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Fuel Cycle Assessment: A Compendium of Models, Methodologies, and Approaches

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PREFACE

This compendium is designed to catalogue and profile a cross section of models, analytical tools, and approaches relevant to fuel cycle assessment. It is not designed to be an exhaustive compilation or to advocate one method over another. It is intended to provide users with a starting point from which to identify alternative approaches and resources to use in a fuel cycle assessment. Finally, this document is designed to be a dynamic resource. The state-of-the-art in fuel cycle assessment and related analytical techniques is an evolving and maturing process. This document is designed to be updated on a regular basis to reflect current analytical capabilities and methods relevant to fuel cycle assessment.

The authors would like to express sincere thanks to all of those individuals who provided information for the profiles contained herein. Because of their number, it would be difficult to name them personally in this preface. However, we would like to extend special thanks to the organizations and individuals who supported this effort including: Dr. Robert L. San Martin and Mr. Andrew Krantz from the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, as well as Mr. Blair Swezey and Mr. Jim Ohi from the National Renewable Energy Laboratory (NREL), without whose help and assistance this document could not have been prepared.

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I. INTRODUCTION

The purpose of this document is to profile analytical tools and methods which could be used in a total fuel cycle analysis. The information in this document provides a significant step towards:

1. Characterizing the stages of the fuel cycle.

2. Identifying relevant impacts which can feasibly be evaluated quantitatively or qualitatively.

3. Identifying and reviewing other activities that have been conducted to perform a fuel cycle assessment or some component thereof.

4. Reviewing the successes/deficiencies and opportunities/constraints of previous activities.

5. Identifying methods and modeling techniques/tools that are available, tested and could be used for a fuel cycle assessment.

Background

In April 1991, the U.S. Department of Energy's (DOE's) Assistant Secretary for Conservation and Renewable Energy (CE), Office of Utility Technologies (OUT), Integrated Resource Planning (IRP) Program commissioned the development of a draft compendium. That draft document was developed to identify and profile methods or analytical approaches which have been or could be considered in fuel cycle assessment as part of IRP. These included methods that had been used to evaluate environmental and non-environmental impacts of the fuel cycle (or some portion of the fuel cycle), evaluations of environmental externalities associated with electric generation, methods for impact analyses of various processes (i.e. manufacturing), and various types of methods for conducting scenario analyses. The document covered a period stretching from the early 1970s to 1989. That earlier report was well received by IRP practitioners, as well as analysts attempting to develop improved fuel cycle assessment approaches. The continued importance of that earlier effort provided the impetus to improve and update it. In addition, new fuel cycle assessment reports and studies have been performed and initiated since the development of the earlier draft report.

In November 1992, this current task was initiated to update the draft document by including those more recent activities, as well as to review and enhance profiles already in the draft compendium.

The first step in the effort was to conduct a literature review of relevant government, academic and private sector resources. The second step was to compile analytical models, applications, computer-based tools, and research papers relevant to fuel cycle assessment. These papers were reviewed and assessed, and profiles were developed for relevant approaches. Approximately 80% of the profiles are for research efforts ongoing or completed since 1985. The remainder represent efforts completed during the early 1980s as well as a few during the 1970s. Sixty studies have been collected and profiled in this document. These profiles seek to describe a representative cross section of the approaches, models and methodologies available for consideration in framing and implementing a fuel cycle assessment.

The compendium is not an exhaustive listing or description of each effort or each model. It is not the intent of this document to select or emphasize any particular method, model or approach. Nor does it seek to conclude whether or not comprehensive fuel cycle assessment efforts are the optimal means of analyzing and comparing energy technologies. Note that information and model analysis is an ongoing effort. For example, there currently are research efforts under way by the National Renewable Energy Laboratory, Electric Vehicle Total Energy Cycle Analysis, Electric Power Research Institute, and Department of Energy's TECA Handbook. This is a working document that is designed to be updated or expanded on a periodic basis, or as required by changes in the state of knowledge.

Fuel cycle assessments may prove to be the only valid means for performing a comprehensive comparison of energy technologies. But if this option is pursued, the analytical framework and approach should be one that produces meaningful results in a cost-effective manner.

This document has been developed to serve as a resource for any organization considering or conducting a fuel cycle assessment. From our initial review, there are a wide variety of relevant analytical efforts that have been performed or are underway in both the private and public sectors. Many efforts attempt to analyze and account for "externalities" associated with energy processes; however, they seem to focus solely on the environmental externalities realized during the electric generation or energy conversion stages of the fuel cycle and do not include non-environmental impacts or other stages of the fuel cycle. Others focus strictly on the economic effects of alternative utility resource options.

DOE's Integrated Resource Planning Program is currently evaluating approaches for performing fuel cycle assessment. OUT/IRP has a high level of interest in those approaches that will assist in facilitating efficient policy analysis and information transfer. It is first necessary, however, to develop an initial framework for analyzing the fuel cycle -- from exploration to waste disposal or recycling -- as well as identifying the range and type of direct and indirect fuel cycle costs/benefits for energy technologies. Secondly, it is important to investigate the variety of analytical concepts, techniques and methodologies/models that could potentially be utilized or could provide insights for performing a fuel cycle assessment. Based on this research, a feasible and meaningful fuel cycle assessment effort can be designed and implemented.

Organization of This Report

The following sections briefly discuss the fuel cycle and fuel cycle assessment. The bulk of this document is dedicated to providing brief profiles of models, methodologies and other resources which could assist in developing a fuel cycle assessment methodology.

Section II provides a brief overview of a concept of a generalized fuel cycle for energy technologies and the stages within the fuel cycle.

Section III discusses fuel cycle assessment. It includes an overview of some of the analytical issues pertinent to fuel cycle assessment and provides a brief overview of the use of fuel cycle assessment. It also discusses the increased interest in understanding externalities associated with technologies/processes, and state-level activities to account for selected components of fuel cycle impacts in energy planning.

Section IV of this document is the compendium of profiles. There are three main sections to the compendium.

1. Computer-Based Models and Valuation Approaches
   A. Models that approximate comprehensive fuel cycle assessment tools.
   B. Models that conduct analysis of components of fuel cycle impacts.
   C. Decision Aiding Packages/Standard Analytical Techniques.

2. Full or Partial Fuel Cycle and Life Cycle Studies
   A. Comprehensive Fuel Cycle Assessment Efforts.
   B. Partial Fuel Cycle Assessment Efforts.

3. Technical Research Papers

Following Section IV are a Glossary and Bibliography developed as part of this effort. Appendix A lists examples of air quality models.

II. THE FUEL CYCLE

This section provides a brief overview of the fuel cycle. Definitions of the fuel cycle and the specific stages and impacts which comprise it vary considerably. Those applying fuel cycle analysis will define the fuel cycle based upon their own objectives. In general, however, the fuel cycle includes all direct and indirect activities that occur from the time of resource extraction (through a technology's useful life) to waste disposal or recycling. The stages of the fuel cycle may vary for each energy technology, by region and for each application. Regardless of the fuel cycle, unique processes within each stage produce impacts. Some impacts become internalized in the cost of the product or service and are passed through to a later stage. Those not internalized in the cost of energy products or other associated products are considered externalities. These impacts are not imbedded in the cost of the ultimate product or associated products or services consumed.

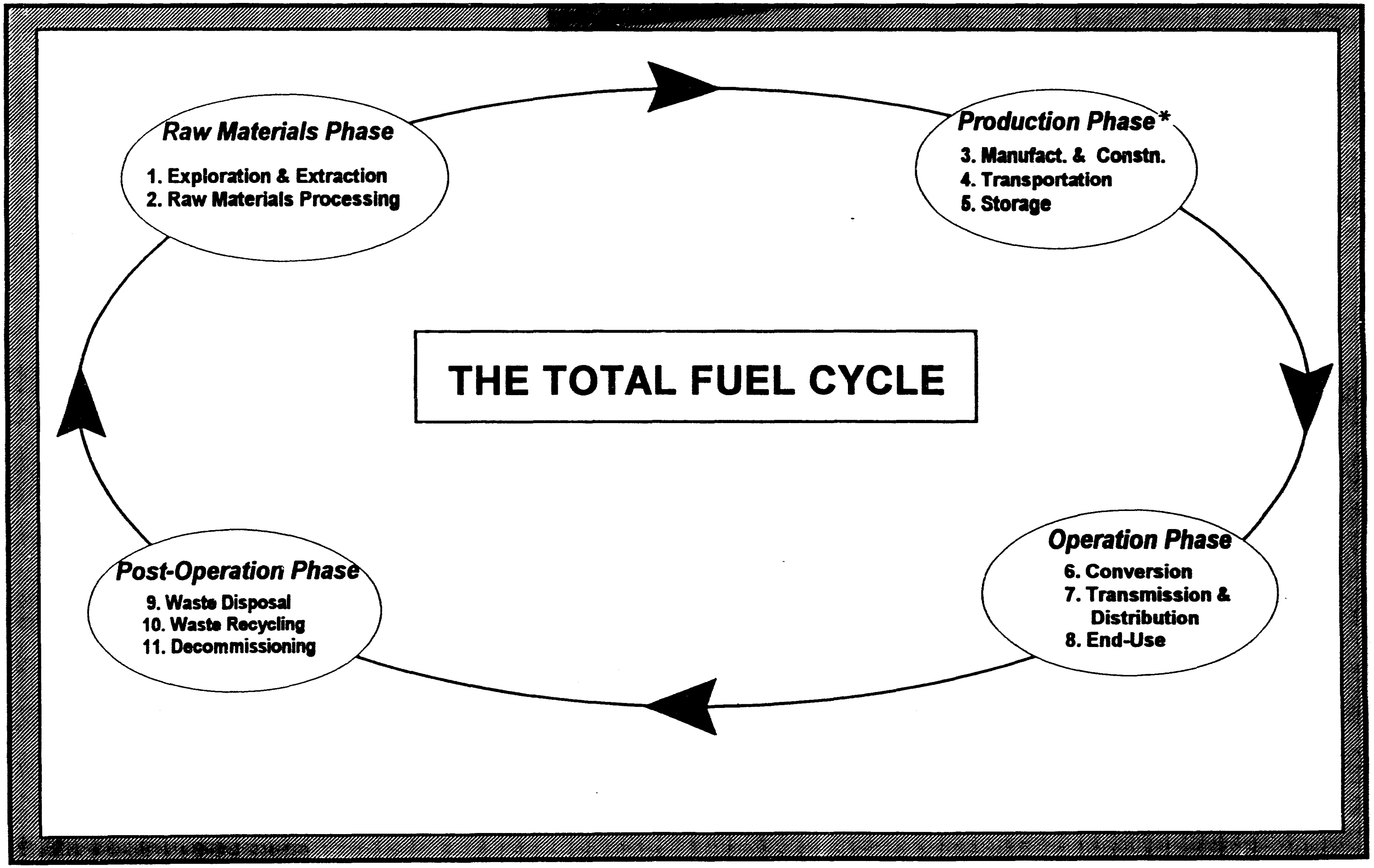
Careful consideration should be given to each impact in deciding if and how to include it in the analysis. For example, temporal and geographic characteristics must be recognized. Some fuel cycle impacts are one-time events, such as those impacts that occur during construction of a power plant. Others, such as power plant emissions, are continuous. In addition, some impacts may be localized in nature whereas others, particularly air emissions, may impact a broader geographic scope.

Also, total fuel cycle analysis must be differentiated from net energy analysis. Whereas total fuel cycle analysis tracks the impacts and total costs and benefits through a technology's useful life, net energy analysis tracks energy and material flows through a product's life-cycle. This is a component of fuel cycle analysis; however, energy and material costs are largely internalized in market prices as technologies pass from one stage to the next. Fuel cycle analysis tracks these activities, along with impacts not internalized in market prices.

In performing a fuel cycle assessment, the analyst is required to define the unique fuel cycle of the specific energy technology and the application to be evaluated. To develop a framework from which to define and analyze a specific fuel cycle, however, it is necessary to identify general fuel cycle stages. The generalized fuel cycle forms the basis for defining and characterizing specific supply-side and demand-side technology fuel cycles.

Exhibit 1 illustrates one concept of a fuel cycle. The activities which occur throughout the fuel cycle produce the unpriced impacts (costs and benefits) that fuel cycle assessment seeks to identify and, where feasible, measure. The cycle proceeds from the upstream stages in the raw materials phase, through the production phase and finally to the downstream stages of waste disposal and post-operation.

Exhibit 1



*Occurs throughout the fuel cycle.

