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**A SYSTEMS MODEL AND POTENTIAL LEVERAGE POINTS
FOR BASE LOAD ELECTRIC GENERATING OPTIONS**

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ABSTRACT

The mission and structure of electric utilities may change significantly to meet the challenges on the next several decades. In addition, providing electrical energy in an environmentally responsible manner will continue to be a major challenge. The methods of supplying electrical power may change dramatically in the future as utilities search for ways to improve the availability and reliability of electrical power systems. The role of large, base load generating capacity to supply the bulk of a utility's electrical power is evolving, but it will continue to be important for many years to come. The objective of this study is to examine the systems structure of five base load capacity options available to a utility and identify areas where technological improvements could produce significant changes in their systems. These improvements would enhance the likelihood that these options would be selected for providing future electrical capacity. Technology improvements are identified and discussed, but it was beyond the scope of this work to develop strategies for specific Idaho National Engineering Laboratory involvement.

EXECUTIVE SUMMARY

Electric utilities may have to change significantly to meet the challenges of the next several decades. Heightened awareness of the importance of protecting the environment, changes in regulations governing the transmission and sales of electric power, and competitive pressures are but a few examples of the more important challenges facing U.S. electric utilities. In the past, electric utility systems have relied on large base load electric generating capacity to supply the bulk of their electric power. However, none of these options are free from concerns over environmental impact or safety problems and alternatives that are more environmentally benign and safer are being considered.

The objective of this LDRD project is to develop systems models of the selection process for future base load electrical generating capacity for a large electrical utility. These models can be used to compare the relative merits of the potential base load options to identify system locations where well focused actions, particularly those dealing with technology, could enhance the option's capabilities. Locations in the system where these well focused actions would be most effective are called leverage points.

An approach was used that would identify options for meeting future electric demand and would highlight differences in the options for base load capacity. The first task in this approach was to develop a general utility systems model that would show the role of base load generation relative to other means of satisfying electric power demand. Next, we expanded the base load portion of the general utility model to examine the considerations that would go into selection of new base load generating capacity. Systems models for several base load options were then developed. These were coal, natural gas, nuclear, hydroelectric, and biomass. The final task was to assess the leverage points of the general systems model and to evaluate the major differences between the individual base load capacity systems models.

Leverage points in the general utility model were used to identify the following areas where added technology would help clarify the need for additional base line electric power:

- Technology and services to develop and extend the uses of Demand Management (conservation, load shaping, etc.). Because demand management has a direct effect on electric power needs, it will become more important as electrical power demand grows and the risks associated with building new generating capacity increase. Future work in this area should expand on both a national and an international scale as developing countries are pressed to incorporate demand management in their energy planning.
- Technology and services to extend the life of existing base load plants will become more important as electric power demand grows and new plant risks increase.
- Identification of technology and services to reduce operating costs while maintaining high electric system reliability will become increasingly important as plants age and rate hike requests come under increased scrutiny.
- Future electric power projections may not account for early retirement of current base load plants. An evaluation of the possible extent of early retirements and their effect on future power demand should be proposed.

The specific base load generation systems models of Section 4 identified the following areas where added technology or services would improve performance for more than one of the base load options:

- Technology to improve the efficiency of plant thermodynamic cycles is needed for most base load options. Technology for both combustion processes and conversion of thermal to mechanical energy should be improved.

- Technology to improve removal of SO₂, NO_x, and CO₂ from plant emissions should be pursued.
- Services to enhance the maturity of renewable resource generating options and new advances in combustion or conversion technologies through pilot plant construction and testing should be proposed.
- Technology and services to address energy policy issues, for example the effect of a carbon tax, will be important in the future as the energy situation becomes increasingly complex.

In addition, the following areas have been identified where added technology and services would improve the performance of specific base load options:

- Technology and services to improve Ag/biomass base load options include: development of biomass crops and agricultural practices, surveys of lands suitable for biomass crops and its agriculture characteristics, assessment of the availability of biomass for electric production versus fuel production, and assessment of the impact of existing fossil fuel regulations on biomass plants.
- Technology to reduce the sulfur content of coal will be important as supplies of low sulfur coal decrease in the future.
- Technology or services to improve hydropower would include: improvements to fish habitat; design of turbines for easy fish passage; development and application of low head turbines; and assisting in the licensing and licensing renewal of hydro plants.
- Technology to improve the extraction of natural gas from its geologic locations, reduction of methane emissions as the gas is extracted and transported, and transport of liquid natural gas would increase the availability of natural gas and enhance the natural gas electric base load option.

- Technology or services to resolve the nuclear waste issue, reduce nuclear plant operating problems, stop creeping nuclear regulation, and assist in the licensing of new plant designs are all necessary to maintain a nuclear option.

It is recommended that an evaluation of these areas be performed to determine if they match the INEL strategic thrust areas and if INEL has unique capabilities to provide services or resolve the technology issues. It is also recommended that INEL investigate those areas where it does not have unique capabilities to determine whether assembling or developing these capabilities would be beneficial.

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A SYSTEMS MODEL AND POTENTIAL LEVERAGE POINTS FOR BASE LOAD ELECTRIC GENERATING OPTIONS

1. INTRODUCTION

The mission and structure of electric utilities may be required to change significantly to meet the projected challenges of the next several decades. Providing energy, particularly electrical energy, in an environmentally responsible manner will continue to be a major challenge. Recent changes in regulations affecting electric power generation and transmission have expanded the possible role of independent suppliers and increased the potential customer base for individual electric utilities. In addition, methods of supplying electrical power may also change dramatically in the future as utilities search for ways to improve the availability and reliability of electric power systems.

For many years the electric utility system has relied on large base load electric generating capacity to supply the bulk of its electric power. Large fossil fuel, hydroelectric, and nuclear power plants currently dominate the mix of this capacity (see Figure 1). However, none of these options are free from concerns over environmental impact or safety problems and alternatives that are more environmentally benign and safer are being considered. An understanding of the relative merits of the base load generation options and their relationship to each other is needed to provide insights on how technology can improve the capability of current and future base load options.

The objective of this LDRD project is to develop systems models of the selection process for future base load electrical generating capacity for a large electrical utility. These models can be used to compare the relative merits of the potential base load options to identify system locations where well focused actions, particularly those dealing with technology, could enhance the option's capabilities. Locations in the system where these well focused actions would be most effective are called leverage points. Both development of base load plant systems models and identification of leverage points could lead to a more focused

Idaho National Engineering Laboratory (INEL) strategy for enhancing technology for electric utilities.

Our initial intent in this LDRD project was to give special emphasis to the nuclear option because of this industry's stagnation under current environmental and other regulatory constraints. However, the examination of the nuclear option addresses only one aspect of a changing climate for electric power generation. The problems, constraints, and costs of regulation impact the development of all electric power base load generating options in the U.S. The approach taken in this report examines a variety of base load options and provides the desired review of nuclear power while at the same time providing a similar review of other base load options.

Figure 1. 1988 mix of U.S. electrical generating technologies.

2. APPROACH

A systems modeling approach was selected to meet the objectives of this LDRD project. The approach outlined in the LDRD project proposal included four tasks that were intended to develop and analyze a system model of base load generating options. The initial task proposed expanding a systems model developed previously for the nuclear power industry. The second task was intended to gather data that would support development of a computer model of the system. The third task was to develop the computer model and the final task was to assess the validity of the computer model and the impact of leverage points on future nuclear power development.

Our initial work using the outlined approach showed that the previously developed nuclear power industry systems model did not contain all aspects needed for a general systems model of an electric utility. By researching the available information on energy systems modeling, we found that there are a number of codes available to energy policy makers for forecasting energy usage and the economic and environmental impacts of energy producing options. We also found there are computer codes currently available to utilities to help plan future capacity projects or develop and optimize demand management programs. There are also large computer models available or under development to forecast future electric energy needs for a utility.

A listing and description of energy systems computer codes is included in Appendix A. These included 11 general analysis codes such as MARKAL, NEMS, LEAP and ARGUS. Each of these is a large, multipurpose code having a different focus and level of complexity. However, none of these computer codes can model all aspects of energy usage because of the enormous complexity of energy systems modeling. Additional codes have been developed for specific energy applications. These include NCM, the National Coal Model; Fossil2, DOE's fossil fuel energy-economic model; WEP, a wind energy planning model; and RPG, a small to mid-sized utility planning model.

Based on these initial findings, we concluded that developing a computer model of our systems models would not provide beneficial results for the development of future work at the INEL. Although it was found that little information exists on comparisons between the computer models cited above, trying to perform such comparisons was beyond the scope of this LDRD.

This project investigated options available to large electric utilities for meeting the electrical demand from its customers. Large electrical utilities were emphasized because they typically have the financial resources necessary to consider the many options available for meeting electrical demand. However, because there are numerous options and their systems are complex, it was advantageous to confine our analysis of the electric utility system to just one option. Historically, large electrical generating units have been used to provide system base load capacity. Although the role of large base load capacity may evolve in the future, it will likely continue to have an important role in supplying electrical power for many years to come.

An approach was developed that would identify options for meeting future electric demand and would highlight differences in the options for base load capacity. The first task in this approach was to develop a general utility systems model that would show the role of base load generation relative to other means of satisfying electric power demand. Next, we expanded the base load portion of the general model to examine the considerations that would go into selection of new base load generating capacity. Systems models for several base load options were then developed. These were coal, natural gas, nuclear, hydroelectric, and biomass. The final task was to assess the leverage points of the general systems model and to evaluate the major differences between the individual base load capacity systems models. These results provide insights into high level issues that are important for utilities and areas where additional technology advances could be important for base load generation options.

3. GENERAL UTILITY SYSTEMS MODEL

We developed a general systems model of an electric utility to aid in better understanding the role of base load generation relative to other means of satisfying the demand for electric power. This model together with the other models presented in this report represent our perception of the forces that influence the supply and demand of electric power for an electric utility. Since it is possible to represent the causes and effects of complex relationships in different ways, some readers may prefer describing some relationships differently or with more or less complexity. These differences would likely emphasize some aspects of the system over others, but should not alter the general results produced.

The general systems model of an electric utility is complex. To speed understanding of the model, we will discuss the system as three subsystems. Initially the subsystem representing the electric power supply and demand portions of the system is presented. Additional complexity is then added by describing the income and cost contributors subsystem. Finally, the external influences on the utility financial position subsystem are added. The combined subsystems represent our perception of the electric utility system.

Only the general utility systems model will be discussed in the remainder of this section; the leverage points of this model will be discussed in Section 5.

3.1 Supply and Demand Subsystem

Figure 2 shows a simple systems diagram of the supply and demand variables for electric power. At the center of this subsystem is a "Gap" that represents the difference between the electric power that is both currently available and planned and the current and projected future demand for power. The utility generally plans to maintain about seventeen percent more power available than will be demanded, which means the gap is always positive.

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Figure 2. Supply and demand subsystem of the general utility systems model.

The left hand side of the subsystem represents electric power supply options: Base Load Electric Power Capacity, Peaking Electric Power Capacity, and Electric Power Purchases. Collectively they represent the electric power that will be available to the utility. When power is needed in the future, the utility must decide how to select from this mix of options. The parallel system structure shows there will be competition between the supply options as the utility attempts to optimize the mix to best meet its objectives.

Base Load Electric Power Capacity is at the center of the utility system. Historically it has been the backbone of the system for supplying electric power. As the availability of electric power decreases, the Gap decreases and there would be pressure for base load capacity and other supply options to increase. An increase in the base load capacity could be accomplished by increasing the power generation of base load plants up to their limits or, if the utility decides an additional plant is in its best interest, by building additional base load capacity. An increase in base load capacity would result in an increase in Electric Power Available which would cause the gap to increase. In systems language this type of loop is referred to as a balancing loop because when a variable changes, for example the Gap decreases, the other variables in the system tend to force the system back towards an equilibrium. Changes in a balancing loop tend to be damped out and the loop eventually stabilizes.

Major balancing loops are identified with a "B" on our system diagrams. Loops which continually reinforce the effects of the variables within the loop are referred to as reinforcing loops and are identified with an "R". The convention of an "S" representing the trend of variables in the same direction (increase in one causes an increase in the other) and an "O" representing a trend in the opposite direction is used for variables in all loops discussed in this report.

The two middle loops on the left hand side of the Gap represent other options for supplying electric power. All are balancing loops with changes in the Gap influencing them in opposite directions (as the Gap decreases, the need for these options increases). The Peaking Electric

Power Capacity loop represents plants that provide power over relative short periods of high demand. Generating systems that can be started up and shut down on relative short notice are generally used (gas turbines for example). The Electric Power Purchases loop represents power purchased by the utility from co-generators, independent power producers, or other utilities that have excess or less expensive electric power available.

