHOICE TOO LARGE--PLEASE REENTER'
[13]  $\rightarrow \mathbf{W}$ 
[14]  $\mathbf{Z} \leftarrow \mathbf{I} + 1$ 
[15]  $\mathbf{N} \leftarrow \rho \mathbf{X}$ 
[16]  $\mathbf{L} \leftarrow 2 \text{ PRINT } \mathbf{X}[\mathbf{I}]$ 
[17]  $\rightarrow \mathbf{L} \times \mathbf{N} \geq \mathbf{I} + \mathbf{I} + 1$ 

```

```
[ 0] RETRACT ID
[ 1] [SVR X+(4 3 p'SVCSVDSVMSVN'), 4 1 p>ID
```

```
[ 0] RETRIEVE ID;SV
[ 1] SV+2'SVN',ID
[ 2] PKL+ 11 2 pSV[122]
[ 3] PEN+SV[22+15]
[ 4] PMAT+SV[27+16]
[ 5] PO+SV[33+114]
[ 6] AS+ 14 11 pSV[47+1154]
[ 7] AP+ 14 11 pSV[201+1154]
[ 8] YF+ 11 4 pSV[355+144]
[ 9] Q+ 5 11 pSV[399+155]
[10] REGS+SV[454+111]
[11] DESCRIPT+2'SVM',ID
```

```
[ 0] REVIEW
[ 1] P:X+QUOTE 'WOULD YOU LIKE A DECISION ENVIRONMENT REVIEW SESSION? (Y OR N): '
[ 2] +2'QP'['YN' ERROR X]
[ 3] Q:+LX1X[1]='N'
[ 4] 'PROCEED WITH REVIEW'
[ 5] 'TYPE ''+6 '' TO RESUME'
[ 6] [AV[160]
[ 7] 'PROCESSING RESUMED'
[ 8] L:[AV[160]
```

```
[ 0] ARG+SOM;A1;MAX
[ 1] 'FNS?'
[ 2] ARG+ 1 1 p' '
[ 3] LOOP:+(0=pA1+,[])/FINIS
[ 4] +((1+pARG)=MAX+[/((1+pARG),pA1)/BELOW
[ 5] ARG+ARG,(((pARG)[1]),MAX-(pARG)[2])p' '
[ 6] +SET
[ 7] BELOW:A1+A1,(MAX-pA1)p' '
[ 8] SET:ARG+ARG,[1] A1
[ 9] +LOOP
[10] FINIS:ARG+ 1 0 +ARG
```

```
[ 0] R+SORT M;S
[ 1] S+46610[AV[153,86+164],M
[ 2] R+M[S;]
```

```
[ 0] STOP I
[ 1] 2'ZIP',(ID),'+',ID
```

```

[ 0] Q←M STRAT CHOOSE N;X
[ 1] →OUT×,DEF=1
[ 2] [AV[160]
[ 3] 'STRATEGY FOR ',ACTORS[M;]
[ 4] 'CURRENT POLICY: ',POLICY[M;N;]
[ 5] '(DEFAULT STRATEGY: ',(2'STRAT',(M ;'[N;DEFSTRAT[M];]'),')' )
[ 6] →L×,FAST=1
[ 7] P:X←QUOTE 'WOULD YOU LIKE YOUR STRATEGY OPTIONS? (Y OR N): '
[ 8] →2'QP'['YN' ERROR X]
[ 9] Q:→L×,0=ρX
[10] →L×,'N'=X[1]
[11] [AV[160]
[12] (5 1 ρ,5)),(5 1 ρ' '), (2'STRAT',(M ;'[N;;]')
[13] L:[AV[160]
[14] R X←QUOTE 'ENTER STRATEGY CHOICE (DEF=0): '
[15] →2'SR'['012345' ERROR X]
[16] S:→OUT×,0=ρX
[17] →OUT×,0=X+2X
[18] Q+STRAT[M]+X
[19] →0
[20] OUT:Q+STRAT[M]+DEFSTRAT[M]

```

```
[ 0 ] Z+STRATDEF;X;Y
[ 1 ] [AV[160]
[ 2 ] '*** THIS STRATEGY NOT AVAILABLE FOR USE ***'
[ 3 ] 'IT IS IN DEVELOPMENT'
[ 4 ] 'PLEASE RENTER POLICY AND STRAGTEGY'
[ 5 ] X+'123456789' QUEST 'POLICY: '
[ 6 ] X+X
[ 7 ] Y+'12345' QUEST 'STRATEGY: '
[ 8 ] Y+Y
[ 9 ] Z+ACTION ID,X,Y
```

```
[ 0] X←SVC N
[ 1] X←1'SVC',(∀ID), '[',(∀W),']'
```

```

[ 0] SVPROC;X;ID
[ 1] ID←1
[ 2] HOST←580196
[ 3] REV←1+FAST←DEF←0
[ 4] [AV[160]
[ 5] #HEADER
[ 6] 50p '*'
[ 7] 'REGIONAL ENERGY ENVIRONMENT GAME (PHASE II)'
[ 8] 'EXTERNAL PLAYER WORKSPACE'
[ 9] [AV[160]
[10] X←QUOTE 'ENTER HOST USER NUMBER (CR IF DEFAULT) '
[11] 2' HOST←2X'[1+17×0≠pX]
[12] X←QUOTE 'ENTER ACTOR IDENTIFICATION INDEX NUMBER--'
[13] 2' ID←2X'[1+15×0≠pX]
[14] [AV[160]
[15] ACTORS[ID;],'- ACTIVE EXTERNAL PLAYER ';ID
[16] 'HOST COMMUNICATION STATUS (HOST USER NO.= ', #HOST), ' )'
[17] '-----SV OFFER STATUS'
[18] HOST [SVO X←(4 3 p 'SVCSVDSVNSV'),(4 1 p ID)
[19] '-----ACV STATUS'
[20] (4 4 p 0) [SVC X
[21] '-----GAME STATUS'
[22] GET
[23] CVS
[24] RESET
[25] 50p '*'
[26] [AV[160]

```

```

[ 0] S←SVS
[ 1] S←((0≠[SVO [NL 2])/([IO] [NL 2])

```

```

[ 0] N SVSET M
[ 1] 2'SVC',(#ID),'+(2'SVC',#ID)[1(N-1)],M,N+(2'SVC',#ID)'

```