Activities take place in each of these fuel cycle stages to render and facilitate the transformation of raw materials into consumable goods. Upon consumption, the fuel cycle continues. Some remaining wastes are recovered and put back into the cycle, others are released to the environment never to be recovered, still others are released into the earth where they later may be extracted and processed through the cycle again. These are the general stages of fuel cycle, however, within each specific stage the same cycle of activities takes place. Thus, within each stage of the general fuel cycle, raw materials are obtained, transformed into useful product and consumed. Similarly, wastes are produced within each stage. Some of these wastes are recovered for re-use -- others are not and become released to the environment.

Stages of the Fuel Cycle

There are four primary phases of a fuel cycle -- raw materials, production, waste disposal (recovered and unrecovered), and post-operation. Within these four phases are ten fuel cycle stages that can be readily adapted to specific supply-side and demand-side utility technologies. The waste disposal (unrecovered), waste recycling, transportation, and storage stages occur throughout the fuel cycle. The four primary phases follow:

Raw Materials Phase

1. **Exploration and Extraction** - This comprises those activities associated with identifying and developing primary energy resources.

2. **Raw Materials Processing** - This stage is composed of activities related to the preparation of raw materials for use in energy production processes. Examples include oil refining and coal beneficiation.

Production Phase

3. **Manufactured and Construction** - This stage is associated with the manufacture and construction of parts, equipment and facilities which will facilitate energy production and consumption throughout the fuel cycle.

4. **Transportation** - Transportation activities occur at many points in the fuel cycle. Transportation is required to move the raw materials to be processed, move processed goods to the point of use, and for the requirements of all other stages.

5. **Storage** - Storage requirements and associated externalities also occur in many stages of the fuel cycle. These include the operation and maintenance of facilities for storing raw materials, parts and equipment, and other items or commodities required for the generation of electricity.

Operation Phase

6. **Conversion to Electricity** - This stage entails the use of generating equipment to convert energy resources into useful energy.

7. **Distribution/Transmission** - This considers those activities associated with operation of transmission lines, step-up and step-down substations, switching stations, and other relevant activities associated with the distribution or transmission of electricity

8. **End-Use** - Customer (non-utility) end-use of demand-side management technologies, gas or oil-fired technologies.

<u>Post-Operation Phase</u>

9. **Waste Disposal: Unrecovered** - This is the production of waste that is released to the environment through controlled or uncontrolled means.

10. **Waste Recycling** - Throughout the fuel cycle opportunities exist for the recycling of process wastes. Activities associated with this stage include the collection and reprocessing of raw materials, or the recycling of parts and equipment.

11. **Decommissioning** - The decommissioning stage includes those activities involved in removing a plant from service, dismantling it, and restoring the site to be compatible with other industrial uses.

Clearly, the extent of the fuel cycle is significant and its depth is complex. Not so clear is the extent to which the total fuel cycle needs to be analyzed. A truly comprehensive analysis is a formidable task, and the validity of fuel cycle data can be the subject for debate.

III. FUEL CYCLE ASSESSMENTS

A key component of fuel cycle assessment is accounting for costs and benefits of an energy supply or demand option from the point of its development to its disposal. Fuel cycle assessments take into account the direct costs and benefits of energy use as well as the indirect costs and benefits. This problem was considered by A.C. Piguo as early as the 1930s in his thoughts on internalizing externalities. Piguo was an economist who recognized the need for identifying the external costs and benefits of marketplace activities. Since that time, a number of noted economists have attempted to identify and evaluate methods of incorporating external costs and benefits in the market price of a good or service. From the review of fuel cycle assessments contained herein, a fuel cycle assessment:

> *Includes all direct and indirect actions and their associated costs from resource extraction -- through its useful life -- to disposal or recycling. In addition, fuel cycle assessment incorporates, quantitatively and qualitatively, external costs and benefits associated with a particular technology. External costs and benefits include costs resulting from impacts that are not internalized in the market price of energy. The impacts occur in economic, technological, environmental and social categories.*

Approaches to fuel cycle assessment have taken various forms and represented various levels of detail. Other approaches have included assessments of selected environmental externalities associated with the conversion stage of electric generation. Many of the approaches that have been used, however, are relevant to IRP and utilize tools and resources that could be considered in framing or performing a fuel cycle assessment. Examples of variations include:

- **Product Life-Cycle Assessment (LCA)** - This is a tool to evaluate the environmental consequences of a product or activity comprehensively across its entire life. The Society for Environmental Toxicology and Chemistry (SETAC) has established a Life-Cycle Assessment Advisory Group to "advance the science, practice and application of LCAs to reduce the resource consumption and environmental burdens associated with products, packaging, processes, or activities." The group has been conducting technical workshops and developing research papers to address major issues associated with life-cycle assessment. Many of the issues SETAC is confronting mirror those of fuel cycle assessment in IRP, such as:

    1. What impacts should be evaluated in the analysis and what are the boundaries/parameters for identifying those impacts; and

    2. What are appropriate methods for quantifying and qualifying those impacts.

- **Total Energy Analysis** - Also known as embodied energy analysis, this calculates the total (direct plus indirect) energy required to produce goods or services. Models have been developed to calculate the embodied energy intensities for selected sectors/industries of the economy or for particular manufactured goods. Depending on parameters of the analysis, fuel cycle analyses could also incorporate embodied energy analysis as a component. Some models are adapted input-output models that calculate the embodied energy intensity in Btus of fossil fuel per dollar of output from an industry or sector of the economy. Other modeling efforts are designed to calculate the total energy requirements of particular demand-side management technologies and monitor total building energy requirements and technical performance of these technologies.

- **Environmental Externalities from Electricity Generation** - This approach identifies selected environmental externalities associated with one stage of the fuel cycle -- the generation of electricity at the source. In recent years, the concept of recognizing, identifying and accounting for utility sector externalities has been actively investigated and employed. Rather than approaches such as product life-cycle assessment or total energy analysis, this approach focuses on air emissions such as (NO_x and SO_2) associated with electric generation. The driving force behind this has been a growing awareness of environmental degradation such as acid rain and urban ozone production associated with these pollutants. While this is only a component of fuel cycle assessment, there are models, tools and research techniques employed in these activities that can be considered in framing a fuel cycle assessment.

The Need for Fuel Cycle Assessment

Over the last 20 to 30 years, public concern over energy prices, job losses, fuel security, environmental damage, and the threat of wars over oil has increased significantly. This has led to a concurrent concern by environmental groups, public officials, and utility industry participants on how to select least cost and energy management options. Public officials have responded by limiting external environmental impacts through greater regulations on air and water emissions. Examples of this overall response are embodied in federal legislation such as the:

- National Energy Policy Act of 1992;
- Clean Air Act and 1990 Amendments to the act (CAAA);
- Clean Water Act; and
- Resource Conservation and Recovery Act.

Federal regulations have focused primarily on providing standards for emissions and toxic releases of specific pollutants. These regulations have forced utilities to install pollution control devices (i.e. scrubbers), make greater use of technologies that reduce total pollution, and investigate alternative load management methods of responding to customer demand that are more environmentally sound than traditional methods. Also, public concern is being manifested at the state level. Many state public service commissions are implementing regulations and planning guidelines to require utilities to account for or consider environmental externalities in the conversion stage in their utility planning and electric generation. In some cases, utilities are exceeding federally established pollution standards. In nearly all of the states, however, the focus has been strictly on environmental externalities associated with select pollutants at the electric generation source, rather than a total fuel cycle assessment. Perceived complexities in the analysis, as well as in the data and methodologies, are reasons total fuel cycle assessments are not considered.

Several activities performed by various academic institutions and industry groups during the 1970s considered net energy analysis and/or fuel cycle assessments.[1] These focused largely on fuel cycles of a particular technology, such as coal or nuclear power. In many cases, not all stages of the fuel cycle were evaluated. One motivation for these studies was the interest in evaluating fuel cycles of technologies that could rely on domestic energy resources -- an interest that resulted from sharp increases in the cost of imported oil.

In recent years there has been broader activity in the area of fuel cycle assessment. This has been driven by several factors, including public interest in reducing environmental and societal impacts from energy production as well as efforts to put all technologies on a level playing field. Examples of recent multi-national and federal level guidance or activities in the area of fuel cycle assessment include:

- The National Energy Policy Act of 1992 calls for the Secretary of Energy to provide a least-cost energy strategy that gives "full consideration to:

  1. the relative costs of each energy and energy efficiency resource based upon a comparison of all direct and quantifiable net costs for the resource over its available life, including cost of production, transportation, distribution, utilization, waste management, environmental compliance, and in the case of imported energy resources, maintaining access to foreign sources of supply;" and

  2. should consider "the economic, energy, social, environmental, and competitive consequences resulting from" federal policies to promote alternative technologies and efficient use of conventional technologies.[2]

- The Federal Energy Regulatory Commission (FERC), in response to requirements under Clean Air Act Amendments Section 808 Renewable Energy and Energy Conservation Incentives, states that the consideration of non-environmental

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[1] Some models and papers were developed in the 1970s to look at the total fuel cycle of specific energy technologies. For example: "TOSCA: The Total Social Cost of Coal and Nuclear Power," Gaines and Berry, 1979; and "The Social Cost of Producing Electric Power from Coal: A First-Order Calculation," Morgan, Barkovich and Meter, 1973.

[2] H.R. 776 Conference Version of the Energy Policy Act, October 7, 1992.

externalities such as national security and employment are not being captured in current state regulations. This is a problem which needs to be resolved to support better decision making.[3]

- DOE and the Commission of European Communities (EC) agreed to develop a comparative analytical methodology and to develop the best range of estimates of external costs from secondary sources for eight fuel cycles and four conservation options for electric generation. It is designed to develop a framework for performing fuel cycle assessment and identifying secondary data resources and gaps.

A review of the legislation and fuel cycle activities leads to the conclusion that:

- There is a recognized need to analyze a broader range of impacts beyond the narrow set of environmental ones such as air emissions. This will provide a more clear picture of the total impact.

- Numerous non-environmental costs and benefits accrue throughout each of the stages of a technology's life-cycle that are not internalized in the market price. There is a need to evaluate these costs and benefits as part of a fair and equal evaluation.

- Many activities underway that only look at certain components of the fuel cycle and or apply adders for a narrow set of impacts may not allow for the full or actual social costs and benefits of technology options to be considered.

- Fuel cycle assessments will provide planners with a more truthful and comprehensive portrayal of the total impact of one technology option versus another. However, it is important to design and test methods that not only result in valid and cost effective research, but also provide results that can be readily used and understood by energy planners.

The Importance of Fuel Cycle Assessments

Fuel cycle assessment offers the opportunity to consider a broader array of energy options. It can incorporate the range of environmental and non-environmental impacts and issues that are relevant to decision makers as well as consumers. From a market perspective, many consumers are demanding "environmentally conscious" or "green" products. Evaluation of environmental externalities in the conversion stage, absent of similar evaluations in other stages, or of economic or societal externalities, may produce results that are not as beneficial to society as a full evaluation would be.

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[3] Federal Energy Regulatory Commission Staff Report, "Report on Section 808 Renewable Energy and Energy Conservation Incentives of the Clean Air Act Amendments of 1990," December 1992.

There is interest at the state level to respond to this concern, build on earlier efforts, and look for methods to perform a fuel cycle assessment cost effectively. The objective is to be able to evaluate a broader range of environmental and non-environmental externalities.

Most states do not have the resources to develop and test fuel cycle assessment. They must rely on national level resources for assistance in addressing fuel cycle research or any component thereof. For example, the state of Maryland participated in a DOE study to test the implementation of the *Fuel Cycle Assessment Guide* as a tool for framing and implementing an assessment of fuel cycle impacts. The guide is a tool for identifying and characterizing environmental and non-environmental externalities associated with the fuel cycle of specific demand and supply technology options. Local and regional experts in the utility and energy fields can be assembled to collaboratively frame and implement the analysis. Evaluation of the guide reveals that fuel cycle assessment can have many applications. It can be used to evaluate a limited number of selected technologies within an IRP setting. It can also be used to evaluate alternative R&D options or technologies for the purposes of state or regional planning, or for technology promotion.

Similarly, the Massachusetts Department of Public Utilities (DPU) monetizes some emissions, yet has expressed an interest in valuing a broader range of environmental impacts, such as air toxins (metallic elements and organic compounds). Lacking sufficient data, however, Massachusetts is awaiting the results of research being done by the U.S. Environmental Protection Agency (EPA). While not a fuel cycle assessment, the EPA work on the CAAA should broaden the level of data resources and the Massachusetts' DPU's ability to evaluate external impacts. The EPA effort is designed to study toxic emissions from power plants during 1993. This will be the basis for regulating power plant emissions.

Exhibit 2 provides an example of state level activities to incorporate environmental externalities. It also discusses some of the current re-evaluation of externality estimates.