The outer loop, Base Load Life Extension, is included as an electric power supply because it represents a practical way for a utility to meet future needs for power without the expense or uncertainty associated with building a new plant. The reverse of this activity is the retirement of base load capacity. As a utility decides not to perform life extension, base load capacity is retired and the Electric Power Available decreases.

Loops on the right hand side of the Gap represent the demand side of our subsystem. The outer loop represents the influence of sales on electric power demand. Marketing Activities are influenced by the gap between electric power availability and demand. As the Gap increases above established margins, and projections indicate that it will remain high, marketing activities increase to dispose of the excess power. In addition, recent changes in federal regulations have opened additional markets, leading to increased marketing activities outside their historical distribution territory for many utilities. Effective marketing results in an increase in the utility's Customer Base which causes the Electric Power Demand to increase. Information on expected growth rates and expected marketing activities are used to estimate electric demand ten or more years into the future. Changes in the current or Projected Electric Power Demand cause the Gap to respond in an opposite manner. As the demand increases, the Gap decreases.

The inner loop on the demand system (right hand side) represents the influence of Demand Management on the Electric Power Demand. Demand management (DM) is a broad term that is used to describe a host of methods that a utility can reduce the demand for power and thereby reduce the need for additional electric power. The most widely used DM programs

utilize conservation methods to reduce the amount of electric power needed. Other DM programs reduce peak power demand and primarily affect the short term power use. Reducing peak demand reduces the need for additional base load or peaking capacity. Examples are direct load control, where power to a customer is interrupted at the discretion of the utility; interruptible load, where commercial customers agree to cut electric loads at the request of the utility in exchange for lower electric rates; and customer incentives, where the utility offers time-of-day rates to its customers in an attempt to shift unessential electric power usage during peak hours to off-peak hours. A change in the Gap causes an opposite trend in demand management and changes in demand management cause an opposite trend in electric power demand (as DM programs increase the demand for power decreases).

Both loops on the right hand, or demand, side of our diagram are balancing loops. The combination of balancing loops on both sides of the gap provide a supply and demand system configuration for current and future electric power generation and use.

3.2 Income and Cost Contributors Subsystem

Figure 3 shows additional systems structure that represent income and cost contributors to the electric utility system. These contributors are added to the supply and demand loops to show, in general terms, the influence of the utility's finances on the overall system.

Electric Power Demand (at the top of the demand loop) represents the total amount of power that is currently needed or is projected to be needed. Gross Income is then a direct function of the power needed and the Electric Rates. As the amount of electric power sold or the price of the power increases, the Gross Income also increases. As Gross Income increases, the utility's Return on Investment (ROI) increases. The other contributor that we have modeled as influencing ROI is the utility's Total Costs. As the Total Costs increase, the ROI will decrease. Contributors to Total Cost have been grouped into five broad categories. Capital and Power Purchase Costs represent outlays by the utilities to cover the costs of constructing new facilities, purchasing new equipment,

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Figure 3. Addition of the income and cost contributors subsystem to the general utility systems model.

and purchasing electric power from others. The cost of all equipment, including transmission and distribution systems, are included in this variable. Related costs, such as interest expenses for money borrowed to finance purchases, would also be included. Capital and Power Purchase Costs are modeled as being influenced by the Electric Power Availability. This influence would be complex since it would depend on the relative amounts of power obtained from each of the supply options as well as the types of plants that are included in the base load and the peaking capacities. In general, however, as more capacity is constructed and more power is purchased these costs increase.

Operations and Maintenance Costs include expenditures for the personnel and supplies necessary to operate and maintain the base load and peaking plants and the transmission and distribution equipment. These costs are also a complex function of the Electric Power Availability for similar reasons as Capital and Power Purchase Costs. As more capacity is added and more power is purchased, increased personnel and system maintenance is required. This leads to an increase in Operations and Maintenance Costs.

Fuel Costs and Waste Costs are a direct function of the Electric Power Demand. As the Electric Power Demand increases, more electric power is produced by the utility's generating plants, and more fuel has to be purchased. This is true for all generating options except hydroelectric power and other renewable options where the power source is free. Disposal of waste forms is an issue for some generating options, especially for coal and nuclear plants. In general, however, the more exotic the waste form, the higher the Waste Costs. Therefore, radioactive waste generated at a nuclear plant will be a greater contributor to a utility's Total Costs than slag generated at a coal plant.

Other costs contributing to a utility's Total Costs would include Marketing Costs, which are driven by marketing activities; and Demand Management Costs, which are driven by the utility's demand management programs. These costs would increase as their driving activities

increased. However, both would be a much smaller contributor to a utility's Total Costs than the four costs discussed previously.

Although the Utility Financial Position would be influenced by such complex variables as total debt and bond ratings, the ROI has a strong influence this variable. As the ROI increases the Utility Financial Position would also improve. Total debt and bond rating would affect the utility's ability to borrow money and at what interest rate. A higher utility debt level decreases its bond rating and makes it more difficult for a utility to borrow money to finance new capital projects. Money that is borrowed under these conditions will be at a higher interest rate.

The Utility Financial Position would have an influence on the current and future plans for many of the variables in the supply and demand portions of the system. If the financial position was good and there was a need for additional power, the utility would be inclined to finance the construction of additional base load or peaking capacity or finance additional demand management programs. Under favorable financial conditions we have assumed that the utility would be less pressured to purchase power, extend the life of base load plants, or substantially increase marketing.

3.3 External Influences Subsystem

The final subsystem of the utility model captures some of the important external influences on the system. Figure 4 shows our complete system with the addition of the external influences subsystem. Public Utility Commissions (PUCs) are regulatory bodies that set electric rates by deciding which expenses incurred by the utilities should be included in the rate base. PUC Allowed Costs result in higher Electrical Rates in terms of cents per kilowatt-hour and a higher Gross Income. A utility's Electric Rates can be compared to their Competitor's Electric Rates through a Price Gap by simply subtracting their competitor's price from their own. As the utility's rates rise, the Price Gap follows the same trend.

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Figure 4. Addition of the external influences subsystem to the general utility systems model.

The Price Gap is an important contributor to the value the customers believe they are receiving from the utility. As utility rates tend to be more competitive (a small or negative Price Gap), the Customer Value would increase. Customer Value is also influenced by Alternative Energy Costs and by the Electric Power Reliability, or the reliability of the electric service. As the costs of oil, gas, or alternative energy sources increases, the value that the customer believes he is receiving from his electric service also increases. As Electric Power Reliability increases, Customer Value would increase. Because the PUC positions are generally political appointments, PUC members are sensitive to input on Customer Value. A decrease in Customer Value could cause a requested rate increase to be rejected.

Electric Power Reliability depends on the Utility Infrastructure, which includes the utility personnel and equipment. If the Utility Infrastructure decreases, it is more difficult to provide the proper maintenance and service so the reliability also decreases. The Utility Infrastructure is affected by the money available from the operations and maintenance budgets. Reductions in Operations and Maintenance Costs would cause reductions in the Utility Infrastructure.

Besides influencing Customer Value, the Price Gap also is an effective way for the utility to judge its position for obtaining new business. If the price gap shows a utility's rates are substantially higher than its competitor's, there will be pressure to reduce costs. Cost Reduction Pressure is also influenced by the ROI. An increase in Cost Reduction Pressure would likely be directed at Operations and Maintenance Costs. As the pressure to reduce costs increases, Operations and Maintenance Costs would decrease.

In conjunction with an increase in Cost Reduction Pressure, a decrease in ROI will result in an increase in Pressure to Raise Rates. Pressure would increased on the PUC to raise rates and allow the recovery of additional costs. This pressure may lead to a formal request for a rate increase.

The final variable in the External Influences Subsystem is the Perceived Risks influence on Base Load Electric Power Capacity and Peaking Electric Power Capacity. These risks may be political, environmental, regulatory, technical, safety, or societal in nature. As the Perceived Risks increase, generating capacity decreases as does Electric Power Availability.

Interaction of variables in the External Influences portion of the utility systems model is very complicated. Providing low rates will enhance customer satisfaction unless rates are too low to provide proper operations and maintenance budgets, which restricts system reliability and reduces customer satisfaction. The relative strength of the relationships between electric rates, electric power reliability, total costs, and PUC actions influences the internal activities of the utility.

Figure 4 is our representation of a utility. As shown in this model, there are options available to a utility to satisfy increases in electrical demand. In the past, this demand has been primarily satisfied by the construction of large, base load capacity. Although the role of base load capacity appears to be evolving, they will continue to provide a viable alternative for meeting electrical power demand for many years to come. The options available to a utility and how a utility decides between these options is the subject of the remainder of this report.

4. GENERAL SELECTION OF BASE LOAD CAPACITY SYSTEMS MODEL

Systems models were developed to aid us in understanding the variables that affect the selection of an option to provide base load capacity for a utility. A general model of the decision process was initially developed based on a knowledge of the important general variables and their relationships. Using the general model as a pattern, systems models for several base load options were then constructed. If subsystems not included in the general model were identified for a specific option, they were added to the general model if they were also found to apply to other options. Following is a brief description of the general systems model followed by a presentation and discussion of differences between the models of the specific options. Specific systems models were developed for the following base load options: coal, natural gas, nuclear, hydroelectric, and biomass.

Only the systems models themselves will be discussed in the following sections; the leverage points of these models will be discussed in Section 5. The purpose for this arrangement is to allow easier comparison of the potential impacts of each option.

4.1 General Selection Process System Model

The general systems model for selecting a new base load option is discussed as four subsystems: decision considerations, environmental and public safety effects, resources (fuel, land, etc.), and plant performance. As each subsystem is discussed, its system structure is added to the systems model.

Decision Considerations Subsystem. Figure 5 shows the variables that directly affect the selection of an option for providing base load electrical power. This subsystem is entered with the Decision to Build New Plant and projects the affect of this decision on future decisions.

The Decision to Build New Plant would result in the construction of a new plant. After a substantial delay (five years or more) there

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Figure 5. Decision considerations subsystem of the general selection of base load capacity systems model.

would be Electric Production From New Plant. The amount of electricity produced from the new plant would influence the Gross Income From New Plant as would the utility's Electric Rates. The gross income and the Total Costs would both influence the New Plant ROI. An increase in gross income would cause the ROI to increase and an increase in Total Costs would cause the ROI to decrease.

The Gap between the New Plant ROI being considered and the ROI of Alternatives would be an important consideration before proceeding with construction of a plant of this type. As the gap increases (the ROI of the new plant exceeds the ROI of all other alternatives), the likelihood that the new plant will be selected also increases.

The utility's Electric Power Needs would influence the decision to build a base load plant in two ways. First, as the need for power increased, the need for a new plant would also increase. The amount of power needed would also have an influence on the base load option selected.

The Decision to Build New Plant would be influenced by the perceived risks associated with that plant and the perceived risks of the alternatives. As the Perceived Risks of New Plant increase, the likelihood that a decision would be made to build that plant would decrease. As the Perceived Risks of Alternatives increase, the likelihood that the new plant would be selected would increase.

The variables that form the decision loop (decision, electric production, gross income, ROI, and gap) all influence each other in the same direction indicating that this loop is a reinforcing loop. If one base load option stands out above the rest and there was a need for power, this loop would indicate a tendency to build multiple plants of the same type.

Environmental and Public Safety Effects Subsystem. Figure 6 shows the addition of the Environmental and Public Safety Effects Subsystem. This subsystem models the composite effects of all plants of a given type on the environment and public safety. This shift in emphasis from one

Figure 6. Addition of the environmental and public safety effects subsystem to the general selection of base load capacity systems model.

plant of a given type to all plants of that type is necessary because one plant may not cause significant environmental and safety effects, but a larger number or plants of the same type could result in larger scale, more noticeable changes. The problems associated with acid rain are an example of this situation for fossil fuel plants.

A decision to build a new plant eventually results in the operation of the new plant which increases the Number of Plants Of This Type. Each plant type may have Positive Environmental Effects and Negative Environmental Effects. There may also be plant types that cause Safety Concerns for the health and safety of the public and plant workers. An increase in the Number of Plants of This Type would result in an increase in each of these three variables.

Positive Environmental Effects would generally influence Public Acceptance but would not have a major impact on other system variables. Trends in Public Acceptance would generally be expected to be the same as the trends in the numbers and types of Positive Environmental Effects that are recognized. Public Acceptance would be an important influence on the Perceived Risks of New Plant. A change in Public Acceptance would be expected to result in an opposite trend in the perceived risks (as Public Acceptance increases, the Perceived Risks of New Plant would decrease).