Exhibit 2
Rethinking on Externalities

There has been a significant amount of rethinking by states such as Massachusetts, California and New York about the validity of specific externality values that have been adopted, as well as the approaches used to internalize externalities. Some of the previous efforts to account for externalities may have been imperfect and could have resulted in less than optimum decisions. New York and California are among those states that are looking at externality estimates anew and revising how estimates may be developed and utilized in decision making. In addition, monetizing only selected externalities does not allow for consideration of various other factors, such as non-environmental externalities or end-user fuelswitching (e.g. to heating oil).[4]

States requiring some form of accounting for externalities are relying on either qualitative approaches or estimated "adders." Primarily, they are focusing strictly on air emissions in the conversion stage. Typically, these estimates are not based on the damage function approach, which seeks to reflect the value of the actual external cost. Instead, they often rely on implied valuation or cost of control. Specific values generally are set by public service commissions after lengthy research and debate and testimony from interested parties. Resources such as the Pace University and Tellus Institute studies are also used by states in setting externality values. There are several wide differences between specific externality values that states are applying. For example, the Massachusetts Department of Public Utilities uses a value of $22.00 per ton CO_2, whereas the draft New York State Energy Plan established a value of $8.60).

Fuel Cycle Assessment Gaps

From a review of the 60 approaches that appear in Section IV for conducting fuel cycle assessments, a number of common gaps appear. The types of gaps that appear follow:

- The conceptual framework of fuel cycle assessment has not yet been refined. This includes a clear definition of stages and types of impacts to be assessed, addressing boundary issues, and identifying how the analysis is to be approached.

- There are significant data gaps in performing fuel cycle assessments. This is particularly true of data required to evaluate impacts upstream and downstream of the conversion stage.

- There is a lack of tested research techniques for performing fuel cycle assessments. Currently, federally supported efforts are underway to design models or test frameworks, the results of which can be communicated to states or a variety of other interested parties.

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4 Federal Energy Regulatory Commission Staff Report, "Report on Section 808 Renewable Energy and Energy Conservation Incentives of the Clean Air Act Amendments of 1990," December 1992, p. 34.

- It is possible that the cost of designing and testing a fuel cycle approach is too high for a state to implement. If not properly designed, the benefit and information provided from performing the data research and calculating damages may not justify the cost. This is particularly true for small organizations or states.

Primary methods of overcoming these gaps include conducting broad based design and testing of research approaches, conducting research for developing data, performing cost/benefit analyses, and designing and testing tools for applying the data into state and regional IRP and decision-making processes. These processes should incorporate perspectives from all relevant parties including:

- Researchers/analysts who will be performing assessments;
- Industry representatives who can provide input on the technologies and the fuel cycles; and
- Energy planners and regulators who will need to use the results and represent consumers.

Involvement of the relevant stakeholders will assist in design and testing of techniques that are well-scoped and will produce results that can be readily used in decision-making. It also will provide an efficient transfer of results directly to states and other interested parties for their consideration and potential use.

Overview of Relevant Fuel Cycle Activities

There are a variety of efforts underway to evaluate fuel cycles or life cycles of particular energy technologies, manufactured goods or processes. While the focus of this project is on fuel cycle assessment as it relates to IRP, these various types of fuel-cycle or life-cycle analyses face many of the same analytical issues and complexities faced by IRP framers and energy planners. Thus, it is useful to monitor these efforts, evaluate their research methods and assess how particular issues are being addressed or how analytical tools for fuel cycle assessment could be implemented for IRP purposes. The following are brief descriptions of life cycle, fuel cycle or related analytical efforts.

DOE/Commission of European Communities (EC) Fuel Cycle Study - In 1990 DOE and the EC began a joint project to develop a comparative analytical methodology and a range of estimates of external costs from secondary sources for eight supply-side fuel cycles for electric generation: 1) coal, 2) biomass, 3) oil, 4) natural gas, 5) hydroelectric, 6) nuclear, 7) wind, and 8) photovoltaic. Four conservation options also will be evaluated. The specific technologies have not yet been selected. There are three principle objectives of the study. They are:

1. To create a unified conceptual design for quantifying the net costs and benefits, based on a damage function approach

2. To demonstrate an accounting framework that can be used to estimate a broad range of costs and benefits. Examples may include employment benefits, road damage, fatal accidents, or visibility

3. To identify critical methodological issues and informational needs that will effect the expanded efforts to develop comprehensive assessments of the costs of energy use.

DOE/NREL Test of the Fuel Cycle Assessment Guide - Through NREL, the DOE tested the use of the Fuel Cycle Assessment Guide (FCAG). The FCAG was developed in draft form for the DOE's Office of Energy Efficiency and Renewable Energy in early 1992. The FCAG is a tool to assist energy planners and state public service commission staff evaluate fuel cycle impacts of utility technologies as part of integrated resource planning. Four case examples were evaluated in the test:

- A 300 MW combined cycle gas turbine system
- A 300 MW pulverized coal boiler system
- The use of photovoltaics to drive circulators at an aquaculture farm on the Eastern Shore of Maryland
- The use of electronic ballasts with T-8 lamps in a commercial office building.

The objectives of the project were:

1. To test the use of the guide as a decision-making aid
2. To obtain input from those who would use the guide to determine how such a tool should be designed
3. To identify available data and information for conducting a fuel cycle assessment and to identify data and information gaps
4. To modify the FCAG, based on the analysis
5. To identify additional applications of the guide and of fuel cycle analysis.

The approach taken in this project was designed to ensure that decision maker and other stakeholder perspectives were accounted for in the design of the decision aid. Thus, those aspects of the fuel cycle assessment that are critical to the state or region implementing the guide could be identified and evaluated. In addition, the project helped screen research needs and focus on those identified as relevant to the analysis.

DOE/NREL, Electric Vehicle Total Energy Cycle Assessment (EVTECA) - The purpose of this current study is to prepare an emissions and residuals inventory for electric vehicles (EVs) and compare that inventory with another for conventional vehicles fueled by reformulated gasoline. The results of the analysis will allow DOE to evaluate the EV technology and address any potential environmental problems.

The EVTECA will consider all energy cycle stages, including raw materials extraction, material transportation, conversion to an energy form, transportation of the energy form, and end-use.

Within each stage, construction and/or manufacturing, operation, and post-operation (e.g. disposal) are included. This study will develop an inventory of emissions and residuals associated with:

- Vehicle and battery manufacturing
- Battery recycling and disposal
- Vehicle operation
- Electricity generation
- Production of reformulated gasoline
- Extraction and transport of feedstock for electricity and reformulated gasoline.

The study will evaluate several scenarios for EV market penetration using four case example regions: Los Angeles, Chicago, Houston, and Washington, D.C. Each scenario will vary in terms of battery type, vehicle type, vehicle use pattern, and EV charging schedule. The results of the analysis will be incorporated into the Total Emissions Model of Integrated Systems (TEMIS). Three national laboratories are participating in the project: Argonne National Laboratory, NREL and Pacific Northwest Laboratory.

Aside from this, a number of other studies are underway which do not look at the total fuel cycle but could be relevant in the design and implementation of IRP related fuel cycle assessment. These are:

- Beginning in 1991, DOE's Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Industrial Technologies (OIT) began developing a PC-based software tool for performing life cycle analysis. It will include a model for calculating energy usage, air, water and solid waste emissions, and resource burdens. The model does not evaluate the life cycle from cradle to grave. Rather, it focuses on the stages from resource extraction through development of an industrial product (e.g. processed raw material) without carrying the life cycle through to manufacture of a consumer good. It will include a data base with data on ten commodities. One of the commodities is electricity. OIT recognized the need for a standardized set of data and tools for LCA that is easily accessible and transparent. The software is intended to provide a transparent model that will clearly identify system boundaries and model assumptions. However, users can manipulate the model to tailor the analysis to their specific needs. The first draft of the software is expected in February of 1994.

- The Office of Technology Assessment is in the early stages of a broad evaluation of renewable energy technologies. One component of this evaluation is to compare the social costs of renewable energy technologies with conventional technologies. Results from this study are not anticipated until late 1993 or early 1994.

- The Electric Power Research Institute is co-sponsoring an extensive project in New York state to perform environmental externality costing research. The project will prioritize many fuel cycle environmental impacts and identify valuation approaches. The project is being done in coordination with the New York Department of Public Service, New York State Energy Research and Development Authority and the Empire State Electric Energy Research Company.

- The United Nations Environmental Programme has developed an environmental data base, which identifies energy-related environmental impacts. It is linked with the Long-Range Energy Alternatives Planning (LEAP) System and has been used by over 20 developing countries in energy planning. Due to user requests, the UN is considering adding a fuel cycle component to the system to allow users to make a more complete evaluation of technology alternatives.

- The EPA is required under the Clean Air Act Amendments (CAAA) to conduct a study of the costs and benefits of the amendments. This is not a study of externalities per se, yet it should produce results relevant to the field of externalities study. Title III of the CAAA requires the EPA to set maximum achievable control technology for 189 substances, many of them found in flue gases. The CAAA requires a special study of toxic emissions from power plants by 1993, which will form the basis for regulating power plant emissions.

- EPA and the University of Michigan are developing life-cycle assessment methods to assist engineers and product designers. These efforts will result in a systematic guide for product and process design to minimize pollution during the product development stage. Numerous products and processes are employed throughout the fuel cycles of energy technologies, and this type of information could help to reduce external costs associated with those fuel cycles.

- The EPA is working to develop a life-cycle-based information system for construction materials. The information is being compiled from available data distilled and reoriented to fit the needs of architects, contractors, and engineers. This information could assist utilities to better evaluate and implement demand-side management programs, as well as support energy-smart buildings.

Status of State Activities to Evaluate Fuel Cycle Components

No state PUCs are evaluating fuel cycle impacts as part of decision-making or IRP reviews. Some states are looking at components of the fuel cycle, however, namely air emissions in the conversion stage. The following is a brief overview of state and utility-level activities to account for externalities. It must be noted, however, that there is a distinct difference between externalities analysis and fuel cycle analysis. Externalities analysis, which many states are beginning to address, is a component of fuel cycle analysis, which only a few states and organizations are addressing.

1. Status

Approximately 25 states are addressing components of fuel cycle externalities in some form as part of utility planning. However, no states are looking at the total fuel cycle of energy technologies as part of this planning. There are a variety of approaches being used to address externalities. These range from stringent approaches (using specific monetized externality values for specific emissions and incorporating these into total costs of supply-side resources) to less stringent requirements for qualitative evaluation of environmental impacts, to no action at all.

A brief status of state activities is shown in Exhibit 3. Most states are looking only at the conversion stage and selected environmental emissions. Some states evaluating air emissions are using monetized adders. A detailed status of those states using a monetization approach is shown in Exhibit 4. States not shown in Exhibit 3 include those without current plans to account for externalities or to seek authority for addressing externalities.

Exhibit 3 STATE APPROACHES TO EXTERNALITIES*		
STATE	**STATUS**	**DESCRIPTION**
Alaska	Under Consideration	Considering reviewing environmental externalities for new plants.
Arizona	Under Consideration	Considering evaluation of environmental and non-environmental externalities associated with new plants.
California	Monetization Approach	See Exhibit 3.
Colorado	Under Consideration	Considering externalities for new plants.
Delaware	Under Consideration	The state is considering monetizing externalities associated with new power plants and imports.
Georgia	Qualitative Approach	Utilities must submit IRPs. Externalities considered for new plants and purchased power. Utilities must develop, assign and justify externality values. In addition, environmental and non-environmental externalities for DSM are considered.
Hawaii	Qualitative/Quantitative approach	Quantify and evaluate cultural impact of new plants.
Idaho	Qualitative	Preference for "environmentally benign" projects, conservation and DSM.
Illinois	Qualitative	Qualitatively evaluate externalities of imported power. Evaluation of externalities from new plants is under consideration.
Indiana	Qualitative	Require an impact assessment in IRPs.
Iowa	Qualitative/Quantitative	Preference given to DSM options (10% credit); considering use of environmental and non-environmental externalities for supply options. Require energy efficiency planning and alternative energy production in IRPs.
Kansas		Legislative authority is needed before externalities can be required in IRPs.
Maine	Under Review	Considering evaluation of externalities and preferences for new plants, power purchases and conservation.
Maryland	Qualitative	Use a negotiation process considering environmental and non-environmental externalities. Use preference/percent adders.
Massachusetts	Monetization	See Exhibit 3.
Michigan	Qualitative	IRPs must meet prudency review standards. No PUC authority for externalities, policy is based on legislative authority.
Minnesota	Under consideration	Modifying cogeneration rules, considering broader review of externalities in power purchases.
Nevada	Monetization	See Exhibit 3.

Exhibit 3 Cont'd. STATE APPROACHES TO EXTERNALITIES*		
STATE	**STATUS**	**DESCRIPTION**
New Mexico	Under Consideration	Under review in PSC Case 2383.
New Jersey	Qualitative/Quantitative	Incentive regulations for DSM. Adders for non-environmental externalities.
New Hampshire	Under Consideration	Considering evaluating externalities from imported power and new plants.
New York	Monetization	See Exhibit 3.
Ohio	Cost of Control/Preferences	Preferences given to DSM. Evaluate marginal cost of control, total resource cost, social costs and benefits. Require IRPs.
Oklahoma	Implementing Qualitative Approach	Implementing discretionary PUC consideration of non-environmental social costs.
Oregon	Qualitative/Quantitative	PUC has no authority to impose required externality adders. Docket UM424 in review stage to assign a range of values for externalities and require utilities to evaluate scenarios of alternative options using those ranges.
Pennsylvania	Qualitative	Consider social costs and benefits of DSM.
South Carolina	Qualitative	Qualitative consideration of environmental externalities incorporated into IRPs.
Texas	Qualitative	Assess environmental costs and benefits in IRPs. Use quantitative and qualitative weighting factors to evaluate environmental externalities.
Utah	Qualitative/Quantitative	Utilities use quantitative values for environmental externalities in developing IRPs.
Vermont	Qualitative/quantitative	Require Integrated Least Cost Resource Plan. 5% credit for DSM.
Virginia	Under Consideration	Evaluate environmental benefits, non-price factors. Legislative authority required to monetize.
Washington	Qualitative/Quantitative	Evaluate environmental costs of externalities; 10% credit for conservation.
West Virginia	Under Consideration	Considering generally evaluating environmental externalities and non-environmental externalities.
Wisconsin	Qualitative/Quantitative	PUC requires utilities to use adders for methane ($150/ton), N_2O ($2700/ton) and CO_2 ($15/ton). CO_2 is approximately 2 cents/kwh for coal and 1 cent/kwh for gas. These adders can be used for calculating avoided costs for DSM.
Wyoming	Qualitative	Environmental externalities incorporated into IRP. SO_2 reduction costs included in rate base.

* Primarily reflects externalities associated with electric generation.

Exhibit 4
States Using a Monetization Approach
($/ton)

State	CO_2	NO_x	N_20	SO_2	PM_{10}	TSP	VOC	CO	CH_4
California PUC (Nominal 1992$)									
- PG&E	9	9,120		4,476	2,624	2,624	4,236		
- SCE	9	31,448		23,490	6,840	6,840	22,462		
Massachusetts (Real 1990$)	22	6,500	4,276	1,500	4,000	4,000	5,300		
Nevada PSC	22	6,800	4,140	1,560	4,180	4,180	1,180	920	220
New York (1992$)	8.60	6,524		1,367	3,642	3,642	4,400	423	

Sources: Draft, New York State Energy Plan, Volume II: Issue Reports.

2. Resources for Determining Externality Values

As Exhibits 3 and 4 show, some states have established monetized values for some externalities used in utility planning and planning review. These states are using various resources for arriving at those values. For example, several studies have been performed to develop damage estimates or review and analyze those estimates. Examples include the Tellus Institute Study and the Pace Study, which have been used by public service commissions in establishing externality guidelines or requirements.

The Tellus Institute developed damage estimates for air emissions using abatement cost estimates as an indicator of society's willingness to pay for environmental quality. Some states such as Massachusetts and Nevada have elected to use the Tellus estimates or to use values that approximate these estimates. As stated earlier, Massachusetts is awaiting the results of EPA research from which it will consider valuing other toxic air emissions. Various other studies have been performed to quantify externalities or review models for quantifying externalities. They include a Bonneville Power Administration (BPA) effort to study environmental and non-environmental externalities associated with seven supply-side technologies. This analysis was site and regional specific; thus, the results are used primarily by BPA and not by utilities outside of that region.

Another study was completed by Pace University to review and analyze various efforts to quantify externalities associated with electric power. While not a source of primary research to quantify externalities, the Pace Study does provide a resource to states and others researching externalities or fuel cycle impacts. Studies such as these serve as additional resources for states to consider if they are pursuing a policy of quantifying selected environmental externalities associated with the conversion stage. However, this reflects only one component of the fuel cycle. Efforts such as the current DOE/EC study will add to the resources for looking at externalities through the fuel cycle.

Two states, California and New York, have developed their own monetized estimates to quantify externalities. In California, the method for determining externalities and the values that are being used is in a state of transition. The state had been using the cost of control approach. Recently, the California Energy Commission (CEC) began a process to estimate externalities using a damage function approach. The CEC is currently in the process of finalizing those values. The values must then be adopted by the Public Utilities Commission.

As mentioned previously, the state of New York is in the process of revising its earlier externality estimates. The New York Environmental Externalities Cost Study is designed to develop a methodology and a computer model that would permit New York regulatory agencies and utilities to estimate the externalities for electric supply and DSM options based on the damage function approach.[5] In addition, the New York State Public Service Commission initiated a formal proceeding (92-E-1187) in December to examine the experience in New York of incorporating externalities into the competitive bid process. Specifically, the proceeding will consider projecting environmental compliance costs into Long Range Avoided Costs (LRACs); consider anew the use of estimates of externalities in DSM; and consider the application of such estimates to payments for supply-side resources and the possible use of a total cost dispatch model to estimate LRACs.

Typically, state public service commissions will research available sources of data and information to develop adders, monetize emissions or establish values for other externalities for particular technologies. In addition, they will hear testimony from stakeholders, interest groups and others. The commissions consider all this information in developing their externality values. For example, the Wisconsin Public Service Commission reviewed estimates from the Tellus and Pace studies, as well as from various other sources. It considered each of these sources and how the data could best be adapted for use in Wisconsin. In addition to using estimates that reflect externality costs (be it cost of control, willingness to pay, or damage cost), commissions may also base their decisions on criteria such as imminent emissions regulations. In Wisconsin and other states, commissions recognize that utilities will be confronting stringent emissions standards under new federal regulations, including the CAAA. The example in Wisconsin illustrates one purpose in establishing externality values. This is to implement adders that are strict enough that utilities will begin reducing emissions to levels that meet or exceed forthcoming emissions standards. Thus, commissions are creating a transition period for their utilities so utilities can prepare to adhere to new federal regulations and so the level of risk to utility customers is reduced. In Wisconsin, the PUC established strict acid rain requirements in anticipation of CAAA requirements. By the time that CAAA requirements took effect, some utilities in the state had reduced air emissions to a point where they were in a position to trade emission credits.[6]

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5 Federal Energy Regulatory Commission Staff Report, "Report on Section 808 Renewable Energy and Energy Conservation Incentives of the Clean Air Act Amendments of 1990," December 1992, p. 35.

6 Based on BCS conversation with representative from the Wisconsin Public Utility Commission.

As Exhibits 3 and 4 indicated, most states are not using monetized values in evaluating externalities. This is due to numerous factors, some of which include:

- Externality data are more valid if they are site specific. There is a lack of site specific data for states to access.

- The studies discussed above are not site specific. In addition, there is some question as to the quality of the data and its use in monetizing externalities.

- In some states, state legislatures or public utility commissions have not adopted policies or requirements to consider externalities.

- Because uncertainties surround existing data, states without the resources to conduct large independent studies, such as New York and California, are deciding it is inappropriate to monetize externalities until better data are available.

As methods for developing information and data resources are tested and improved, more states should begin evaluating externalities by using either monetary or qualitative measures that are more telling and valid in their characterization of externalities.

IV. COMPENDIUM OF PROFILES

Summary profiles are provided for 60 fuel cycle assessment efforts. The techniques profiled herein have been developed under various contexts and used for a range of purposes. In each case, an attempt was made to provide the context that the effort was performed in as part of the profile.

As mentioned earlier, this compendium is not intended to be an exhaustive compilation. It is a representation of approaches and tools that can be considered in framing and implementing a fuel cycle assessment effort or in deciding whether or not to pursue such an effort. The profiles herein represent a cross-section or representative sample of the models, methodologies and technical research performed. They represent a range of analytical objectives, approaches, tools and results.

The profiles are descriptive outlines of fuel cycle assessment models and methodologies. The focus of this document extends beyond those which have been applied only for performing fuel cycle assessment of energy technologies. Some of the profiles in this compendium are brief descriptions of non-energy applications, process impact analyses, or standard "textbook" analytical techniques. These additional profiles provide a broad view of the impacts that can be considered, as well as a variety of techniques that may be implemented for evaluating impacts and that may apply to fuel cycle analyses. The profiles have been organized under the following categories and subcategories:

A. **Computer-Based Models and Valuation Approaches**

- Models that approximate comprehensive fuel cycle assessment.

- Models for evaluating components of fuel cycle externalities such as air quality or human health impacts associated with the conversion stage. There are a significant number of these models. Because the bulk of research on external impacts has surrounded "externalities" from electric generation rather than fuel cycle assessment only selected air quality models have been profiled. Additional air quality models are listed in Appendix A.

- Decision aiding tools. These are examples of software packages that can be used in decision analysis or dynamic programming.

- Standard analytical modeling techniques.

B. **Total Fuel Cycle and Life Cycle Studies** - These include ongoing efforts such as the DOE-EC study, which are broad in scale and incorporate environmental and non-environmental impacts in multiple stages.

C. **Partial Fuel Cycle Studies** - These include approaches or methodologies implemented to evaluate components of fuel cycle impacts, such as the environmental externalities associated with electric generation.

D. **Technical Research Papers** - These are collected papers which discuss the use of fuel cycle assessment, methodologies for conducting fuel cycle assessment, or are otherwise relevant to the study.

A review of this compendium, as well as any other relevant methods or models not included in this draft, will serve to form a basis for outlining what analytical activities have been instituted, for what purpose, and with what type of results. The compendium is designed as a document which can be updated on a periodic or ongoing basis when relevant efforts are identified and as the state of the art advances. Reviewing this document is a first and important step in developing a plan for implementing a total fuel cycle analytical effort.

A. COMPUTER-BASED MODELS AND VALUATION APPROACHES

This section of the compendium profiles a number of computer-based tools that are being developed or have been tested to assist in energy decision making.

Models That Approximate Comprehensive Fuel Cycle Assessment

The following are profiles of models and related activities that have been developed or are in the development stages and approximate a full fuel cycle assessment.

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1. NEW YORK ENVIRONMENTAL EXTERNALITIES COST STUDY

Source Organization: Empire State Electric Energy Research Corporation
Date: 1992 - 1994

PURPOSE

The purpose of this study is to identify priority externalities and develop a methodology and computer model that will permit state regulatory agencies and utilities in New York to estimate externalities costs attributable to electric supply and demand-side management resources. The project is being undertaken in response to the New York Public Service Commission Order 89-15 (May 23, 1989).

This study is still in its early stages. The profile has been included in this section because the objective of the project is to develop a computer-based model for conducting assessment of fuel cycle impacts. Information on the model is not yet available. This profile will briefly focus on the objectives of the specific tasks to be undertaken.

FUEL CYCLE FRAMEWORK

The study is evaluating a number of technology resources. These include nuclear, natural gas, oil, coal, municipal solid waste, hydroelectric and other renewables, including wind and solar. Site-specific case studies are anticipated.

The entire fuel cycle is being considered at least during the initial stages of this project. Specifically, the study is evaluating impacts associated with the fuel extraction, transportation and processing, generation/conversion, and the solid waste disposal stages of the fuel cycle. Within these stages, a broad range of external impacts are being considered in the prioritization phase of the analysis. These include environmental and economic impacts, with the focus primarily on environmental impacts. A screening process will be implemented to focus the analysis on high priority impacts.

RESEARCH APPROACH/METHODOLOGY

This project is being performed over a 30-month period. The approach is to conduct six tasks for performing the necessary research and analysis:

> **Task One: Scoping Study** - The purpose of this initial task was to identify the overall project objectives and outline the methodology for completing the project.
>
> **Task Two: Externalities Screening and Recommendations** - The purpose of this study is to identify and prioritize environmental and economic external impacts. It also will identify impact pathways and damage/externality groups. The screening process will employ expert judgment and literature/data reviews to identify high priority impacts for use in the analysis.
>
> **Task Three: Approach for Estimating Impacts** - The purpose of this task is to focus on the high and medium priority impacts that will be identified in Task Two. It will develop an approach for estimating these impacts.
>
> **Task Four: Model Design** - An interactive computer-based model will be designed to develop estimates for each of the priority impacts.
>
> **Task Five: Data Collection** - The focus of this task will be to collect the data necessary for implementing the model.
>
> **Task Six: Model Implementation** - In this stage of the project, the model will be run for each of the case studies to develop estimates of major external impacts.