Negative Environmental Effects would lead to Environmental Concerns by the public, regulatory bodies, and utility personnel. When these concerns are proven to be well founded and their causes are not voluntarily prevented or mitigated by the utility, Environmental Regulation may be imposed by governmental agencies. There may also be environmental concerns for which there are no regulations, but there is Pressure to Reduce Environmental Effects from concerned citizens, organizations, or regulatory agencies. Regulations would result in the implementation of Environmental Improvement Measures and Pressure to Reduce Environmental Effects would move utilities to institute additional measures. Delays are shown for implementation of improvements because it would take time for sufficient pressure to build and for regulations to be implemented. As Environmental Concerns increase or decrease,

implementation of Environmental Improvement Measures would follow the same trend. Implementation of Environmental Improvement Measures should reduce Negative Environmental Effects. This is a balancing loop for the environmentally related variables.

Environmental Improvement Measures that are required or desired for a plant type would have an influence on both the New Plant Capital Costs and New Plant Operations and Maintenance Costs. As an example, the need for scrubbers to reduce SO₂ emissions on some types of fossil fuel plants increase both the hardware costs and the operations and maintenance costs of these plants.

Mounting safety concerns would result in strengthened or additional Safety Regulation for the plant type. These Safety Regulations would result in Safety Improvement Measures that are intended to reduce or eliminate the Safety Concerns. A balancing loop for plant safety is the result. Implementation of Safety Improvement Measures may require additional capital equipment for a new plant or may require additional personnel or services that would increase both the New Plant Capital Costs and New Plant Operations and Maintenance Costs.

The connection between regulation and plant costs can cause financial uncertainties for plant types that experience excessive or creeping regulation. Utilities do not look favorably on plant types that have the potential to experience ever increasing regulatory scrutiny. The influence of Regulatory Uncertainties has been included in the Perceived Risks of New Plant. As the Regulatory Uncertainties increase, the Perceived Risks of New Plant would increase also.

Environmental Concerns and Safety Concerns would influence both Public Acceptance and Perceived Risks of New Plant. As these concerns increase, Public Acceptance would decrease and Perceived Risks of New Plant would increase.

Another variable influencing the Perceived Risks of New Plant is Political Uncertainties. Political uncertainties for a plant type may

be the uncertainty of continued government support of a technology through either research or tax incentives of the uncertainty of additional taxes, such as the "carbon tax", on those technologies that are perceived to be environmentally harmful. Technologies with limited political support are not favorably viewed by a utility.

Resources Subsystem. Figure 7 shows the addition of the Resources Subsystem. This subsystem models the effects of all plants of a given type on resource demand and availability. Resource means different things for different plant types. Resource is synonymous with fuel for many of the plant types. It is the coal, oil, or gas needed for fossil fuel plants and the fissile materials, particularly enriched uranium and plutonium, needed for nuclear plants. However, resources take on a different meaning for plants that use renewable resources. Hydroelectric power plant resources would be those available sites that are suitable for construction of a hydroelectric power station. Resources for wind power and solar power plants could also be related to suitable sites. Biomass plant resources would be the land available that has the capacity to grow the biomass crops utilized to generate electrical power. For the renewable resource options, the topographical features and climate of the land make it a resource.

The importance of the Resources Subsystem varies strongly among the plant types. For plant types where the long-term availability of resources is becoming less abundant, this subsystem may be an important consideration in a utility's decision to build a plant of this type. This is the situation for oil and natural gas. For plants types whose technology is relatively new, resources may be abundant and resource availability may be a minor consideration to the utility. Whatever its influence, it is nevertheless important to recognize that this subsystem exists and that it may influence the future performance of a plant type.

As the Number of Plants of This Type increase, the Resource Demand also increases. Demand for a resource affects the availability of that resource. An increased Resource Demand would result in a decrease in Resource Availability. The strength of this relationship would be very different for the different plant types. The relationship is fairly

Figure 7. Addition of the resource subsystem to the general selection of base load capacity systems model.

strong for fossil fuel plants where availability is influenced by the number of producers and the reserves that are currently available. Nuclear plants currently have a weak relationship between demand and availability because there is an over abundance of fissile material. The sites available for hydroelectric power generation are diminishing and are concentrated in certain regions of the country.

Resource Availability influences Resource Exploration And/Or Exploitation, Resource Price, and Perceived Risks of New Plant. As the availability of a resource declines there will be increased exploration for new resources and the development of methods to exploit existing resources. This relationship is strongest for those plant types where land is important, for example hydroelectric power and other renewable resource power generation plants. Successful exploration and exploitation will increase the resources available, setting up a balancing loop.

A decrease in Resource Availability will also result in an increase in the Resource Price. This relationship would be strongest for plants that exploit limited natural resources, for example fossil fuels. An increase in Resource Price would result in increased exploration for new sources and the development of methods to better exploit existing resources. The loop formed by Resource Price, Resource Exploration and/or Exploitation, and Resource Availability is a balancing loop that tends to stabilize prices through supply and demand. Additional costs would be added to the fuel price as a result of increased Resource Exploration and/or Exploitation, but this influence would be a much weaker influence on Resource Price than the influence of Resource Availability. The price would also influence Other Resource Uses which would influence Resource Demand. As an example, an increase in the price of natural gas could eventually result in a decline in the use of natural gas for industrial drying applications and a decrease in the demand for natural gas.

Resource Price and the New Plant Resource Requirements would affect the New Plant Resource Costs. As the price or the amount of the needed resource increases, the New Plant Resource Costs would also increase.

This resource cost would be the fuel costs for a fossil fuel or nuclear power plant. The new plant resource costs would have a direct influence on the Total Costs for the new plant.

The Resource Availability and Total Estimated Resource Reserves would both influence the Perceived Risks of New Plant. If the Resource Availability declined or was projected to decline, the Perceived Risks of New Plant would increase. This has been the situation with oil since the early 1970s. A similar situation would occur if the Total Estimated Resource Reserves were believed to be sufficiently low that the reserves would run out before adequate cost recovery was possible for the new plant. No new plant resources are known to be in this situation at this point in time, but this could become a factor in the future as the reserves of natural resources decline.

Plant Performance Subsystem. The final subsystem to be added is the Plant Performance Subsystem. Figure 8 shows the addition of this subsystem to complete the general selection of base load capacity systems model. This subsystem models the performance of all plants of this type on the utility's decision to build a plant of this type.

Plant performance can be judged by many different indicators. Both the efficiency of the conversion of fuel to electricity and the availability of the plant to produce electricity are important indicators of performance. Other indicators may include the number of people necessary to operate the plant and the number of violations of environmental or safety regulations. The performance indicators would be different for the various base load options.

We show that Plant Performance is influenced by four other variables in our system. Plant performance would generally increase as the Number of Plants of This Type increases because technical and operational problems that occurred for one plant would be fixed for the next plant. Both Environmental Improvement Measures and Safety Improvement Measures would also directly affect Plant Performance. These measures are shown as having an opposite effect on Plant Performance because the addition of these measures could reduce the efficiency and

Figure 8. Addition of the plant performance subsystem to the general selection of base load capacity systems model.

availability for the plant and they could also make the plant more difficult to operate. Although the plant would be better from an environmental and safety standpoint, its performance would be reduced.

Plant Performance would influence the perceived Maturity of Technology. Plant performance for newer technologies, for example some renewable resource plants, may be lower than expected. This indicates that the Maturity of Technology is also low. A recognition that the Maturity of Technology is low results in Plant Performance Improvements. This relationship is shown with a delay because it generally takes time between the recognition of a problem and the implementation of a corrective measures or technology improvements. As a technology matures, the number of plant improvements decrease. Plant Improvements result in an increase in Plant Performance. The loop through Plant Performance, Maturity of Technology, and Plant Performance Improvements is a balancing loop that enables new technologies to improve and mature.

Plant performance also influences the Electric Production From New Plant and the Electric Rates. When the performance of all plants of a particular type is high, the efficiency and availability of a new plant of that type would also be expected to be high. This results in increased Electrical Production from New Plant. The influence of Plant Performance on Electric Rates would primarily be through the Public Utilities Commissions. Some utilities have their rate structures tied to the performance of some or all of their plants. If this tie is not formally recognized, plant performance is still a convenient way for PUCs to judge a utility's performance which influences decisions concerning the rate base.

Government intervention can significantly influence the Maturity of Technology for new technologies. Government Incentives have traditionally been provided to enhance the maturity of promising technologies. The loop through Maturity of Technology, Government Incentives, Decision to Build New Plant, and the Number of Plants of This Type is a balancing loop that tends to eliminate incentives as more plants are built and the technology matures. Government Incentives also

may affect Total Costs through tax incentives. As incentives of this type increase, the Total Costs of operating the plant decrease.

Maturity of Technology influences the New Plant Capital Costs, New Plant Operations and Maintenance Costs, and the Perceived Risks of New Plant. As more plants of a type are built and the technology becomes more mature, the capital costs associated with building the plant and the operations and maintenance costs would decrease. This is true because the industry base required to support the construction and equipping of these plants increases as more plants of this type are built. This should result in a decrease in capital costs. Also, as more experience is gained operating a plant type, the utility becomes more efficient at operating and maintaining them, thereby lowering their operations and maintenance costs. In addition, as the maturity of the technology increases, the perceived risks of a new plant decrease.

4.2 Coal Base Load Capacity Systems Model

Figure 9 shows the systems model for a base load coal plant. This model was developed using the general selection model discussed in the previous section as a template. Since the general model is intended to cover all base load options, some of the variables and system structure of the general model are not applicable to coal and have been deleted or modified. Our discussion of the coal model emphasizes these changes rather than providing a variable-by-variable model description. Discussion would normally begin with the Decision Considerations Subsystem, but because there are no changes to this subsystem for coal (or to any of the other options' models), the discussion begins with the Environmental and Public Safety Effects Subsystem.

Environmental and Public Safety Effects Subsystem. This subsystem was modified to represent conditions for a base load coal plant. The Safety Concerns variables and structure were not judged to be significant for the coal system because there are no major public and worker safety problems uniquely associated with the operation of a coal plant. It was also not clear that there were significant positive environmental effects derived from a coal plant, so this variable was also deleted from this

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Figure 9. Coal base load capacity systems model.

subsystem. Negative environmental effects for coal were CO₂ Produced, SO₂ and NO_x Produced, and Slag Produced. An increasing or decreasing trend for each of these variables would cause a similar trend in Air Pollution and Waste Concerns which would result in Pressure for CO₂ Reduction and SO₂ and NO_x Regulations. Public Acceptance of coal would also be affected by Air Pollution and Waste Concerns and its trends would be in an opposite direction (as pollution increases, public acceptance decreases). Environmental Improvement Measures would be affected directly by regulations and pressure to reduce emissions and would have a similar impact. Three specific improvement measures that are important are Emission Control Features (for example scrubbers), Improvements In Coal Combustion and Conversion (for example coal gasification and improved gas turbine cycles), and Low Sulfur Coal Use (which also affects the Resource Subsystem). Implementation of these improvements would reduce the negative environmental effects associated with greenhouse gases and acid rain. Environmental Improvement Measures would generally affect the New Coal Plant Capital Costs because additional or more sophisticated equipment would be necessary. The New Coal Plant Operations and Maintenance Costs would also be affected because additional staff would be required to install and maintain the emissions control equipment.

Changes in the Environmental and Public Safety Effects Subsystem from the general model emphasize the importance of pollution concerns for the coal base load option. Environmental Improvement Measures, such as scrubbers, have already been mandated and some of the pollution concerns have been addressed. However world efforts to reduce CO₂ emissions may result in future changes in regulations which makes Regulatory Uncertainty a major factor in the Perceived Risks of a Coal Plant.

Resources Subsystem. The Resources Subsystem for coal is very similar to the general selection model with two exceptions. First, the general model has a direct link between Resource Availability and Resource Exploration and/or Exploitation. This link has been eliminated for the coal model because this link is very weak. The second exception is the addition of Low Sulfur Coal Need to the subsystem, which is primarily driven by Environmental Concerns. Low Sulfur Coal Need can be

satisfied by two mechanisms. The first is through the Direct Purchase of low sulfur coal. However, low sulfur coal is found only in certain regions of the country. Its availability is lower than higher sulfur coals and its transportation costs may be higher because its location may be further from the plant site. Both of these factors would influence the Coal Price which would raise the New Coal Plant Fuel Costs and could reduce the ROI.

The second mechanism for satisfying Low Sulfur Coal Need is the removal of sulfur from the coal. This alternative would increase Coal Availability because coal with a high sulfur content would become usable. The technology for Sulfur Removal would increase the Coal Price, but the increased Coal Availability would tend to decrease the Coal Price. The more dominant effect would similarly impact New Coal Plant Fuel Cost and the ROI.

The Resources Subsystem for coal may not be a major influence on the utility's decision to build a coal plant. Some utilities may consider the necessity of using low sulfur coal as increasing the Perceived Risks of a Coal Plant, but that could depend on the location of the proposed new plant, the increase in transportation and other coal related costs, and the reliability of the coal supply.