Three general approaches for quantifying the externalities are being considered. These included:

1. Full damage function analysis
2. Case study analysis
3. Bounding analysis

It is anticipated that the focus of this effort will be on the damage function approach because it provides the highest level of specificity regarding economic impacts. In a number of cases, however, the level of resources would be significant to develop values using this approach. In those cases, other methods, such as case study analysis, may be suggested.

STRENGTHS AND WEAKNESSES

It is difficult to comment in depth on the strengths and weaknesses of this project due to the fact that it is still ongoing. At this stage, the screening approach appears to be an efficient means of focusing the analysis upon a relevant and feasible modeling/research agenda. Moreover, matching impacts to selected damage groups is another means of setting boundaries around the analysis and developing a clear delineation between externality emittants and receptors.

2. FUEL CYCLE ASSESSMENT GUIDE

Source Organization: DOE, Assistant Secretary for Energy Efficiency and Renewable Energy, Integrated Resource Planning Program; NREL; and BCS Incorporated
Date Developed: 1993

PURPOSE

The Fuel Cycle Assessment Guide is a tool for framing and implementing fuel cycle analysis of supply-side and demand-side energy technologies. It is designed to be used in integrated resource planning; state, regional or national energy planning; utility planning; and R&D prioritization. The guide provides the user with a flexible approach to meet specific analysis and planning requirements.

The guide provides a brief description of fuel cycle analysis and its applications. It includes summary worksheets for users to collaboratively identify boundaries for framing fuel cycle research and analysis. The bulk of the guide, however, is comprised of detailed worksheets developed in Excel 4.0 which outline a broad range of potential impacts for each stage of the energy technology fuel cycle (exploration & extraction to waste recycling/disposal). Users can select the method to be used for qualitatively and/or quantitatively evaluating fuel cycle impacts. The guide has been designed as a tool for framing a fuel cycle analysis with the state of Maryland as a test case. Four case example technology applications were researched to evaluate the fuel cycle framework, as well as to determine the availability of data resources for assessing impacts throughout the various stages of the fuel cycle.

FUEL CYCLE FRAMEWORK

The guide outlines activities/impacts in 11 stages of the fuel cycle. These stages include:

<u>Raw Materials Phase</u>
1. Exploration and extraction
2. Raw materials processing

<u>Production Phase</u>
3. Manufacturing and construction
4. Transportation
5. Storage

<u>Operation Phase</u>
6. Conversion
7. Transmission and distribution
8. End-use

Post-Operation Phase

9. Waste disposal
10. Waste recycling
11. Decommissioning

The guide provides worksheets to profile each technology to be assessed. In addition, it lists example impacts within three general categories:

Environmental	Social	Economic
1. Terrestrial	1. Educational	1. Employment
2. Aquatic and Groundwater	2. Social Patterns	2. Economic Development
3. Atmospheric	3. Infrastructure	3. Economic Competitiveness
4. Species/Vegetation	4. Social Issues	4. Public Sector
5. Aesthetics	5. Demographics	
	6. Safety/Health	

The specific impacts to be evaluated can be defined by user working groups or collaboratives. To a large degree, the impacts selected will depend upon the specific technology being analyzed.

RESEARCH APPROACH/METHODOLOGY

The guide outlines an approach for framing the fuel cycle analysis task to meet the specific needs of users. It provides worksheets that can be used by state and utility representatives and others to collaboratively identify the boundaries to frame analysis and research. The detailed worksheets, which will be used to characterize the technologies and measure and evaluate environmental, economic, and social impacts in each stage, are developed in Excel 4.0. Because the guide is tailored to user-determined requirements, methods for calculating the value of specific impacts will depend upon user specifications. Thus, no algorithms are included in the current version of the guide's detailed worksheets. Yet algorithms can be placed into the Excel spreadsheet format.

DATA CHARACTERISTICS

During the process of testing the guide, a number of potential data resources for performing fuel cycle analysis were identified. These are listed in an appendix to the guide. The guide in its current form does not provide specific data for measuring impacts. These would not be appropriate due to the fact that they can vary significantly by technology, application and location.

HARDWARE/SOFTWARE REQUIREMENTS

The worksheets in the guide have been developed using Excel 4.0 software for Windows, which requires an IBM-compatible PC 386 or greater.

LABOR/TIME/COST REQUIREMENTS

These requirements will depend on the boundaries established by the users in framing the research and analysis and the method(s) to be used in qualitatively and/or quantitatively evaluating the impacts. At a minimum, the guide is designed to bring together experts in the field and representatives of key relevant organizations to frame the analysis.

CURRENT UTILIZATION

As indicated, the guide was evaluated in the state of Maryland using four case example technologies. These included:

1. A pulverized coal boiler
2. A gas combined cycle boiler system
3. A building retrofit to T-8 lamps and electronic ballasts
4. Photovoltaics at an aquaculture farm.

Representatives from the Maryland Public Service Commission, Maryland Energy Administration, Baltimore Gas & Electric, Potomac Electric Power Company, and the solar, lighting, gas and coal industries were brought together to frame the analysis for the four specific case examples, as well as provide input on how the guide could be refined. The guide has not been applied to perform a detailed fuel cycle analysis, but is at a stage where it can be tested for a specific technology comparison.

STRENGTHS AND WEAKNESSES

The guide has several unique and positive characteristics. These include:

- State and utility representatives have often indicated that many models currently available provide results that are not applicable to local situations, the assumptions are not transparent, and the results are not particularly useful. The guide uses a bottoms-up approach that can be tailored to reflect user-specific needs.

- The guide covers an extensive 11-stage fuel cycle and lists a broad range of potential impacts. Users can take this broad scope and frame the specific analysis they wish to perform.

While the guide lists data resources for performing a fuel cycle analysis, a data base of various descriptors that measure fuel cycle impacts would be very helpful, especially for those users who do not have the resources to assemble such a tool.

3. THE TOTAL EMISSIONS MODEL FOR INTEGRATED SYSTEMS (TEMIS)

Source Organization: OKO Institute of West Germany
Date Developed: 1990

PURPOSE

TEMIS estimates the physical effects associated with the fuel cycles of a variety of energy systems. These include standard energy systems for space heating and electrical generation. Some of the primary functions of the model are to establish data bases on energy, efficiency, air emissions, solid waste, and land use; estimate pollution loads associated with materials in each stage of the fuel-cycle; compare energy systems based on units of delivered energy; and help integrate quantitative and qualitative impacts for improved environmental decision-making.

FUEL CYCLE FRAMEWORK

TEMIS estimates emissions in three categories:

1. Site Emissions: these include SOx, NOx, and CO^2.
2. Global Emissions: those are emissions that occur in upstream stages of the fuel cycle, such as in mining, processing and transportation.
3. Materials Processing: this includes emissions associated with the manufacture and transportation of materials used in plant construction.

The model calculates the physical effects associated with a wide variety of energy systems. It produces estimates of all quantifiable impacts in physical units. It is not a complete fuel cycle analysis model in the sense that it only evaluates direct environmental impacts and not complete environmental costs. The model estimates direct, physical environmental impacts such as air emissions for specific pollutants, solid waste impacts, land use impacts, and qualitative impacts like accidents or hazardous releases. The impacts are measured as "economic" values, or the cost of avoiding those impacts, rather than as the actual environmental cost. The model can be augmented to include sub-modules for estimating exposure and responses to the physical impacts and for valuing those impacts.

TEMIS is broad in that it accounts for nearly all stages of the total fuel-cycle for numerous energy technologies—both upstream and downstream. It covers the extraction, processing, transportation, materials processing, manufacture and construction, and conversion in the fuel cycle. TEMIS does not incorporated waste disposal or recycling.

RESEARCH APPROACH/METHODOLOGY

As an environmental costing model, TEMIS simulates the characteristics and impacts of actual or hypothetical resources being considered for acquisition by a utility. Simulating those effects permits analysts to examine the impacts that would result if the resource were constructed and operated. Those impacts and costs can be compared to alternative resource options. The main menus of the model allow users to determine the parameters and operating characteristics of the resource options to be analyzed.

In the Fuel Menu, the user specifies the fuel type and its components. Fuel data is stored in the model's data base, or it can be supplied by the user. The Process Menu differentiates seven categories of activities to provide logical benchmarks. These categories are 1) combustion, 2) conversion, 3) transportation, 4) production, 5) dispatch, 6) scenario dispatch, and 7) process chains. The seventh category, process chains, treats the entire upstream fuel cycle as a single activity.

The model is constructed of a series of process chains with linear linkages representing various stages of the fuel cycle being modeled. However, as an emissions model rather than an entire systems dynamics model, TEMIS does not appear to contain multiple feedback loops.

DATA CHARACTERISTICS

TEMIS utilizes a self-contained data base modeled on the West German economy and energy infrastructure. The data base contains data on new fuels, changes in fuel cycles, new energy systems that may be developed, hypothetical systems, and energy scenarios. In addition, users can augment the data base, use separate data inputs, and identify the emissions for any stage of the fuel cycle or for the fuel cycle as a whole. The data outputs consist of what would be the avoided costs for specific emissions per specific technologies.

HARDWARE/SOFTWARE REQUIREMENTS

TEMIS runs off of its own software and requires only an IBM-compatible personal computer. It is menu driven and provides interactive routines for the user.

LABOR/TIME/COST REQUIREMENTS

The model is designed for use by utility planners and requires no previous programming experience. Because it contains a data base, data collection is not required unless the user wishes to incorporate additional operational characteristics, etc.

CURRENT UTILIZATION

TEMIS was developed to assist in energy planning and decision making. Because it was developed for the West German economy, however, it cannot be used to model U.S. energy systems at the present time.

STRENGTHS AND WEAKNESSES

TEMIS is one of the most complete models for estimating the physical impacts of environmental emissions through the entire fuel cycle. However, it is designed for the German energy system and is not readily adaptable to the United States. Moreover, it does not seek to measure indirect impacts or the range of economic costs/benefits. DOE is working to modify the TEMIS structure for easier use and United States adaptation.

Computer Based Models for Evaluating Partial Fuel Cycle Impacts

This section profiles selected models that conduct analyses of components of fuel cycle impacts, such as air quality or the human health impacts associated with the conversion stage. There are a significant number of these models due to the fact that the bulk of research on external impacts has surrounded "externalities" from electric generation rather than from fuel cycle assessment. Because of the abundance of these models, only selected air quality models have been profiled. Additional air quality models are listed in Appendix A.

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4. ESTIMATING ENVIRONMENTAL IMPACTS OF ALTERNATIVE ENERGY RESOURCES

Source Organization: California Energy Commission
Date: 1989 - ongoing

PURPOSE

This five-phase effort is based upon the assumption that technologies should be evaluated according to their social cost. Measures or values of social costs/environmental effects are not currently available, however. This forces many decision makers to use proxy measures. The objectives of this project include:

Phase I - To investigate the feasibility of utilizing the damage function approach for assessing air quality impacts associated with various generating technologies. The primary conclusion of this initial effort was that sufficient information existed to convert air emissions into dollars.

Phase II - To perform preliminary construction of an interactive computer program, based on the damage function approach, and to assess air quality effects corresponding to various energy technologies.

Phase III - To evaluate additional valuation issues. Specifically, alternative general approaches to valuing environmental impacts were evaluated further; the feasibility of valuing impacts other than local air quality effects was assessed; and an assessment was made on incorporating the emissions/air quality relationship into the damage function software system. This study found that: 1) the damage function approach out-performed other evaluation methods; 2) sufficient information existed to use the damage function approach in evaluating other environmental impacts; and 3) air quality modeling could be incorporated into the existing damage function system.

Phase IV - To complete development of the interactive computer model begun in Phase II.

Phase V - To extend the analysis by assessing air quality impacts on human health, forests, and materials, as well as the interactive effects of air pollutants.

FUEL CYCLE FRAMEWORK

This study is looking primarily at the electric generation stage of the fuel cycle and not at other upstream or downstream stages. One of the objectives of the effort is to assess environmental effects from alternative energy resources. Thus, a number of energy technologies can be modeled. The user can tailor source and site data based on his or her requirements.

The project design was to focus on air quality impacts, but the feasibility of valuing additional environmental impacts was also assessed. These included impacts of electrical generation on water quality, biological resources and global temperatures. It was determined that sufficient information existed for evaluating these impacts, and efforts were performed in later stages of the project to begin including these impacts in the overall analysis. Non-environmental impacts are not being included in the analysis.

RESEARCH APPROACH/METHODOLOGY

In general, the research approach has been to identify if and how the damage function approach could be used to evaluate environmental externalities and then develop a modeling capability to develop damage function estimates. This section of the profile will focus on the approach implemented to develop the modeling capability. Specifically this will address the approach for developing a software package which requires users to input the geographic area of interest and the expected change in any of the standard air quality measures to identify physical effects and the associated monetary value of the air quality change.

The damage function approach requires information on four specific relationships:

1. Sources and their emissions
2. Emissions to changes in air quality
3. Air quality changes to physical response (dose-response relationship)
4. Valuation of the physical responses.

Detailed data are included on existing air quality for specific regions in California. Using this as a basis, the change in air quality can be calculated through user-provided data on source technologies and emission levels.

An extensive literature review was performed of dose-response studies and valuation functions. Screening criteria were used for selecting dose-response functions to be included in the Health Effect Module of the model. These criteria included:

- The study should have a microepidemiological design
- The results should be published in recognized professional journals
- The study should be current and use appropriate statistical techniques
- The health endpoints should be such that an economic value can be estimated
- The results should at least be partially verified by other studies
- The sample data should be applicable to a well-defined target population.

Dose-response relationships are not easily translated into traditional financial data. This particular study focuses on the resource cost and contingent valuation methods for valuing external impacts. The resource cost method uses available market data to directly value the cost of reversing or preventing the effects of air pollution. Contingent valuation methods use non-market or survey information to determine the values that individuals attach to environmental changes.

Literature on both of these methods was reviewed to develop a data base of valuations on a number of specific health effects, effects on agricultural and non-agricultural vegetation, materials and aesthetics. Selected data were then included in the software data files.

In running the software, users are responsible for providing two inputs:

1. The geographical area of interest
2. The anticipated air quality change (%).

The remainder of the input data includes the baseline air quality level, the dose-response functions, the valuation factors, and the target populations. These are all supplied in the program. Two conversions must be made to the dose-response functions before they can be used to predict changes in health effects in a manner that is consistent among functions. First, it is necessary to standardize the functions in terms of units used to measure the pollutants. The second conversion of the dose-response functions facilitates a standardization of the predictions in terms of time.

DATA CHARACTERISTICS

Results are provided in tabular form detailing the physical effects associated with a change in air quality. Corresponding monetary valuation of the assumed change is also illustrated in tabular form. The sensitivity of the results can be examined by altering the nature of the air quality change (the magnitude, the selection of pollutants) or the area of interest (other counties, multiple counties).

As indicated above, users are responsible for providing two data inputs: the geographical area of interest and the anticipated air quality change (%). Baseline air quality level, the dose-response functions, valuation factors, and the target populations are all supplied in the program.

LABOR/COST/TIME REQUIREMENTS

A significant amount of labor costs were incurred in development of the model. Users, however, are not required to provide significant amounts of data. As such, the user labor and cost requirements are not likely to be considered.

CURRENT UTILIZATION

The model and its results are currently under review by the CEC. Statements regarding the strengths and weaknesses of the project would be premature at this time.

5. DEGREES: U.S. DOE CLIMATE CHANGE ANALYTIC FRAMEWORK

Source Organization: Office of Planning and Environment, Office of Fossil Energy, U.S. DOE
Date Developed: 1993 (still under development)

PURPOSE

The model is being developed with support from ICF to perform climate change analysis regarding various energy technology and policy options. It is structured to examine climate change impacts from various supply-side and demand-side technologies, programs or policies. The model can be used to evaluate climate change impacts associated with the utility sector as well as residential, commercial and industrial sectors.

FUEL CYCLE FRAMEWORK

DEGREES does not evaluate the fuel cycle of energy technologies. It focuses specifically upon energy demand and greenhouse gas emissions from the conversion stage of electrical generation technologies, including:

- Gas combined cycles
- Oil, gas, coal, and hydro turbines
- Pulverized coal
- Wind
- Biomass
- Geothermal
- Photovoltaic
- Industrial steam.

In the coal supply algorithm, DEGREES models 40 coal supply regions and up to 15 coal types. A separate transportation route was established for each coal type from each supply region and an average transportation cost for that coal was calculated. In terms of natural gas, the delivered price of natural gas to a region is assumed to be the same regardless of the source.

DEGREES also evaluates energy consumption and emission impacts from over 100 end-use technologies in the industrial, commercial and residential sectors. DEGREES evaluates DSM program options, including:

- Energy conservation
- Load management
- Fuel switching
- Government programs
- Standards.

DEGREES also assesses the energy demand and emission impacts associated with light duty vehicles (electric, CNG, methanol from biomass, and gasoline).

RESEARCH APPROACH/METHODOLOGY

The demand model structure contains three basic modules as follows:

1. **The Baseline Demand Module** - This simulates the demand for fuels (electric, oil, gas, and other) under the assumption of naturally occurring conservation.

   The modeling framework within the demand module is flexible in terms of alternative policy analysis. The following policy switches have been incorporated or are under development:

   - Payback period used to set incentives
   - Discount rates
   - Level of potential (technical, economic or market)
   - Technical potential multiplier
   - DSM cost multiplier
   - Energy savings multiplier.

2. **DSM and Other Program Impacts (using the REALM Module)** - This adjusts the baseline demand results for the impact of utility-sponsored programs to encourage conservation or load management.

   The Regional Efficiency and Load Management (REALM) module adjusts regional demand forecasts developed by the demand model to account for electric and gas DSM. It has a flexible structure that incorporates vintaging of equipment, programmatic DSM and government programs. REALM uses input demand, avoided costs and rates to select DSM options based on passing the Total Resource Cost (TRC) test and is run during each iteration of the climate change model.

3. **Hourly Load Module** - This module maps the results of the first two modules (together with electric vehicles) and produces hourly electric demands. The hourly loads are the electric demand inputs to the supply model.

DATA CHARACTERISTICS

Overall model outputs consist of regional energy prices and demand as well as emissions and global warming potential.

The baseline module contains three primary EPRI demand models (REEPS, COMMEND and INFORM). For each of these models, the inputs consist of:

- Fuel prices
- Macroeconomic drivers (e.g. GNP growth, population, household size, per capita income)
- New technology characteristics
- Current characteristics of the sector.

The outputs are fuel consumption by end-use, as well as the associated capital stock over time.

The demand module (REALM) inputs include:

- Demand forecasts by region, end-use and technology
- Technology information (costs, lifetimes, UECs) by efficiency level
- Electric and gas avoided costs and rates
- Load shapes
- A data base of energy conservation measures (ECM).

Model outputs include calculations of the total resource cost ratios for all energy conservation measures and chooses those conservation measures that have a total resource cost less than 1.0. The module also defines optimal rebates based on payback criteria. DEGREES estimates the maximum market share and expected market penetration for selected energy conservation measures. Based upon these calculations the module outputs the change in end-use energy demand to the hourly load model.

Specific inputs to the hourly load model include:

- The endogenous end-use sales forecast
- An exogenous set of end-use load shapes
- Transmission and distribution loss information.

The hourly load model calculates forecast electricity hourly demands for the supply model, and the hourly impacts of each energy conservation measure.

HARDWARE/SOFTWARE REQUIREMENTS

DEGREES runs on two different hardware platforms. It requires an IBM RS/6000 workstation, which runs the UNIX operating system. In conjunction, it requires a second IBM-compatible PC platform that assumes an upper-end 486 (i.e. DX-2) with an approximately 100M hard drive, running under DOS.

There are several software requirements for running the model. The UNIX platform requires OSL (an IBM product). FTP communication software is also required: the PC/TCP communication package. Also, users must obtain a license for running several proprietary software packages, including EPRI products (e.g. INFORM/INDEPTH and REEPS), as well as an ICF product: the Integrated Planning Model (IPM). A Fortran compiler is not required.

LABOR/COST/TIME REQUIREMENTS

Initially, use of the model is restricted to model developers, DOE and the EPA. It will employ simple menu-driven procedures which should be relatively straightforward for the average user. However, data manipulation must be done manually and will require some level of knowledge in editing data on an ASCII file. Naturally, the model also requires skill in understanding the scenarios to be analyzed and the parameters to be manipulated.

CURRENT UTILIZATION

DEGREES is being developed as a tool for estimating the impact on energy demand and climate change from alternative energy technology and policy scenarios. It is not yet complete, however, and the finished model has not been implemented.

Currently, the primary user of the model will be DOE. The model will be used to evaluate the impact on the utility sector from various climate change policies and scenarios. It will also help to identify how different energy technologies can help or detract from achieving climate change objectives.

STRENGTHS AND WEAKNESSES

Some of the unique advantages over the DEGREES Model REALM submodule is that it has the ability to examine DSM options within a vintaging structure (equipment aging, replacement and retrofit). Load shape impacts are produced by the model and are used in screening and choosing DSM options.

REALM directly ties DSM screening into end-use forecasting models. One of the key concepts of REALM is that efficiency levels increase over time and the economics and penetration of DSM is dependent upon these trends.

Because the model is still under development, many of its constraints in applications have not been fully evaluated. One identified limitation, however, is its inability to model consumer choice for passenger vehicles. In addition, the current structure of the model does not feed back forecast electricity rates to economic data to predict rate impacts on economic growth. Moreover, because it is a climate change model, it looks specifically at global warming emissions and does not evaluate as comprehensively as some other models. Also, it does not estimate the emissions associated with the fuel cycle. It focuses primarily on the conversion or end-use of supply and demand-side energy technologies.

There are some significant hardware/software requirements as well, so DEGREES will not be a model accessible to a wide range of users.

6. LONG-RANGE ENERGY ALTERNATIVES PLANNING SYSTEM (LEAP) VERSION 92.0

Source Organization: Stockholm Environment Institute, Tellus Institute
Date Developed: 1992

PURPOSE

LEAP is a computer-based tool for performing scenario analysis under alternative assumptions and developing ongoing integrated energy-environmental plans. It is structured as a group of "easy-to-use" microcomputer programs. LEAP was developed within the context of integrated sets of energy policies, programs and investments to be used on an ongoing basis for energy planning. LEAP was initially developed as part of a Kenya fuelwood project to provide an analysis of the Kenyan energy picture and long-range energy prospects. It has evolved to improve user interface features and allow for energy assessments in industrialized or developing countries, for multi-country regions, or for local planning exercises.

LEAP is linked to the UN's environmental data base, described in Section IV.C.1 (page IV-65).

FUEL CYCLE FRAMEWORK

LEAP is not a fuel cycle analysis model; however, it evaluates energy demand and environmental impacts associated with energy consumption. It follows a track from 1) resource production (e.g. wood, coal, solar, wind, natural gas, oil, geothermal, crops/residues, animal waste or electricity imports); to 2) transformation; to 3) final demand/end-use.

It has the capability to evaluate a number of supply-side resources and resource combinations. Energy demand can be analyzed by sector and subsector (i.e. industrial and chemical industry) as well as end-use (e.g. boilers) and device or resource (e.g. gas, oil, etc.).

The model is limited to estimating energy balance, land use impacts, environmental emissions, and selected safety/health impacts.

RESEARCH APPROACH/METHODOLOGY

The LEAP structure is centered around three basic programs:

- Energy Scenario Programs
- Environmental Data Base
- An Aggregation Program.

Energy Scenario Programs - The Energy Scenario Program performs the integrated energy analysis, including demand analysis, energy conversion and resource assessment. The Energy Scenario Program can be used for scenario building to calculate current energy balances, projections of supply and demand trends, and scenarios representing the effects of energy policies, plans and actions.

A biomass module is also included which examines the impacts of biomass demand and land-use changes on the biomass resource base. It is designed primarily for policy analysis and planning related to rural energy (i.e. deforestation and adequacy of energy supply).

An environmental module computes the air and water emissions, solid and hazardous waste generation as well as direct, on-site health and safety impacts under alternative scenarios.

An evaluation module compares the physical impacts from moving from one scenario to another, the economic costs and benefits, and the comparative environmental repercussions.

Aggregation Program - This program allows for multi-area aggregation of the energy accounts and projections into multi-area results. These can include national, regional, state, district, village, or electric service territory.

Environmental Data Base (EDB) - The EDB provides a comprehensive summary of information linking energy production, conversion and consumption activities to air and water emissions, and other environmental and health consequences. It is a stand-alone, fully referenced and annotated compendium program of energy and environment statistics. The user can add additional data appropriate to local facilities or specific studies.

DATA CHARACTERISTICS

LEAP contains default data for standard fuels/resources that should be adequate for most applications. Default conversion factors are also provided for energy content, density and fuel composition. Users can modify data to meet local conditions if necessary. Users must provide monetary and cost parameters such as the general inflation rate and the discount rate.

Also, the EDB contains extensive data and coefficients on energy-related environmental emissions (air, water, land) and impacts (direct health and safety) by resource and transformation category.