Plant Performance Subsystem. Maturity of the Technology and Government Incentives were not included in the Plant Performance Subsystem for coal because the general technology was considered to be relatively mature. However, it is likely that a new coal plant would include improved Emissions Control Features and Improvements in Coal Combustion and Conversion. Both variables are shown influencing Plant Performance. The tie between Plant Performance and Utility Electric Rates is not shown because it is not as strong for coal plants as other base load options. A direct link between Plant Performance and the Perceived Risks of a Coal Plant is shown because changes in the emissions control systems or the combustion and conversion systems may be viewed as changes in the technology for using coal which would increase its risk.

4.3 Natural Gas Base Load Capacity Systems Model

Figure 10 shows the system model for a base load natural gas plant. This model was developed using the general selection model discussed in Section 4.1 as a template. Since the general model is intended to represent all base load options, some of the variables and system structure of the general model are not applicable to natural gas and have been deleted or modified. Our discussion of the natural gas model emphasizes these changes rather than providing a variable-by-variable description. Discussion would normally begin with Decision Considerations Subsystem, but because there are no changes to this subsystem for natural gas (or to any of the other base load options' models), the discussion begins with the Environmental and Public Safety Effects Subsystem.

Environmental and Public Safety Effects Subsystem. This subsystem was modified to represent conditions for a base load natural gas plant. This subsystem is similar to the general selection model in that the combustion of natural gas has both positive and negative environmental effects. However, natural gas was judged to have no public or worker related safety concerns that were uniquely associated with a plant of this type. Therefore, the variables and system structure associated with Safety Concerns on the general model have been omitted.

The Positive Environmental Effects of natural gas is that this fuel type is cleaner burning than other fossil fuels and is not a significant contributor to acid rain. Natural gas produces approximately 70% more energy per unit release of CO_2 than coal and natural gas has a low sulfur content. SO_2 is not produced in sufficient quantities even on an industry basis to justify removal devices such as scrubbers.

However, natural gas plants do have CO_2 and NO_x Emissions. These are considered greenhouse gases and as such are negative environmental effects that lead to Environmental Concerns. As the Environmental Concerns over greenhouse emissions increase, Public Acceptance of this fuel form decreases and the Perceived Risks of a Gas Plant increase.

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Figure 10. Natural gas base load capacity systems model.

Public and regulatory Pressure to Reduce CO₂ Emissions and NO_x Regulation is increasing as a result of Environmental Concerns. These pressure and regulations result in an increase in Environmental Improvement Measures.

Although strategies have been proposed for capturing and sequestering CO₂ emissions, the long-term environmental effects of these strategies are unknown and the process are highly expensive. Therefore, Environmental Improvement Measures have been concentrated on increasing the performance of gas plants. Improvements in Gas Combustion and Conversion would reduce the emission of greenhouse gases from natural gas plants (thereby reducing Environmental Concerns and increasing Public Acceptance of natural gas). However, the increased equipment required to achieve these improvements would result in higher New Gas Plant Capital Costs and New Gas Plant Operational and Maintenance Costs. The new equipment would most likely be more sophisticated and require a greater amount of maintenance.

Resources Subsystem. The Resources Subsystem for natural gas is very similar to the general selection model except the general model has a direct link between resource availability and exploration and/or exploitation. This link was eliminated for the natural gas model because it is very weak for this option. We believe the price of natural gas is the driving factor for increased exploration and exploitation of this resource.

Currently, natural gas is more expensive than coal and may become more expensive as demand for this resource increases. The increasing Gas Price increases the New Gas Plant Fuel Costs which increases the New Gas Plant Total Costs which then in turn decreases New Gas Plant ROI. However, the high Gas Price will probably increase exploration for new reserves of natural gas and the exploitation of current reserves.

Although natural gas offers a viable solution for reducing the emissions of greenhouse gases and SO₂ through higher combustion efficiency and for the replacement of coal and oil plants, the limitation of Gas Availability may limit its applications. The world's distribution

of natural gas increases the Gas Availability problem. Currently, natural gas use is centered primarily near its source. International transportation of natural gas through pipelines accounts for only 11% of total use and transportation via tanker shipments accounts for only another 3%. Technically, the problems of transporting natural gas to areas of need can probably be resolved. Political uncertainty of the gas supply is much less predictable. If the U.S. reserves of natural gas were solely to be relied on, these reserves will last 18 years. The natural gas supply in the former Soviet Union could last an additional 70 to 80 years if a reliable supply can be established.

The Total Estimated Gas Reserves of the world will increasingly become a larger factor in the Perceived Risks of a Gas Plant. At current world consumption rates and with current technology, the world's supply of natural gas would last 120 years. In contrast, using these same assumptions, the world's coal reserves would last 1500 years. Natural gas reserves could be made to last two to three times longer if the higher costs of recovering less accessible reserves becomes acceptable or if technology improves to recover it more economically. If natural gas was substituted for coal and oil in all applications as is being advocated by the current administration, the world's gas reserves might last only 55 years.

Both Gas Availability and the Total Estimated Gas Reserves are important factors in the Perceived Risks of a Gas Plant. Uncertainties in the regulatory and political environment towards natural gas also keep perceived risks high. Although the current political administration favors natural gas, the gas shortages of the 1970s resulted in the government not allowing any new natural gas plants to be built.

Because there is no waste generated from the combustion of natural gas, there are no Waste Costs. This variable has been omitted from the natural gas model.

Plant Performance Subsystem. Maturity of the Technology and Government Incentives were not included in the Plant Performance Subsystem for natural gas because the general technology was considered

to be relatively mature. However, it is likely that a new natural gas plant would include Environmental Improvements Measures which would influence Plant Performance through Improvements in Gas Combustion and Conversion. Research is currently being performed to increase the efficiency of the combustion and energy conversion processes of natural gas plants. These proposed improvements to the natural gas combustion and energy conversion cycles could potentially increase the efficiency of natural gas plants to as much as 52%. The tie between Plant Performance and Utility Electric Rates is not shown because it is not as strong for natural gas plants as other base load options.

As discussed previously, the subsystem regulating natural gas plant performance is closely related to the Environmental and Public Safety Effects Subsystem. Environmental Improvement Measures usually translate into plant performance improvements for natural gas plants in order to reduce the emission of greenhouse gases. Although these improvements may entail increases in the capital costs and operations and maintenance costs of a natural gas plant, the increased costs would be offset by the increased plant performance which would increase the New Gas Plant Electrical Production. The generation of more electricity with less natural gas would also reduce the New Gas Plant Fuel Costs.

However, the equipment necessary to improve the fuel cycle efficiency may also be more prone to failure, thereby reducing the availability of the plant. This would reduce the New Gas Plant Electrical Production and would result in a decrease in New Gas Plant Gross Income and a reduction in ROI.

4.4 Nuclear Base Load Capacity Systems Model

Figure 11 shows the systems model for a base load nuclear power plant. This model was developed using the general selection model discussed in Section 4.1 as a template. Since the general model is intended to cover all base load options, some of the variables and system structure of the general model are not applicable to nuclear power and have been deleted or modified. Our discussion of the nuclear power model

Figure 11. Nuclear base load capacity systems model.

emphasizes these changes rather than providing a variable-by-variable model description. Discussion would normally begin with the Decision Considerations Subsystem, but because there are no changes to this subsystem for nuclear power, the discussion begins with the Environmental and Public Safety Effects Subsystem.

Environmental and Public Safety Effects Subsystem. The structure of the Environmental and Public Safety Effects Subsystem for nuclear power is very similar to the general model. There is the potential for Environmental Benefits as the Number of Nuclear Plants increases. Some base load plants burn fossil fuels, which release gases that are potentially harmful to the environment. Some of these gases, such as CO_2 , may contribute to global warming and no practical means is currently available for removing and sequestering CO_2 from plant emissions. Others byproducts of the combustion of fossil fuels are precursors to acid rain, particularly SO_2 and NO_x . Emissions of these gases are non-existent in nuclear power plants which gives nuclear power the potential to have a positive effect on the environment. The positive effects of nuclear power on the environment is part of a reinforcing loop that could play an important role in decisions on nuclear power.

Radioactive Waste Production from nuclear power plants is currently a major negative environmental effect for nuclear power. It increases in direct proportion to the number of plants. The general perception is that radioactive waste is being generated in large quantities and there is no reliable means of disposing this waste. Efforts to open storage repositories are behind schedule and are being further delayed by politics. These factors have caused significant Waste Disposal Uncertainties. The result is that the public has lost confidence in the ability of the nuclear industry to solve its waste problems. This problem is sufficiently important that it is shown in the system as having a direct affect on both Environmental Concerns and the Perceived Risks of a Nuclear Plant.

The Number of Nuclear Plants is also shown with a direct link to Environmental Concerns. This link represents concerns over release of

radioactive material from nuclear power plants and its potential effects on the environment and the food chain. Environmental Concerns have an effect on Public Acceptance and on the Perceived Risks of a Nuclear Plant. The effects of Environmental Concerns and Environmental Benefits from nuclear power on Public Acceptance is currently skewed heavily towards Environmental Concerns. Unless global warming issues are shown to require immediate fixes, it is doubtful that the positive benefits of nuclear will outweigh the negative concerns in the foreseeable future. Environmental Improvement Measures result in increased New Nuclear Plant Capital Costs and New Nuclear Plant Operations and Maintenance Costs.

Safety Concerns are part of the history of the nuclear power system. Because nuclear power plants are relatively complex, Operational Problems have been experienced. As the number of Operational Problems increased, there was the perception that nuclear power plants had underlying safety problems which lead to Safety Concerns. These perceptions were reinforced by the TMI-2 accident in the U.S. and further heightened when the Chernobyl accident occurred in Russia. Safety Concerns resulted in the implementation of additional Safety Regulations. As the number of Operational Problems grew, so did the number of Safety Regulations. The new Safety Regulations resulted in Safety Improvement Measures which required extensive manpower to implement and additional hardware to be installed. Increases in both New Nuclear Plant Capital Costs and New Nuclear Plant Operations and Maintenance Costs resulted. Operating plants experienced dramatic increases in their operations and maintenance costs as they underwent extensive backfits to meet regulatory requirements. Plants under construction had their capital costs increased due to the additional interest costs because of delays in construction and startup. Capital costs also increased dramatically because the required design modifications included additional hardware and backfitting in many plants. All of these historically based Safety Concerns and their resultant cost escalations have a strong influence on the Perceived Risks of a New Nuclear Plant.

Resources Subsystem. The structure of the Resources Subsystem for nuclear power is similar to the general model with the following differences. Fissile material is not widely used for applications other

than nuclear power plants. The Other Resource Uses variable has been deleted from the subsystem even though national defense purposes has a demand for this resource. However, it is unlikely that the defense purposes demand would ever be large enough to severely restrict the commercial supply. Disarmament and destruction of nuclear weapons could, however, make large quantities of fissile material available for commercial use which could affect the Resources Subsystem. Because there is currently an abundant supply of fissile material, the relationship between resources and the remainder of the system is considered to be weak for nuclear power.

Plant Performance Subsystem. Nuclear Plant Performance has had a strong influence on the nuclear power system in the past. Although Safety Improvement Measures and Environmental Improvement Measures have been implemented to improve Nuclear Plant Performance, improvements were perceived to be slow in coming. Safety Concerns influenced perceptions of plant performance and resulted in both the nuclear industry and the Nuclear Regulatory Commission (NRC) instituting a Nuclear Plant Performance Ratings system. As the number of Safety Concerns increase, the Nuclear Plant Performance Ratings drop. The safety condition of the plant as perceived by the regulatory staff will also affect the ratings. These ratings are important because in many states they are monitored by the PUC and by special interest organizations that are for or against nuclear power. As ratings go up, the PC has evidence that the utility management is working to improve the plant operations and safety. Under these conditions the PC is more likely to allow costs proposed by the utility to be included in the rate base, allowing a rise in Utility Electric Rates. Poor performance may result in rejection of requested rate increases.

The perceived poor performance of nuclear power plants has resulted in New Design Improvements for plants that are intended to be safer and easier to operate. Since none of these designs have been built and operated, they are not considered to be mature and the lack of New Design Maturity would increase the Perceived Risks of a Nuclear Plant.

4.5 Hydroelectric Base Load Capacity Systems Model

Figure 12 shows the systems model for a base load hydroelectric plant. This model was developed using the general selection model discussed in Section 4.1 as a template. Since the general model is intended to represent all base load options, some of the variables and system structure of the general model are not applicable to hydroelectric and have been deleted or modified. Our discussion of the hydroelectric model emphasizes these changes rather than providing a variable-by-variable description. Discussion would normally begin with Decision Considerations Subsystem, but because there are no changes to this subsystem for hydroelectric (or to any of the other base load options' models), the discussion begins with the Environmental and Public Safety Effects Subsystem.

Environmental and Public Safety Effects Subsystem. This subsystem has been modified to represent conditions for a base load hydroelectric plant. The Positive Environmental Effects variable of the general selection model has been incorporated into the Hydro Benefits variable. These benefits are increased wildlife habitat (primarily waterfowl), irrigation, transportation, flood control, community water sources, and recreation. The benefits of a hydroelectric plant increase Public Acceptance of these plants. However, hydro benefits must be weighed against the land that would be lost and the negative environmental effects due to the increased number of hydroelectric plants. The large land areas that are lost to hydroelectric plants is usually valued by the public for farming or its scenic beauty. The Loss of Land decreases Public Acceptance.

Negative environmental effects of hydroelectric plants include Loss of Wildlife Habitat and Disturbance of Fish Habitat. Both of these effects lead to Environmental Concerns that decrease Public Acceptance and increase the Perceived Risks of a Hydro Plant. The Disturbance of Fish Habitat includes such diversified items as the interruption of upstream and downstream fish passage, turbine passage mortality, and dissolved oxygen levels both downstream and in the hydro plant lake.

These effects are influenced by instream flow, water level fluctuations, and streambank erosion. These environmental concerns have increased Environmental Regulation and public and regulatory Pressure to Reduce Environmental Effects. Increased pressure to reduce environmental effects of hydro plants is especially true for rivers where decreased fish passage has resulted in the near extinction of some species. Environmental Improvement Measures take two forms: Water Release to Increase or Maintain Downstream Flows and Improved Fish Passage. Downstream flow measures will address the downstream fish passage and instream flow needs. Improved fish passage measures include the retrofit of hydro plants with low impact turbines, construction of fish ladders, and the increase of fish barging around the plants during spawning. All of these improvements will lead to a decrease in the Disturbance of Fish Habitat.

Increasing or maintaining downstream flow needs will result in a decrease in Plant Performance as more water is released and is not available for the generation of electricity. As fish passage becomes improved, plant performance may deteriorate further if low impact turbines prove to be less efficient than current turbines. As Plant Performance decreases, New Hydro Plant Electrical Production decreases, decreasing New Hydro Plant Gross Income, and ROI. Improved Fish Passage measures increase New Hydro Plant Capital Costs through the installation of new turbines or the construction of fish ladders. New Hydro Plant Operations and Maintenance Costs increase because of the manpower required to operate and maintain the improvements and to transport fish around the structure.

Increasing the number of hydroelectric plants also increase the Safety Concerns about these plants, primarily about the probability of catastrophic failure of the dams. As Safety Concerns increase, Public Acceptance decreases, and the Perceived Risks of a Hydro Plant increase. These links to perceived risks are believed to be relatively weak. Increased Safety Concerns will result in additional Safety Regulation and Safety Improvement Measures. The improvement measure should reduce hydro plant safety concerns, but will also increase New Hydro Plant Capital

Costs and New Hydro Plant Operations and Maintenance Costs through their implementation.

Resources Subsystem. The Resources Subsystem for hydroelectric plants is substantially different than represented by the general selection model. The resource for a hydroelectric plant is site locations. There is a limited number of acceptable siting locations. As the Number of Hydro Plants increases, there is a one-to-one decrease in the Availability of Acceptable Siting Locations. Most acceptable siting locations using technology available today have been identified. Therefore, a decrease in acceptable siting locations will lead to research into methods for exploiting marginal siting location. These improvements may include turbines that can operate on a lower head pressure or better ways to seal rock fissures to allow construction of dams at previously unacceptable locations. Either of these improvements will lead to the availability of additional siting locations. The availability of an acceptable siting location directly influences a utility's decision to build a hydroelectric plant.

There are no analogous variables for Resource Price, New Plant Resource Costs, and Waste Costs in the hydroelectric plant model. These variables and system structure have been omitted from this model.

Federal regulatory factors significantly affect the siting and licensing of hydroelectric plants. These regulations are so complex that they can impede the construction of a hydroelectric plant. This appears as Regulatory Uncertainty which increases the Perceived Risks of a New Hydro Plant. Hydroelectric plants must also be relicensed after a number of years of operation. Approximately 300 plants must be relicensed over the next decade. Each of these will face challenges based on economic and environmental issues. The uncertainty of relicensing a hydroelectric plant is another form of regulatory uncertainty.

Plant Performance Subsystem. Maturity of the Technology and Government Incentives were not included in the Plant Performance Subsystem for hydroelectric because the general technology was considered to be relatively mature. As discussed previously, the Plant Performance

of a new hydroelectric plant is influenced by environmental improvements measures. However, improvements in turbine efficiency may make it advantageous to retrofit current hydroelectric plants for higher electrical production.

4.6 Biomass Base Load Capacity Systems Model

The story of Ag/biomass is one of new technology development. The EPRI study on renewable energy concepts states that

"Today, while technical advancement continues, the emphasis has shifted to the marketplace -- getting the technology into the field and nurturing markets in locations where existing renewable technology can be economically competitive. Spurred by efficiency improvements of the past decade, several options have already been able to find such market niches -- wind and solar technologies in particular. The evolution of these markets should broaden the scope for all renewable applications: government research indicates that renewables could be contributing between 28% and 40% of U.S. energy supply by the year 2030, with biomass by far the largest source."

Ag/biomass is expected to be an important contributor to the future energy supply for this country.

Figure 13 shows a system model for the decision to build a agricultural/biomass plant. A model to examine all renewable resources available for electric power plants would have encompassed a wide variety of technologies from wind power, to photovoltaics, to hydrogen cells, to biomass conversion processes. The issues and structure of these technologies are so diverse that it was decided to use biomass as a representative example. Even biomass is diverse enough that our model was further refined to consider only agricultural/biomass (Ag/biomass) technology.

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Figure 13. Ag/biomass base load capacity systems model.

Unlike more familiar electric power base load options, biomass is unfamiliar to many people and needs further discussion. Biomass is any organic matter, available on a renewable basis, that can be converted to energy. This could include agricultural crops and waste, wood and wood wastes, animal wastes, aquatic plants and municipal waste. These all are potential feedstocks for energy conversion. Biomass is unique in that it can be combusted directly or converted to liquid or gaseous fuels. Biomass fuels may need no further processing, for example burning wood wastes, or they could require harvesting, shredding and drying. Conversion to liquid or gaseous fuels can require extensive processing.

Direct combustion, or burning, is the most common form of biomass use. Direct combustion systems can generally use any biomass feedstock so long as its moisture content does not exceed 60%. Chunk wood, chips, bark, sawdust and other wood by-products are the most common fuels in the United States. However, sugar cane, vineyard pruning, corn cobs, coconut husks and other types of agricultural residues are also used.

Anaerobic digestion is a biochemical process which converts organic materials into a gas which can be burned like natural gas for space heat, process heat and steam, and electricity generation. Anaerobic digestion is used with high moisture content feedstocks such as food processing waste, sewage sludge, or animal manure.

Gasification processes use heat in converting biomass into combustible gases. The gas produced can be burned like natural gas to produce heat or steam, injected into engines as fuel to produce mechanical or electrical power, or converted to make synthetic liquid fuels including ethanol, methanol and gasoline. Of these three, ethanol is currently the most commercially available. Liquid fuels are usually used for direct energy conversion but methanol is a potential source for hydrogen production.

A recent EPRI report "Renewables on the Rise" indicates that two opportunities for utilities lie in generating electric power using municipal solid waste or whole tree burning grown on specialized energy

tree farms. Ag/biomass could also be important for the wood and food industry where waste products for both process heat and co-generation are projected to increase significantly over the next 30 years.

Our Ag/biomass system models electric plants using feedstocks that derive either directly or indirectly from lumber and agricultural sources. The decisions submodel has the same structure as the general model so the discussion begins with the Environmental and Public Safety Effects Subsystem.

Environmental and Public Safety Effects Subsystem. As the number of Ag/biomass plants increase, they result in environmental effects which encourages public acceptance. The use of Ag/biomass plants would result in reduced emissions of sulfur and nitrogen and thereby avoiding acid rain. Efficient biomass conversion also limits the release of organic compounds that produce smog. Additionally, the use of biomass fuels, produced on a sustainable basis, does not contribute to atmospheric carbon dioxide concentrations, a prime factor in global climate change, popularly referred to as the "greenhouse effect." While Ag/biomass does generate some wastes and ash these may be useable directly or indirectly for fertilizer. The U. S. Biomass Industries Council summarizes biomass pollutants as follows. The primary pollutant from a biomass system is particulate matter and that most federal and state regulations in the United States deal only with this pollutant when regulating biomass systems. The particulate consists of ash and unburned carbon which becomes intermingled or "entrained" in the flue gas. Well designed combustors minimize the amount of entrainment. Biomass combustors generally produce small amounts of ash, though the actual amount depends on the feedstock. Ash contents range from 1% for clean wood chips to 20% for rice hulls. Most biomass fuels are in the 1-5% range. The ash can usually be used as a fertilizer but should be analyzed before land application.

Because the environmental effects of Ag/biomass are significantly less severe than pollution and wastes from other technologies, the subsystem was modified by eliminating some of the environmental constraint feedback loops. Generation of emissions, ash and process

waste generates some environmental concerns. These lead to environmental improvement measures but the system is less complex than for other base load options. Environmental uncertainty still plays an important role in the Perceived Risks of Ag/biomass. These uncertainties primarily have to do with prohibitive licensing and regulatory requirements generated from fossil technologies that may also be affected by poor land use and agricultural practices for dedicated energy crops. Also, Ag/biomass is new and evolving so that legislation and regulation may not always consider its particular requirements and application.

Resources Subsystem. The resources subsystem for Ag/biomass considers the availability of land for growth of energy crops. The crops themselves are not shown as a resource because the grower would switch to another crop if there was no demand for biomass. Research to improve crops and develop crops capable of production on marginal lands results in an increase of lands available for energy crop production. This effect is balanced by a reduced need for such research if land is abundant. Demand for land for other uses such as city sprawl or increased food production could limit the Ag/biomass feedstocks.

Additional Resource issues that affect the Perceived Risks of Ag/biomass are issues of Feedstock reliability, Total Feedstock Potential, and Total Estimated Land available for feedstock production. Agricultural wastes and wood wastes are not shown in the Resource loop because are not considered part of the resource because they will be available regardless of whether there is land to grow biomass. Risks from crop failure or lack of suitable land to grow biomass increases the perceived risks of Ag/biomass. Generally the perceived risk of insufficient land available can be reduced if the power plant is designed to utilize a variety of biomass feedstocks.

A big change in the system surrounding perceived risks for Ag/biomass lies in the change of the political uncertainty variable to political support. Reduced environmental risks and the renewable nature of the resource has generally resulted in political support for Ag/biomass development. According to EPRI studies and the Inter-laboratory White Paper on Renewables such support can be expected to

continue. Another issue bolstering the Political Support issue are economic effects. These will be discussed under the section Plant Costs.

Plant Performance Subsystem. The Plant Performance loop has a structure similar to the general decision model. Plant performance will be enhanced as experience is gained in designing, building and operating these plants. The combination of more plants and increased experience is expected to result in a significant increase in the maturity of the Ag/biomass technology. The current lack of Maturity of Ag/biomass Technology is a major contributor to the perceived risk of these plants.

As the technology matures the need for plant performance improvements will decrease. For Ag/biomass, these plant performance improvements would include research into more effective bioconversion processes, more efficient burn technologies, and may even include storage and feedstock transport improvements. Research to improve operations may also be needed as Ag/biomass combustion systems tend to require more hands on control than a natural gas fired system.

Plant Performance will likely be more variable for Ag/biomass plants until substantial growth in the technology occurs. For this reason, Plant Performance improvements increase the Maturity of Ag/biomass Technology. Ag/biomass Technology growth is shown to reduce the Perceived Risks of Ag/biomass. Increasing the Maturity of Ag/biomass Technology reduces O&M costs and Capitol Costs. According to a recent EPRI report on renewables:

"Utilities need to realize that many renewable energy technologies are already cost-effective for power generation in particular circumstances," says EPRI's James Birk, director for storage and renewables R&D. "The path to full commercial viability for these technologies lies in identifying and exploiting the early markets, then following through as they evolve toward bulk power applications. In addition to continuing technological development, EPRI's role in this area is to help utility members identify emerging

opportunities and to catalyze markets through strategic alliances with both vendors and customers."

Total Plant Costs. Plant costs appear similar to the general model with plant capital costs and O&M costs driving Total Costs which affect the technology's ROI. Issues particular to Ag/biomass around cost are increased Capital Costs from perceived risks due to the immature state of the technology. An additional issue are Transmission and Distribution Costs. Siting of Ag/biomass would depend somewhat on the crop location which could increase Transmission and Distribution costs. If land was abundant, Transmission and Distribution Costs would be low because there would likely be land close to the existing grid. Increased transmission and distribution costs would increase Totals Costs.