LEAP outputs include projections for:

- **Energy Balance** - Including production, imports, and exports by fuel type, and sectoral consumption;

- **Environmental Projections** - Including forecast air and water emissions for various pollutants, solid waste, and deaths;

- **Land Use** - Land requirements by type of use; and

- **Biomass Impacts** - Wood (or other biomass source) supply and demand balance.

HARDWARE/SOFTWARE REQUIREMENTS

LEAP can be installed onto an IBM-compatible PC and supports most monitor types. The model is menu-driven. It is recommended that LEAP be used on computers with a full 640k of DOS memory.

LABOR/COST/TIME REQUIREMENTS

The primary labor/cost/time requirements result from data assembly and data entry. Users define the base case for their specific analysis and enter the data through a series of data entry screens. Following entry of the base case data, users enter deviations from the data to develop the scenario analyses.

CURRENT UTILIZATION

Current versions of LEAP can be used for performing energy/environmental assessments in industrialized or developing countries, for multi-country regions or for local planning exercises. LEAP is also linked to the United Nations Environmental Programme for environmental assessment of energy systems.

STRENGTHS AND WEAKNESSES

LEAP's strengths include the fact that it is a PC-based tool and its pull-down menu-driven system should make it user-friendly to those experienced in programs such as Lotus 1-2-3 or dBASE. It evaluates a relatively wide range of air, water an solid waste impacts, and can evaluate energy balances at a fairly good level of detail (e.g. kerosene for lighting in the rural low-income sector). Moreover, the model is flexible and users can define local specific characteristics or run any number of alternative energy scenarios.

Although the model has been adapted to industrialized countries, much of its focus remains on the developing world and rural applications. It may not be the optimal tool for analyzing the impact of alternative tax policies. Nor does it include energy efficiency or DSM components and thus is not adequate from a least-cost planning or integrated resource planning perspective.

Moreover, the model is not a fuel cycle model per se. While it does integrate energy resource, transformation and end-use, it does not evaluate stages of the fuel cycle independently.

7. ELECTRIC AND GAS UTILITY MODELING SYSTEM (EGUMS)

Source Organization: Energy Policy Branch, Office of Policy Planning and Evaluation, EPA; and DOE, Assistant Secretary for Fossil Energy
Date Developed: 1990

PURPOSE

EGUMS was developed for the Energy Policy Branch of EPA and was profiled in the 1991 draft of the compendium. The purpose of the model for EPA is to provide the agency with a framework in which to assess a wide range of policy options related to utility sector environmental issues. The objective of the model is as a flexible tool to simulate emissions changes caused by different types of programmatic and non-programmatic energy conservation and demand-side initiatives. Ongoing revisions are being made to the model.

FUEL CYCLE FRAMEWORK

The model focuses on the conversion stage of the fuel cycle for a range of supply-side and demand-side technologies. The primary impacts evaluated are environmental emissions during the conversion stage of supply-side technologies, as well as emissions deferred through use of conservation and DSM.

RESEARCH APPROACH/METHODOLOGY

The model flows through a general five-step methodology to arrive at emissions projections under various scenarios. The steps are briefly described as follows:

1. **Base Year Electric and Gas Consumption** - Using EIA consumption surveys (RECS, NBECS, and MECS), estimates of electricity and gas consumption are developed by region, building type or SIC code, and end-use for the commercial, industrial and residential sectors.

2. **"No-Conservation" Scenario Energy Consumption Forecasts** - Energy consumption forecasts are developed using a "no-conservation" scenario. This scenario assumes that efficiencies for end-use technologies remain constant over the 1990 to 2010 forecast period (with the exception of already-mandated federal appliance efficiency standards). The model does incorporate other impacts affecting demand, however, such as economic growth, industrial production, and changing market patterns. The "no-conservation" scenario is used because it allows the user to project actual demand for energy and it allows for greater analysis of fundamental changes impacting energy demand.

3. **Estimate Technical Potential DSM Savings** - The third step in the model is to estimate the maximum savings achievable through the "overnight implementation"

of all commercially available and technically applicable technologies which provide similar or increased levels of energy service.

4. **"Economical" and/or "Marketable" Energy Savings** - Technical potential energy savings are made more realistic by looking at the economic and market potential of energy conservation measures. Economic potential is determined by the percentage of potential users judged to find a measure economically attractive based on a number of factors. Market potential is estimated through a number of factors, such as user attitudes, alternative investments, risk, and incentives. The actual amount of achievable energy savings then becomes a function of technical potential as modified by an applicability factor, an economic attractiveness factor, a market penetration factor, a market diffusion/replacement factor, and other adjustments.

5. **Avoided Emissions** - The final module estimates electricity generation by fuel type for each region that is used to meet the electricity demand levels determined in the previous modules. Associated carbon emissions are then estimated.

DATA CHARACTERISTICS

Model outputs include 1) base-level demand for electricity and natural gas in the industrial, commercial and residential sectors; 2) technical, economic, and achievable levels of improved end-use efficiency; and 3) changes in greenhouse gas emissions due to changes in end-use demand levels. The model reports regional energy consumption and emissions levels by North American Electric Reliability Council (NERC) regions in five-year increments from 1990 through 2010.

HARDWARE/SOFTWARE REQUIREMENTS

The model can be run on an IBM RS-6000 workstation with a Unix operating system. At least 16 MB memory and a 200 MB hard drive are needed. Software requirements include IBM OSL (optimization subroutine library), Unix OS software and an IBM Fortran Compiler.

LABOR/TIME/COST REQUIREMENTS

Model development was a long term and intensive effort. Additional model enhancement is still ongoing. A model run generally requires about four hours.

CURRENT UTILIZATION

The model has been used by EPA as part of policy analysis activities. Recently, the DOE's Office of Fossil Energy provided funds to include a supply-side sub-module. This module interfaces with the demand-side module and utilizes penetration of demand-side program penetration rates coupled with energy demand forecasts to develop load forecasts.

STRENGTHS AND WEAKNESSES

EGUMS can be a useful means of performing scenario analysis for quantifying anticipated emissions and determining the impact from various DSM and fuel mix options. While the model does not perform a total fuel cycle analysis, its use as a policy analysis tool can be strong. The ability to perform scenario analysis, utilizing alternative fuel mixes and conservation measures based on anticipated market penetration, provides output that can model expected market occurrences in a sound manner.

8. GEMINI: AN ENERGY - ENVIRONMENTAL MODEL OF THE U.S.

Source Organization: Energy Policy Branch, Office of Policy Planning and Evaluation, U.S. EPA
Date Developed: 1990 (frequent modifications/enhancements continue to occur)

PURPOSE

GEMINI was developed as a decision-oriented model to explore alternative policy options involved in national energy policy planning as it relates to the issue of global climate change. It also is used for energy tax evaluation purposes and a range of other energy related policy analysis evaluations. GEMINI is a dynamic, generalized equilibrium model of the U.S. energy system. GEMINI solves for market equilibrium U.S. energy use and consequent emissions of greenhouse gases under alternative policy scenarios. Initially developed in 1990, GEMINI continues to be applied for various policy analyses.

FUEL CYCLE FRAMEWORK

Numerous conventional and alternative energy technologies can be evaluated. The model is not a fuel cycle model and does not explicitly evaluate impacts on a stage-by-stage basis. In addition, it primarily evaluates environmental impacts. It does not evaluate socioeconomic impacts.

RESEARCH APPROACH/METHODOLOGY

GEMINI includes a detailed U.S. energy-economy sector, a U.S. agricultural sector, a global environment sector, and a representation of worldwide and U.S. sectoral greenhouse gas emissions. The energy-economy sector includes four primary resources (oil, gas, coal and renewables) and four end-use sectors (residential, commercial, industrial, and transportation). Detailed data on end-use technologies are also included. The sectors are interrelated and the model incorporates several environmental feedback loops. The model is not intended to be a macroeconomic model, but rather an energy/environmental policy analysis model.

Some of the scenarios and policy options examined with GEMINI include:

- A renewables supply case for more rapid introduction of renewables
- An end-use energy efficiency case to assess higher long-run efficiency for selected end-use technologies
- A carbon tax
- An ad valorem energy tax (10%) on all fossil and nuclear primary energy
- A Btu tax ($0.30/MMBtu) on all fossil and nuclear energy
- A $4/ton tax on $C0_2$ emissions.

GEMINI is a dynamic generalized equilibrium model that solves problems for equilibrium prices and quantities for all processes and sectors within the scope of the model. At the same time, GEMINI is engineering based and characterizes economic agents and processes in terms of engineering cost and performance parameters, as well as financial parameters and economic behavioral assumptions. It contains a representation of capital stock vintages to reflect additional operating costs associated with aging, as well as estimated plant retirement. It can also model retrofits and upgrades to capital stock.

DATA CHARACTERISTICS

GEMINI has self-contained data bases covering each of the energy resources identified above, as well as data on end-use technologies, including technology availability, costs, and market penetration rates. These data can be modified by users in order to conduct sensitivity analyses.

HARDWARE/SOFTWARE REQUIREMENTS

Hardware requirements include an IBM compatible PC 386 (486 is recommended). GEMINI is built in GEMS modeling system software and requires a site license from Decision Focus.

LABOR/COST/TIME REQUIREMENTS

To become proficient in GEMINI takes a significant amount of time and is labor intensive. Once proficient, however, running the model is relatively fast and does not require a major amount of time or labor.

CURRENT UTILIZATION

GEMINI continues to go through evolutionary modifications and enhancements. It has been used extensively for comparative analysis of alternative energy tax policies, including carbon taxes, Btu taxes, and ad valorem taxes and their effectiveness in obtaining carbon reductions. Carbon trading proposals also have been evaluated using GEMINI. Some recent applications of the model include an effort to assess and improve the efficiency of policies to reduce CO_2 emissions and to evaluate implications of alternative paths of emissions constraints.

STRENGTHS AND WEAKNESSES

GEMINI is not intended to be a tool for forecasting but rather a scenario/policy analysis tool. GEMINI provides a strong level of detail to adequately assess alternative impacts from various R&D policy options, market deployment of policy options, and tax plans upon the economy at several impact levels and among a number of end-use sectors. Moreover, GEMINI, as planned, provides a tool for assessing the impact and/or success of improvements and/or greater penetration of energy conservation technologies on utility operations or end-use consumption.

9. ENERGY PROGRAM EVALUATION USING P/G% DECISION-AIDING SOFTWARE

Author: Thomas S. Stanton
Source Organization: Michigan Public Service Commission
Date: 1990

PURPOSE

The purpose of this effort was to evaluate three different options for the next generation of electric power supplies for the state of Michigan. The analysis employed the decision aiding software P/G%. The objectives of the analysis were to provide policy makers and evaluators with a modeling tool to facilitate comprehensive comparisons of energy supply options, including indirect and external effects of energy decision making.

FUEL CYCLE FRAMEWORK

Three power electric utility supply/demand options were modeled for the evaluation. They were:

1. A conventional 675 MW high-sulfur coal-fired steam unit.

2. Power from 10,000, 60 kW natural gas-fired packaged cogeneration units. The specific technology was selected because the primary component was a V-8 automotive engine manufactured in Michigan and one of the manufacturers of such packaged cogeneration systems is also located in Michigan.

3. Conservation through a variety of energy efficiency measures. The conservation options modeled included only readily available technologies for the residential, commercial and industrial sectors. These included energy efficient lighting, water heaters, air conditioners, refrigerators and freezers and building envelopes, as well as industrial motor drive and air compressors.

The purpose of this analysis is not to conduct a fuel cycle analysis but to evaluate various impacts of alternative options. These are impacts that occur in various stages of a technology's life cycle and/or accumulate throughout the life cycle. All three options were compared across 20 different criteria that included economic, employment and environmental impacts. The specific criteria are:

1. Cost per installed kW
2. Cost per kWh
3. Labor costs, input/output (I/O) multiplier per million dollars invested
4. Capital costs, I/O multiplier
5. Fuel costs, I/O multiplier

6. Michigan materials, a measure of the in-state economic activity resulting from expenditures in each sector, I/O multiplier
7. Direct employment, I/O multiplier in jobs per million dollars invested
8. Indirect employment, I/O multiplier in jobs per million dollars invested
9. Reliability as a percentage of time available
10. Longevity or durability in months
11. Solid wastes in tons/year
12. Sludge and ash in pounds per MWh
13. Transmission system in acres
14. Water discharge in gal/MWh
15. Air and water thermal pollution as a percent of heat input
16. CO, pounds/MWh
17. CO_2, pounds/MWh
18. NOx, pounds/MWh
19. SO_2, pounds/MWh
20. Vulnerability to accidents, natural events or sabotage -- measured on a subjective, qualitative scale from 1 to 5, where 1 is most vulnerable and 5 is least vulnerable.