An additional factor affecting Ag/biomass fuel costs are both the quantity and quality of the feedstocks. The energy content per ton of fuel is several orders of magnitude less than fossil based fuels so that the costs of handling the volume needed for electrical production drive up costs. Also size, moisture content and energy content of the feed stock can vary creating problems with plant performance and subsequently O&M costs.

Government Incentives can significantly affect both total costs and electric rates. These incentives are encouraged by public support and interest in renewable energy. The incentives can take several forms, tax incentives, rate reductions, funding for research or subsidized capitol loans. Both state and federal governments are looking at methods to promote renewable energy development. These incentives are based on environmental advantages of clean fuels as discussed under environmental issues. An additional factor appearing in the systems model for Ag/biomass is the Local Economic Benefit of Ag/biomass Plant. Both Federal and local legislative studies of biomass emphasize the creation of local jobs for construction, cultivation of crops, harvest, plant operation and feedstock preparation. These studies also cite state income advantages of utilizing local fuels rather than spending money for fuel imports. The Interlaboratory White Paper on Renewables states that the use of biofuels (all uses of biomass) could reducing imports and

"result in an annual balance-of-payments saving of up to \$100 billion while creating a domestic biofuel industry that would provide jobs, economic growth, additional tax revenue, and a potential export market."

5. LEVERAGE POINTS IN THE UTILITY SYSTEMS MODELS

As discussed in Section 1, leverage is the use of well-focused actions to produce significant, enduring changes in a system. Identification of points in the system where leverage can be effective is one of the important results that can be obtained from systems models. We have examined the systems models shown in Figure 4 and 8 through 13 to identify locations where either breaking links between variables or reinforcing them would dramatically alter the system in a way that would have the potential to improve the system in the future. The general utility model of Figure 4 is examined first followed by an analysis of the general base load selection model of Figure 8. The remaining sections identify and discuss the leverage points of the individual base load option models.

5.1 General Utility Systems Model

Three leverage points have been identified for the general utility systems model of Figure 4. These leverage points are identified and discussed in the remainder of this section.

Electric Power Demand. The future demand for electric power is projected to rise at a rate of about two percent a year for the next decade. Based on these projections, new utility base load capacity may be needed. However, these projections could be low if premature retirement of generating capacity is properly accounted for. A recent example is the closure of the Trojan nuclear power plant which operated for only sixteen years, less than half of its design lifetime. Its closure was the result of hardware problems whose repairs were not considered sufficiently cost effective to keep the plant operational. This example indicates that electrical power projections may not be as stable as forecasters believe. Examining the likelihood of early retirement on different plant types could aid in improving the credibility of the demand projections.

Future demand for electric power is a leverage point for all of the remaining system models. To avoid repetition, it will not be discussed for each model.

Return on Investment (ROI). Return on investment has a direct influence on three main variables: utility financial position, which influences many other system variables; cost reduction pressures; and pressure to raise rates. ROI, in turn, is affected by both total costs and electric rates. High total plant costs reduces a utility's return on investment and restricts their financial position. Variables that contribute to total plant costs are: Capital Costs, Operations and Maintenance Costs, Fuel Costs, Waste Disposal Costs, and (for nuclear power plants) Decontamination and Decommissioning Costs. Devising means to reduce costs from their current levels could be very beneficial to the utilities. However, cost reduction pressure can reduce the reliability of service to the customer which has a negative effect on the perception of customer value. To be successful, cost reductions should not have a major influence on the reliability of services to the customer.

The general system model indicates that influencing electric rates directly is difficult. There is no clear actions that can be taken to generally influence the rate structure by technology development from outside the utility.

The effect of the ROI leverage point including total costs and electric rates is similar for the remaining systems models and will not be discussed in each model's section unless there are new insights to be gained.

Supply Options and Demand Management. The structure of the supply and demand portion of the system provides insights into additional areas where leverage exists. The supply options that are parallel to base load capacity, peaking capacity, power purchase, and life extension will become increasingly important as utilities attempt to minimize their risk and improve their financial positions. Peak generating capacity options such as gas turbines will likely continue to grow in popularity. Purchasing larger amounts of power from co-generation facilities and from

independent producers could also increase in popularity. Life extensions options should present opportunities for utilities and suppliers to maintain electric power capacity without the risks of constructing new plants.

Demand management is positioned in the system as a direct competitor to the supply options. Both conservation and demand shifting will continue to play important roles in the utility system because they do not carry the financial and environmental risks associated with the supply options. Further technological developments in these areas would benefit the utilities.

5.2 General Decision to Build Base Load Capacity

Six leverage points have been identified for the general selection of base load option systems model shown in Figure 8. These leverage points are identified and discussed in the remainder of this section.

Positive Environmental Effects. Identification of alternatives that reduce contributors to global warming, the effects of acid rain, and the disposal of waste would result in positive environmental effects and reduce the perceived risk of base load options. The feedback loop in the systems model that includes positive environmental effects is a reinforcing loop. This means that well-planned actions in this area would increase the likelihood of an option's selection. However, the system's structure shows that public acceptance must be positively influenced for this feedback loop to be active. Public acceptance is also influenced by environmental concerns which tend to be more influential in shaping public opinion than positive effects. The "soft" nature of public acceptance indicates that positive influences would have to show major benefits and few negative influences before it would strongly influence the system.

Negative Environmental Effects. Negative environmental effects include solid waste, liquid waste, and emission gases that are contributors to environmental problems such as the greenhouse effect and acid rain. These effects are located in the systems model where they

influence a number of loops that bias the selection of a base load option. Reducing or eliminating negative environmental effects would help reduce or eliminate the perceived need for additional environmental regulation, increase acceptance by the public, and decrease the perceived risks of a given base load option. The means of reducing environmental effects are somewhat different for the different options and are included in the discussions of the options.

Safety Concerns. Some of the base load options have, or are perceived to have, safety problems. Eliminating the safety concerns, or their perception, would help eliminate the need for additional safety regulation, increase public acceptance, and decrease the perceived risks of a given base load option.

Plant Performance. Performance of the base load plants in terms of their efficiency in converting fuel to electricity, their availability to produce electricity, their environmental compliance, their safety compliance, each influence various aspects of the system. As a result, improving plant performance could take many different directions. Efficiency improvements would result from incremental improvements or major changes to the basic thermodynamic cycles. Availability improvements would likely require changes in plant operations or in plant equipment. Other improvements could change plant operations and require additional personnel to ensure proper implementation of environmental and safety regulations and guidance. There are opportunities to improve plant performance for all base load options.

Maturity of the technology is also influenced by plant performance and is considered to be important for several of the base load options. For the well established base load options (coal, nuclear, hydropower, etc.), maturity of the technology does not have a major influence on the system unless improvements are necessary to improve the environmental, safety, or economic performance of the option. For newer options (primarily the renewable resource options), maturity of the technology would be a big influence on perceived risks.

Resource Availability. The availability of the resource for each base load option influences the resource price and the perceived risks for that option. Increasing resource availability would have a positive influence on the system for base load options. Methods for finding resources or extracting more of a resource from existing deposits would both benefit the utility and other resource users as well.

Political and Regulatory Uncertainty. The uncertainty of the effect of future changes in regulations for individual technologies and the political uncertainty surrounding future support for individual technologies or the allowance of plant costs into the utility's rate base are important influences on the perceived risks of building new base load capacity. Creeping regulation increases capital costs and operations and maintenance costs and is likely to decrease plant performance. Some of the uncertainty in these areas could be removed by developing a consistent technical basis that can be used to guide production of regulations for new technologies. Future uncertainty for current technologies could be reduced by determining the limits of improvements that would be expected and comparing that those projections with projected changes in regulations. For example, the potential reduction in CO₂ per kilowatt generated could be estimated for various improvements in fossil fuel cycles and which would then be compared with projected goals or regulations for CO₂ reduction.

5.3 Coal Base Load Capacity Systems Model

Four leverage points have been identified for the base load coal option from its systems model of Figure 9. These are discussed and compared to the leverage points of the general selection model in the remainder of this section. The two leverage points identified in the general selection model, but not found in the coal systems model are Positive Environmental Effects and Safety Concerns. As discussed in Section 4.2, these aspects of the general selection model are not uniquely identified for coal plants.

Negative Environmental Effects. The negative environmental effects of coal plants are: slag, fly ash, CO₂, SO₂, and NO_x production. Scrubbers and the use of low sulfur coal have already been implemented for the reduction of SO₂ emissions. However, CO₂ and NO_x emission reduction cannot be achieved in a cost effective manner at this time. There have been methods proposed for the capturing and sequestering of CO₂, but in addition to being expensive, the long-term environmental impact of these methods is unknown. The quantity of slag and fly ash produced is a direct function of the amount of coal burned.

The system structure shows that the impact of negative environmental effect could be reduced by improvements in emissions controls, improvements in combustion and energy conversion processes, and in the use of low sulfur coals. Improvements in technology could provide enhancements in these areas.

Plant Performance. Plant performance improvements would increase the energy production per ton of coal and thereby reduce coal related negative environmental effects as well as increase the ROI. The system shows that improvements in emission controls and improvements in combustion and conversion cycles would lead to improvements in this area. Current coal technology is certainly mature but new combustion or conversion cycles may cause uncertainties that would influence the perceived risk. Reducing these uncertainties would require extensive development and testing of new technology improvements.

Resource Availability. At current coal demand levels, coal reserves are estimated to be adequate for about 1500 years. Low sulfur coal reserves, however, are not so abundant. As the availability of low sulfur coal decreases, coal prices will increase, reducing the ROI of coal plants. The system model shows that there is the need to find an economical means of extracting the sulfur from coal. This expands the availability of low sulfur coal which tends to stabilize prices. If technology is developed to remove sufficient quantities of sulfur from the effluent of the plant at low costs, low sulfur coal may not be

required. Under these conditions, the influence of the resource availability leverage point would be weak.

Political and Regulatory Uncertainty. Increased regulation of coal plants may occur if there is a consensus to decrease CO₂ emissions. Politically, there is increasing likelihood that a tax will be levied on utilities that have plants with certain pollution characteristics. This likelihood will increase as public concern about the "greenhouse effect" increases. This so called "carbon tax" could potentially impact the cost of coal plants dramatically. Technological changes to plants that would reduce emissions, as discussed above, would be the most likely means of reducing these uncertainties.

5.4 Natural Gas Base Load Capacity Systems Model

Five leverage points have been identified for the base load natural gas option from its system model of Figure 10. These are discussed and compared to the leverage points of the general selection model in the remainder of this section. The leverage point identified in the general selection model, but not found in the natural gas systems model is Safety Concerns. As discussed in Section 4.2, this aspect of the general selection model is not uniquely identified for natural gas plants.

Positive Environmental Effects. The positive environmental effects of natural gas plants are the lack of SO₂ emissions and the reduced production of CO₂ and NO_x for each kilowatt-hour of electricity generated as compared to other fossil fuels. This leverage point increases the public acceptance of this technology.

Negative Environmental Effects. Although natural gas plants do not produce CO₂ and NO_x on the same levels as other fossil fuel plants, they do result in their emission. Regulations and pressure to reduce these emissions may result in costly removal measures which reduce the ROI for natural gas plants. Improvements in gas combustion and conversion to electricity will reduce emissions and enhance this option further.

Plant Performance. Any improvement to the gas combustion and power conversion cycles will result in a reduction of negative environmental effects and an increase in natural gas plant ROI. The increase in ROI is the result of increase electrical production per unit consumption of natural gas and a decrease in natural gas fuel costs. Advances in this area will increase both public and utility acceptance of this option.

Resource Availability. Resource availability may be the most influential and limiting leverage point of the natural gas system. Currently, natural gas use is located near its production centers. Less than 15% of the natural gas produced in the world is transported great distances from its production source. However, increased availability of natural gas will result in its depletion at an even faster rate. At current worldwide usage levels and extraction technology, current estimated natural gas reserves will last 120 years. If consumption of natural gas increases to replace all current coal and oil usages, these reserves will last 55 years. Better and more cost effective extraction technology would increase the availability of natural gas and could potentially extend usage by two to three times current estimates.

Political and Regulatory Uncertainty. Uncertainty in the future environmental regulation and political uncertainty regarding whether natural gas plants will be allowed in the future need to be resolved prior to natural gas becoming a viable option for future base load capacity.

5.5 Nuclear Base Load Capacity Systems Model

Five leverage points have been identified for the base load nuclear option from its systems model of Figure 11. These are discussed and compared to the leverage points of the general selection model in the remainder of this section. A leverage point identified in the general selection model, but not found in the nuclear systems model is Resource Availability. As discussed in Section 4.2, this aspect of the general selection model is not strongly identified for nuclear plants.

Positive Environmental Effects. Nuclear power plants do not produce products of combustion that cause air pollution, possible global warming, and acid rain. However, the positive environmental benefits of nuclear power are currently outweighed by negative environmental concerns. The positive benefits of nuclear power will remain a secondary effect in the nuclear system unless global warming is confirmed to be a significant threat and other base load options are found to be less acceptable. The influence of positive environmental effects could be enhanced by developing better public education programs.

Negative Environmental Effects. Although release of radioactive material is a concern for the public, disposal of nuclear waste is a more important impediment for the nuclear power option. The inability of the United States to resolve the high-level waste problem results in significant perceived risks for this option. First, the issue of high-level waste is a major contributor to the public's unfavorable attitude towards nuclear power. Second, states are beginning to make disposal of high-level waste an issue. For example, California now has a law that requires the California Energy Commission to certify that the high-level waste problem is solved before additional nuclear power plants can be built in that state.

Resolution of issues associated with the high-level waste are difficult because the problems are political as well as technical. Research should be conducted to resolve this problem using alternate methods of waste disposal that are more acceptable to the state governments and the public.

Safety Concerns. The nuclear option has a history of safety concerns that have increased the amount of regulation and caused the public to distrust the credibility of the industry and its regulators. Changes in regulation have caused costs to escalate to the point where construction and operation of nuclear power plants is considered a very high risk. Eliminating serious operational problems would help eliminate the perceived need of additional regulation, improve plant ratings, and could positively influence public acceptance. Many of the types of operational problems that initially resulted in increased regulation and

adverse public acceptance have been eliminated through the efforts of programs sponsored by the Department of Energy (DOE), the Institute for Nuclear Power Operations (INPO), and the NRC. An adequate plant performance data base exists to assess the root causes of problems and to develop means to resolve them. Since INPO currently has responsibilities in this area for the nuclear industry, they are well positioned and qualified to eliminate serious operational problems for nuclear power plants.

Plant Performance. Plant performance data indicate that the number of safety trips have been reduced dramatically over the past several years and the capacity factor for the nuclear industry is generally moving upward although it is still below the other major nuclear power producing countries in the world. Further improvements in performance are projected when newly designed plants are built and operated. However, these new plants are first-of-a-kind which causes the perceived risks to be higher. Programs that would build and operate these new designs would reduce the risks to utilities.

Political and Regulatory Uncertainty. The proliferation of new NRC licensing regulations and requirements is a major influence on the perceived risks of nuclear power. These perceived risks will not decrease unless there is a change in the way nuclear power plant regulation is carried out. Congress recently passed legislation that will implement a one step licensing process. Even with the passage of this legislation, there will continue to be concerns about the licensing process. Assistance will be required to certify advanced plant designs and to halt creeping regulation. In addition, the licensing process will not be directly applicable to all types of advanced reactors considered as future energy sources. This is particularly true for the liquid metal reactor and its support systems, particularly the concept of on site fuel reprocessing. Assistance in developing information to support licensing of the advanced plants will be necessary to reduce perceived risks.

5.6 Hydroelectric Base Load Capacity Systems Model

Six leverage points have been identified for the base load hydroelectric option from its system model of Figure 12. These are discussed and compared to the leverage points of the general selection model in the remainder of this section.

Hydroelectric Benefits. Hydroelectric plants have many benefits, not all of them related to the environment. The beneficial aspects of these plants may be increased barge transportation, irrigation, flood control, recreation such as fishing and boating, community water sources, and increased habitat for fish and waterfowl. Any action that emphasizes these benefits would increase public acceptance of hydroelectric plants and decrease their perceived risks. However, this leverage is considered weak when compared to negative environmental effects.

Negative Environmental Effects. There are many negative environmental effects of hydroelectric plants for which there are no easy or inexpensive solutions. For two of these effects, the loss of land and wildlife habitat, there are no solutions for. Solutions for the disturbance of fish habitat caused by the interruption of migratory patterns or the degradation of streams have the most potential for impacting a utility's decision to build a hydroelectric plant.

Safety Concerns. The primary safety concern for hydroelectric plants is catastrophic dam failure. Public perception of the likelihood of such failures is high, although in reality the likelihood is very low. Actions that would increase public confidence in hydroelectric plant construction would increase public acceptance. However, this leverage is believed to be weak.

Plant Performance. Improvements in hydroelectric plant performance which would increase their electrical production and result in an increase in hydroelectric plant ROI. However, any plant performance improvements will probably have to be compatible with offsetting negative environmental effects. Turbine passage fish mortality is very high. Turbine technology which increases electrical production while at the

same time allows safe fish passage would provide the ultimate benefit for this leverage.

Resource Availability. Advances in this leverage point would result in the availability of new potential hydroelectric sites. Technology which would seal faults in rock formations better or turbines which could operate at lower head pressures would increase the availability of hydroelectric sites.

Political and Regulatory Uncertainty. Political and regulatory uncertainties can be attributed to the negative environmental effects of hydroelectric plants. Any action to decrease these effects will reduce the uncertainty of political support for this technology or the uncertainty of additional environmental regulation.

5.7 Biomass Base Load Capacity Systems Model

Six leverage points have been identified for the base load Ag/biomass option from its system model of Figure 13. These are discussed and compared to the leverage points of the general selection model in the remainder of this section. A leverage point identified in the general selection model, but not found in the biomass systems model are Safety Concerns. As discussed in Section 4.2, this aspect of the general selection model is not uniquely identified for Ag/biomass plants. The Total Costs leverage point discussed for the general decision model in Section 4.1 is also discussed for Ag/biomass because of the unique contributor to this leverage point.

Positive Environmental Effects. Ag/biomass has substantial environmental benefits which can be used as leverage to increase public and governmental support. Use of Ag/biomass plants would replace plants using fossil based and nuclear based fuels which would reduce emissions of SO_2 and NO_x thereby avoiding acid rain. Efficient biomass conversion also limits the release of organic compounds that produce smog. The use of biomass fuels, produced on a sustainable basis, does not contribute

to increased CO₂ concentrations, which may be a prime factor in global climate change, popularly referred to as the "greenhouse effect." While Ag/biomass does generate some wastes and ash these may be useable directly or indirectly as a fertilizer.

Negative Environmental Effects. Generation of emissions, ash and process waste generates some environmental concerns requiring remediation measures. The emissions from Ag/biomass plants would be particulate in nature and would need to be monitored and controlled. Research into effective operations and control systems could reduce emission of particulates. Research on feedstocks and burn temperatures that created fertilizer grade ash could be developed. Environmental uncertainty still plays an important role in the perceived risks of Ag/biomass. Public opinion could change radically if Ag/biomass resulted in poor land use and poor agricultural practices for dedicated energy crops. Addition of fertilizers could also offset environmental benefits. Research into development of Ag/biomass crops and agricultural practices could alleviate these concerns.

Plant Performance. Improvements in plant performance would boost ROI, improve competitiveness of the industry and contribute to growth in maturity of the technology. Actions that would enhance the maturity of the technology would provide significant leverage for Ag/biomass. Examples would be the development of improved control systems and an improved understanding of the effects of feedstock variability on plant efficiency and operation. Analysis and testing of biomass pilot plants would speed maturing the technology.

Additionally, utilities should be encouraged to seek current markets where Ag/biomass is now feasible. The story of Ag/biomass is one of new technology development and assistance should be provided to assist in this development. The EPRI study on renewable power sources states

"Today, while technical advancement continues, the emphasis has shifted to the marketplace -- getting the technology into

the field and nurturing markets in locations where existing renewable technology can be economically competitive. Spurred by efficiency improvements of the past decade, several options have already been able to find such market niches -- wind and solar technologies in particular. The evolution of these markets should broaden the scope for all renewable applications: government research indicates that renewables could be contributing between 28% and 40% of U.S. energy supply by the year 2030, with biomass by far the largest source."

Resource Availability. The diversity in possible fuels for biomass plants results in a large amount of variability in resource availability. There is need for research to consistently define the potential biomass fuel that is available, its quality in terms of possible energy production, and its accessibility. Additional information on the lands areas that could grow biomass crops and the possible crops for the lands would also be necessary. An assessment of the availability of Ag/biomass for electrical production versus its use for development of liquid biofuels would aid utilities in decisions on the use of biomass.

Total Costs. A significant and immediate leverage on total costs are government incentives. Identification of policy that would enhance the use of biomass would aid policy makers in developing future regulation and legislation. Improvements in capital costs and operating and maintenance costs will be delayed until the technology is further developed. Additional leverage in accelerating this process could be obtained from increased research and development. Some states have encouraged industry spending in biomass research and development by providing matching funds.

Political and Regulatory Uncertainty. As indicated by the EPRI study on renewables, political support that encourages development of biomass technology can be expected for at least the next decade. Regulatory uncertainty is primarily caused by existing restrictive legislation that does not account for the unique needs of Ag/biomass

electrical production. Assistance could be provided by reviewing new regulation for unintended effects on renewable energy systems.

6. CONCLUSIONS AND RECOMMENDATIONS

Systems models have been developed to identify the important variables and their interrelationships for selected base load electric power plant options. These models were used to compare the variables affecting a utility's selection of a base load option and to identify what added technology or services could change the systems in a way that would enhance the likelihood of a favorable utility decision for each options. A brief description of the identified opportunities for technology development follows. Because we are not familiar with all of the technologies available at the INEL, no attempt was made to match available capabilities with those identified.

The general utility model described in Section 3 identified the following areas where added technology would help clarify the need for additional base line electric power:

- Technology and services to develop and extend the uses of Demand Management (conservation, load shaping, etc.). Because demand management has a direct effect on electric power needs, it will become more important as electrical power demand grows and the risks associated with building new generating capacity increase. Future work in this area should expand on both a national and an international scale as developing countries are pressed to incorporate demand management in their energy planning.
- Technology and services to extend the life of existing base load plants will become more important as electric power demand grows and new plant risks increase.
- Identification of technology and services to reduce operating costs while maintaining high electric system reliability will become increasingly important as plants age and rate hike requests come under increased scrutiny.

- Future electric power projections may not account for early retirement of current base load plants. An evaluation of the possible extent of early retirements and their effect should be considered.

The specific base load generation systems models of Section 4 identified the following areas where added technology or services would improve performance for more than one of the base load options:

- Technology to improve the efficiency of plant thermodynamic cycles are needed for most base load options. Technology for both combustion processes and conversion of thermal to mechanical energy should be included.
- Technology to improve removal of SO_2 , NO_x , and CO_2 from plant emissions should be pursued.
- Enhance the maturity of renewable resource generating options and new advances in combustion or conversion technologies through pilot plant construction and testing.
- Technology and services to address energy policy issues, for example the effect of a carbon tax, will be important in the future as the energy situation becomes increasingly complex.

In addition, the following areas have been identified where added technology and services would improve the performance of specific base load options:

- Technology and services to improve Ag/biomass base load options include: development of biomass crops and agricultural practices, surveys of lands suitable for biomass crops and its agriculture characteristics, assessment of the availability of biomass for electric production versus fuel production, and assessment of the impact of existing fossil fuel regulations on biomass plants.

- Technology to reduce the sulfur content of coal will be important as supplies of low sulfur coal decrease in the future.
- Technology or services to improve hydropower would include: improvements to fish habitat; design of turbines for easy fish passage; development and application of low head turbines; and assisting in the licensing and licensing renewal of hydro plants.
- Technology to improve the extraction of natural gas from its geologic locations, reduction of methane emissions as the gas is extracted and transported, and transport of liquid natural gas would increase the availability of natural gas and enhance the natural gas electric base load option.
- Technology or services to resolve the nuclear waste issue, reduce nuclear plant operating problems, stop creeping nuclear regulation, and assist in the licensing of new plant designs are all necessary to maintain a nuclear option.

It is recommended that an evaluation of these areas be performed to determine if they match the INEL strategic thrust areas and if INEL has unique capabilities to provide services or resolve the technology issues. It is also recommended that INEL investigate those areas where it does not have unique capabilities to determine whether assembling or developing these capabilities would be beneficial.

7. BIBLIOGRAPHY

1. American Public Power Association, *Energy Services Planning: A Public Strategy for the 1980s*, ANL/CNSV-TM-100, August 1982.
2. Bath, T. D. et al., *The Potential of Renewable Energy: An Interlaboratory White Paper*, SERI/TP-260-3674, March 1990.
3. Birk, J. and Sullivan, C., "Evaluating Hydro Relicensing Alternatives", *EPRI Journal*, pp 40-44, March 1991.
4. Burns, T. R. and Midttun, A., *Economic Growth, Environmentalism, and Social Conflict: A Case Study on Hydro-Power Planning in Norway*, International Institute for and Environment and Society, IIUG/dp--85-10, 1985.
5. Douglas, J., "Renewables on the Rise", *EPRI Journal*, pp 16-25, June 1991.
6. Dreyfus, A. D. and Ashby, A. B., "Fueling Our Global Future", *Environment*, Vol. 32, No. 4, pp 17-41, May 1990.
7. Energy Information Administration, *Federal Energy Subsidies: Direct and Indirect; Interventions in Energy Markets*, DOE/EIA/SR/EMEU--92-02, November 92.
8. Energy Information Administration, *The U.S. Coal Industry, 1970-1990: Two Decades of Change*, DOE/EIA-0559, DE93 006352, November 1992.
9. Fickett, A. P., Gelling, C. W., and Lovins, A. B., "Efficient Use of Electricity", *Energy for Planet Earth: Reading from Scientific American Magazine*, pp 11-24, 1989.
10. Fri, R., "The Challenges of Global Sustainability", *EPRI Journal*, pp 14-17, June 1992.
11. Fulkerson, W., Judkins, R. R., and Sanghvi, M. K., "Energy from Fossil Fuels", *Energy for Planet Earth: Reading from Scientific American Magazine*, pp 84-94, 1989.
12. Fulkerson, W., *Energy Technology R&D: What Could Make a Difference?*, Oak Ridge National Laboratory, ORNL-6541/V1, May 1989.
13. Government Institutes, Inc., "Repowering America", *Energy Technology XV*, Proceeding of the Energy Technology Conference, Washington, D.C., February 17-19, 1988.
14. Government Institutes, Inc., "Energy Progress and Environmental Protection", *Energy Technology XVI*, Proceeding of the Sixteenth Energy Technology Conference, Washington, D.C., February 28 - March 2, 1989.

15. Hafele, W., "Energy from Nuclear Power", *Energy for Planet Earth: Reading from Scientific American Magazine*, pp 95-106, 1989.
16. Hanson, D. J. and Brownson, D. A., *Identification of the System Structure and Potential Leverage Points for Revitalization of the Nuclear Power Industry*, EGG-RAAM-10502, September 1992.
17. Helm, J. L. (ed), *Energy; Production, Consumption, and Consequences*, National Academy of Engineering, 1990.
18. Hirst, E., "Boosting U.S. Energy Efficiency Through Federal Action", *Environment*, Vol. 33, No. 2, pp 7-11 & 32-35, March 1991.
19. Howard, J. O., *Biomass estimates for five western states*, Forest Service, Pacific Northwest Research Station, Portland, Oregon, RD: DOEBP353971, October 1990.
20. Larsen, R. S., "Running Out of Resources", *IEEE SPECTRUM*, pp 43-45, July 1993.
21. O'Connell, R. A., *Northeast Regional Biomass Program Final Progress Report, July - September 1991*, CONEG Policy Research Center, Inc., Washington, DC., DOEOR2138934, November 1991.
22. National Renewable Energy Laboratory, *Electricity From Biomass: A Development Strategy*, DOECH10093152, April 1992.
23. Perlack, R. D., Ranney, J. W., and Wright, L. L., *Environmental Emissions From Biomass Energy Feedstocks*, Oak Ridge National Laboratory, CONF9212071, 1992
24. Rossin, A. D. and Fowler, T. K. (ed), *Conversations About Electricity and the Future*, The First 1990 Group on Electricity, Berkeley, California, 1991.
25. Solar Energy Research Institute, *The Potential of Renewable Energy, An Interlaboratory White Paper*, SERI/TP-260-3674, March 90.
26. Swezey, B., and Sinclair, K., *Status Report on Renewable Energy in the States*, National Renewable Energy Laboratory, NRELTP4625175, December 1992.
27. Weinberg, C. J. and Williams, R. H., "Energy from the Sun", *Energy for Planet Earth: Reading from Scientific American Magazine*, pp 107-118, 1989.

APPENDIX A
COMPUTER CODES FOR ANALYSIS OF ENERGY SYSTEMS

Table A-1. Summary of Computer Codes for Analysis of Energy Systems

Codes	Application	Code Description
ARGUS	General Energy Systems	The Argonne Utility Simulation (ARGUS) model: An analysis tool for evaluating energy and environmental strategies. ARGUS accounts for the interplay of economic, environmental, and technological factors in energy policy issues and emission-control strategies.
AUSM	General Utility Forecasts	Advanced Utility Simulation Model (AUSM): The computer program simulates the operation of all electric utility generating units in the U.S. The model forecasts emissions, costs of electric generation and electric rate schedules by year and by state
DESS	General Energy Systems	The DESS (Detailed Energy System Simulation) Model is a tool for translating energy demand forecasts into their economic and environmental consequences. DESS was developed and extended within the energy modelling program of the Commission of the European Communities
DYNAMOII	Simulation Language	The DYNAMO II simulation language was used to develop dynamic mini-models of the world and the United States. These models were developed to simulate United States growth trends.
EGEAS	General Utility Planning	EGEAS (Electric Generation Expansion Analysis System) developed by the Electric Power Research Institute for analysis of utility capacity expansion.
EFOM-12C	General Energy Systems	EEC's Energy Flow Optimization Model (EFOM-12C) This model was developed to assist in policy analysis and technology assessment and is part of the European Community's energy research programme.
ESNS	General Energy Systems	the Energy Systems Network Simulator, developed at Brookhaven but is no longer being maintained
Fossil2	Fossil Energy Systems Planning	The Fossil2 energy-economic model is used by the US Department of Energy (DOE) for a variety of energy and environmental policy analyses.
GSMP	Process Energy Systems Analysis	GSMP; General Systems Analysis Modeling Code. Developed primarily for the modeling of advanced energy conversion systems
JALTES-II	Nuclear Energy Systems	JALTES-II: A Systems Analysis Model for Long-Term Strategy on Nuclear Power Development, developed by JAERI
LEAP	General Energy Systems	Long-term Energy Analysis Program (LEAP) The code is a large scale, long-range (50 year) equilibrium model of energy supply and demand in the US economy used for government and industrial forecasting.
LSAP	simulation language	The computer program Linear Systems Analysis Program (LSAP) is an interactive program with graphics capability that can be used for the analysis and design of linear control systems.
MARKAL	General Energy Systems	MARKAL (Market Allocation) is a flexible, multi-period, linear-programming (LP) model of a generalized energy system. It is capable of representing a wide variety of configurations of national and regional energy systems and is particularly suited for comparison studies of various options under a variety of constraints and policy assumptions.

Table A-1. Summary of Computer Codes for Analysis of Energy Systems

Codes	Application	Code Description
MARKAL-MACRO	General Energy Systems and Economic model	MARKAL-MACRO: MARKAL-MACRO is an experiment in model linkage for energy and economy analysis. It is designed specifically for estimating the costs and analyzing the technologies proposed for reducing environmental risks such as global climate change or regional air pollution.
NCM	Coal Energy Systems Forecasting	National Coal Model(NCM): The National Coal Model (NCM) is a linear programming model used by the Department of Energy to investigate the impact of Federal and State legislation on the coal and electric utility industries. NCM is designed to forecast coal production; to project the production, consumption, and price of coal.
NEMS	General Energy Systems and Forecasting	National Energy Modeling System (NEMS): NEMS is the result of many years of development of energy modeling and analysis tools, many of which were developed for different applications and under different assumptions. NEMS is currently the most comprehensive tool currently used by U.S. agencies to deal with global, national and regional energy modeling, and energy analysis needs.
NUFS	Financial model	National Utility Financial Statement (NUFS):NUFS is a financial model used by the Energy Information Administration (EIA) to forecast financial variables for the electric utility industry.NUFS is normally used in conjunction with the National Coal Model or the Intermediate Future Forecasting System.
PC-MARKAL	General Energy Systems	MARKAL, an acronym for MARKet ALlocation, is a large scale Linear Programming (LP) optimization model which captures the complex interrelationships of energy systems across the spectrum from primary energy supply to energy service demands. The model now operates in a "user-friendly" PC-based processing environment centered around an integrated analysis support tool.
RAMC	Mine Forecasting Model	Resource Allocation and Mine Costing Model The model produces supply-price relationships for 30 coal types and 31 producing regions based on the 1980 EIA Demonstrated Reserve Base, engineering estimates of mining costs for various surface and underground regional mines, and coal-type-specific cost elements
RPG	General Utility Planning	Resource Planning Guide (RPG): This is a multifaceted set of tools to support small to mid-sized utilities analyze supply- and demand-side management alternative as part of a planning process for new energy resources that evaluates the full range of alternatives, including new generating capacity, power purchases, energy conservation and efficiency, cogeneration and district heating and cooling applications, and renewable energy resources.
SALT	Process Energy Systems Analysis	SALT (Systems Analyses Language Translator) is a comprehensive systems code for Analysis and Simulation of Advanced Energy Systems. The SALT code has been used to study open-cycle and liquid-metal magnetohydrodynamic systems, fuel cells, ocean thermal energy conversion, municipal-solid-waste processing, fusion, breeder reactors, and geothermal and solar-energy systems
SALTD	Process Energy Systems Analysis	SALTD Dynamic Systems Code A dynamic systems code has been developed for the dynamic analysis of power plants. The code has been used to analyze power plant transients and determine control system design specifications. The SALTD code is an enhancement to the SALT systems code, which was also developed at ANL.
TESOM	General Energy Systems	Time-Stepped Energy System Optimization Model (TESOM): TESOM is the principal time-dependent energy integrating model used at Brookhaven National Laboratory for energy systems analysis.
WEP	Wind Energy Planning	Wind Energy Planning system (WEP)is a decision support system to be used in the economic evaluation of wind energy projects.

APPENDIX A: BIBLIOGRAPHY

Alexander-J.F.; Sipe-N.G.; Odum-H.T.; Dynamic Energy Models of the United States and the World; Florida Univ., Gainesville; DOETIC10105XSP; 1976

Berry-G.; Geyer-H.; SALTD Dynamic Systems Code; Argonne National Lab.; CONF8312395; 1983.

Caramanis-M.C.; Schweppe-F.C.; Tabors-R.D. Electric-Generation-Expansion Analysis System. Volume 1: Solution Techniques, Computing Methods, and Results. Final Report; Massachusetts Inst. of Tech.; EPRIEL2561V1; 1982.

Cohen-S.; Crockett-R.; Resource Allocation and Mine Costing Model (RAMC85) Model; DOE Energy Information Administration; DOESWMT86024; 1985.

Computer Data Systems, Inc., Bethesda, MD.; National Coal Model (NCM) Users Manual; DOE/EIA101281; 1982.

Cook-J.M.; GSMP; General Systems Analysis Modeling Code. Software; Argonne National Lab.; ANLNESC882; 1984.

Goldstein-G.A.; PC-MARKAL and the MARKAL Users Support System (MUSS). User's guide; Brookhaven National Lab.; BNL46319; 1991.

Grohnheit-P.E.; DESS model. A detailed energy system simulation model for the EC countries; Risoe National Lab., Roskilde (Denmark); RISOM2809; 1989.

ICF, Inc., Fairfax, VA.; Documentation of the National Utility Financial Statement (NUFS) Model: Final Report; DOE/EI19801H1; 1988.

International Energy Agency: Energy Technology Systems Analysis Project (IEA - ETSAP). Final Report on Annex II, July 1983 - June 1986; Kolb-G.; Kernforschungsanlage Juelich G.m.b.H. (Germany, F.R.); JuelSpez421; 1987.

Kydes-A.S.; Rabinowitz-J.; Time-Stepped Energy-System Optimization Model (TESOM): Methodology and Case Study; ERDA/290100-; 1981.

APPENDIX A: BIBLIOGRAPHY

Larsen-H.V.; WEP. A wind energy planning system. User's manual; Risoe National Lab., Roskilde (Denmark); RISOM2927; Nov 91.

Manne-A.S.; Wene-C.O.; MARKAL-MACRO: A linked model for energy-economy analysis; Brookhaven National Lab.; BNL47161; 1992.

National Research Council; National Energy Modeling System; LC9168549; 1992.

National Research Council; SALT Steady State Systems Code; CONF8312393; 1983.

Sato-O.; Yasukawa-S.; JALTES-II: A Systems Analysis Model for Long-Term Strategy on Nuclear Power Development; Japan Atomic Energy Research Inst; JAERIM85129; 1985.

Stockholm Environment Inst. (Sweden); LEAP. A computerized energy planning system. V. 1. Overview; NEISE74; 1990.

Veselka-T.D.; VanKuiken-J.C.; Parker-G.D.; Rose-K.; Introduction to the Argonne Utility Simulation (ARGUS) model; Argonne National Lab.; ANLEAISTM10; 1990.

Wise-M.A.; Woodruff-M.G.; Ashton-W.B.; Analysis of the industrial sector representation in the Fossil2 energy-economic model; Battelle Pacific Northwest Labs; PNL8185; 1992.

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