These measures were selected because they represent many of the important direct and indirect impacts of energy supply or demand-side options. Many of the relevant data were readily available for Michigan. In addition, they fit neatly within the P/G% framework.

RESEARCH APPROACH/METHODOLOGY

As mentioned above, P/G% software was used for this analysis. Policy/Goal Percentaging (P/G%) is a multi-criteria decision-aiding software system. It can be used with micro-computer spreadsheet formats, including Lotus 1-2-3 or Excel. The software is relatively simple to use. P/G% also can be used to analyze and evaluate any decision that involves choosing among multiple options or actions. It can be used for analyzing problems that involve multiple criteria or goals to be achieved, measured in different units or scales. P/G% offers a methodical means to include analysis of many types of externalities and "soft" data in decision-making and evaluation.

Using data supplied by the user, P/G%'s matrices compute costs for each option/criteria combination. Based on user-specified policy/goal identification, other matrices calculate the percentage of a criteria policy/goal achieved for each option. This can also by performed for a cluster of criteria or all criteria for each option.

The results of this particular effort identified a combination of conservation (60%) and micro-cogeneration (40%) are the most beneficial. They provided more benefits in nearly every category, with the exception of indirect employment and CO emissions.

DATA CHARACTERISTICS

In this particular application, data were available from various sources. Data availability was one of the criteria in selecting primary criteria. This type of analysis could be modified to include other data points identified as important by the user.

HARDWARE/SOFTWARE REQUIREMENTS

This effort was run on a microcomputer. Similar analyses using this software require nothing more than a this level of hardware.

LABOR/TIME/COST REQUIREMENTS

The approach used for this analysis is fairly straightforward and user friendly. Moreover the software is under $300. The primary labor, time and cost requirements are likely in framing the analysis and performing the data research and collection necessary to run the analysis.

CURRENT UTILIZATION

This analysis was used by the Michigan Public Service Commission in a state-specific analysis. Similar analyses could be modified for evaluating other technology options or in other states as needed.

STRENGTHS AND WEAKNESSES

This analytical effort is an example of a straightforward approach for analyzing alternative options based on combinations of decision criteria. For the purposes of policy analysis, this appears to be an effective tool. It does not provide a total cost or "adder" that some decision makers have become accustomed to using. Thus it may not be as easily accepted or used by some decision-makers. But it provides more information on which to evaluate decisions, and more subjectivity as to what are the important decision points.

10. INCLUDING SOCIETAL BENEFITS IN RATES FOR COGENERATION AND SMALL POWER PRODUCTION: A METHODOLOGY AND HANDBOOK

Author: Douglas R. Maag, Project Director
Source Organization: Public Utilities Commission of Ohio
Date Developed: 1990

PURPOSE

The document and accompanying Lotus 1-2-3 spreadsheets were designed to develop a methodology for better incorporating both the economic (internalized) costs of cogeneration projects as well as the intangible or "non-economic" costs and benefits of small-scale power production into the analysis and rate-making process. The diskette portion of the approach focuses primarily on the economics of specific projects, anticipated employment requirements, and emissions. The report then proceeds to describe an approach for incorporating non-economic factors into the analysis of alternative resource options.

In particular, it includes such quantifiable and non-quantifiable factors as social, environmental, economic, and technological impacts as part of a methodology for designing tariffs. The project draws on the Ohio experience, yet is designed to be easily applied in any region of the country.

The approach deals with costs and benefits from three different points of view: the utility, the private power producer, and society. All three viewpoints are integrated into a common framework that produces overall results. The methodology attempts to identify net social costs, but does not attempt to be so precise as to decide on the overall value of a project. It augments, rather than replaces, the conventional decision-making process. It presents novel ways of calculating the utility and small power producer benefits, as well as methods for cost/benefit analysis that can capture impacts to all parties.

Two years after its development, the representatives from the Ohio PUC feel positive that the effort resulted in interesting results that could be used when considering rates for cogeneration and small power production. Originally, the handbook was designed to assist in developing tariffs. It became clear, however, that there was no statutory authority in the state to pass on the value of externality costs or benefits to ratepayers. Thus, the handbook has not resulted in any practical application but still offers valuable insights and possibly analytical techniques to be assessed.

FUEL CYCLE FRAMEWORK

In terms of stages of the fuel cycle, this methodology does not account for the full fuel cycle. The primary focus of the equations in this methodology is on the electric generation phase of the waste tire cogeneration fuel cycle. The methodology is flexible, however, in that the user can subjectively incorporate equations to measure additional externalities which may be associated with other phases of the fuel cycle. These include measuring and subjectively placing a value on projected reductions in oil imports if an oil-fired generator were replaced by a non-oil alternative. Another example is the costs/benefits associated with a waste-to-energy plant versus landfilling in terms economic impacts, trash disposal costs, or land and water impacts.

The methodology characterizes social costs and benefits, including the environmental externalities associated with electric generation, as "indirect" costs, and characterizes conventional financial utility/small power producer costs as direct costs. It provides mechanisms to account for direct costs. Indirect costs are not limited to environmental externalities but can include other social costs, such as the value of supply reliability, land, air and water pollution, or tax effects. Also assessed are benefits, including employment, health, trash removal, etc. The type and extent to which these costs and benefits are assessed is largely up to the user.

RESEARCH APPROACH/METHODOLOGY

The approach to integrating indirect factors into a conventional regulatory cost/benefit framework relies on converting as many of those factors as possible into dollar equivalents, and maintaining a separate framework for those factors that remain essentially nonquantifiable. This approach is consistent with conventional cost/benefit analysis, with the exception that the range of factors where a dollar quantification is proposed goes well beyond the normal economic approach. Where quantification is not feasible, the methodology incorporates the value of informed judgment to deal with qualitative issues. The process for quantifying/qualifying indirect costs/benefits follows three stages:

1. Classification of indirect economic factors
    a. Social issues
    b. Economic issues
    c. Environmental issues
    d. Technical issues

2. Translation to dollar terms - allowing impacts from alternative supply or demand options to be evaluated on a comparable basis.

3. Sensitivity analysis - to assist policy analysts in assessing the relative importance of an externality in a cost-benefit analysis.

As mentioned, the approach can be user defined. There is no hardwired method that the user must incorporate. The Lotus 1-2-3 spreadsheets use sensitivity analysis to allow the user to project long range costs, labor requirements, and emissions for alternative resource options. Determining which indirect economic factors apply to those equations can be done through various methods, including surveys, group dynamics, expert judgment or other techniques. Indirect economic factors are then weighted to assign value.

The methodology is designed to assist in developing utility rates. It incorporates a number of lateral and top-down linkages. For example, it accounts for the dollar value realized by society from job growth associated with new plant construction. However, the methodology is limited in its ability to perform internal feedbacks. For example, resultant job growth does not translate to higher electricity demand during out years, but this is beyond the scope of the purpose of the model.

DATA CHARACTERISTICS

Data inputs include but are not limited to capital cost investment, construction period in years, plant capacity, input load, labor costs, interest rates, taxes, insurance, and fuel costs. These data will be case specific and can be developed or adequately assumed with a moderate investment of research and analysis.

In addition, externalities which are to be accounted for in determining total social costs must also be quantified and input. This could include, for example, the cost per pound of particulate emissions, labor rates, employment multipliers to determine societal effects, and weights to be applied to specific factors making-up "total" social costs. The report suggests several sources for these data, including the National Emissions Data System (NEDS) for historical levels of particulates output; survey research; Delphi or Nominal Group techniques; and individual judgment.

The data outputs represent those costs and revenues deemed necessary for rate-setting when costs can incorporate a certain level of social costs, including environmental externalities. Data outputs include but are not limited to fixed and operating costs, revenue streams, the discount factor, net income, discounted net cash flow, and internal rate of return. In general, the type, extent and integrity of the data inputs reflect the overall flexibility of the methodology. The user is able to subjectively incorporate and weigh select data items which are developed from user-determined processes and resources. The overall output is thus to a large extent user-defined in order to meet specific user needs.

In terms of "non-economic" factors, the report discusses several that could be included in the analysis, including reliability, land use, economic development, community support, air quality, water quality, land use, and resource diversification.

The depth of the data outputs reflect the level to which the user wants to incorporate direct and indirect costs. However, these outputs typically will be limited to the electric utility operation phase of the fuel cycle.

HARDWARE/SOFTWARE REQUIREMENTS

The software requirement is Lotus 1-2-3. Hardware requirements consist of a personal computer and a line printer. Labor and time requirements can range from moderate to significant.

LABOR/TIME/COST REQUIREMENTS

Labor and time requirements will include the research and analysis necessary to develop the data inputs for direct costs, determine the type, depth and weight of social costs to be incorporated, develop the associated data, implement the model, and analyze the output.

CURRENT UTILIZATION

The methodology was released in June of 1990. Its intended utilization was to assist Ohio utilities and the Ohio PUC to account for the "non-economic" costs and benefits of small-scale power production in the analysis and rate-making process. As of 1992, the PUC recognized that externality costs/benefits could not be passed on to the consumer in the form of rates under current statutes. The document is utilized, however, as a framework for identifying and evaluating technology alternatives and in planning and decision-making activities.

STRENGTHS AND WEAKNESSES

One of the prime strengths of the methodology is its flexibility and ability to respond to user-determined needs for assessing various types of social costs. This allows users to tailor the methodology to their specific needs and apply it in numerous applications.

The flexibility of the model also results in two of the primary weaknesses of the methodology - lack of structure and a high level of subjectivity. By allowing the user to be selective as to which social costs are determined and subjective in defining the source of the data and its level of importance, users may not truly account for total costs from electricity generation. In addition, the magnitude of specific cost components may be distorted.

11. AIR EMISSIONS RISK ASSESSMENT MODEL (AERAM) VERSION 1

Source Organization: Electric Power Research Institute (available through the Electric Power Software Center). Contact Leonard Levin.
Date Developed: 1988

PURPOSE

The Air Emissions Risk Assessment Model (AERAM) was designed to be used by utilities for quantifying the risks associated with atmospheric emissions from fossil fuel-fired electric generation plants. The outputs then can be used in determining and implementing the most cost-effective control technologies.

FUEL CYCLE FRAMEWORK

While the model can be used to evaluate emissions from all fossil fuel generating technologies, it covers only the conversion stage of the electric generation fuel cycle for those technologies.

AERAM only accounts for air emissions and selected direct and indirect impacts associated with those emissions. The model tracks emissions to sub-populations through various modules and uses those data in a final risk module to estimate effects such as resultant health costs.

RESEARCH APPROACH/METHODOLOGY

AERAM is strictly a linear model and does not incorporate internal feedback loops. It estimates the flow of emissions and a limited measure of the resulting impacts. It is not a fuel cycle or life cycle model and does not analyze the dynamics of a process. AERAM consists of four modules:

1. Emissions Module
2. Air Quality Module
3. Exposure Module
4. Risk Module.

Emissions Module - The emissions module uses information on firing rates, fuel types and plant sizes to produce a tabulation of particle size distribution classifications for selected pollutants. A number of coal types can be modeled. Data are provided for a many fuel elements, including the percentage of sulfur, ash, carbon hydrogen, oxygen moisture, and nitrogen. In addition, the heating value in Btus per pound is also accounted for. The user specifies parameters, such as which pollutants are to be modeled, and supplies the necessary information to run the model for those parameters. In addition, the user must specify control devices that are to be used. The output of this module consists of three parts.

1. Tabular summary of the input data

2. Summary of how each variable was calculated
3. A tabulation of particle size distribution classification for each pollutant of interest.

Air Quality Module - The data from the emissions module are inputs to the air quality module. The air quality module requires receptor locations for the purpose of exposure assessments as well as climatology data. For each receptor location, it lists and ranks fly ash and pollutant concentrations. The outputs from the air quality module are input to the next module, the exposure module.

Exposure Module - In the exposure module, the pollutant concentrations are translated into an inhaled concentration per individual in each district where there exists at least one receptor. The user specifies the population for each district for which there is at least one receptor. The output consists of:

1. A tabular summary of the input data
2. A histogram of the number of people exposed per concentration range and per exposure range
3. Exposure levels and total exposures for each subpopulation and the total population by district
4. Total exposures summed over all districts for each subpopulation and the total population.

This output then serves as input to the final module, the risk module.

Risk Module - The risk module uses dose-response data to translate the population exposure of various pollutants into estimates of the expected value of effects resulting from those exposures. The user must specify the incidence for various known dosage levels. This module provides several different estimates of risk:

1. Per capita risk.
2. Mathematical description and parameter values for the different risk models. Statistical goodness of fit is estimated for each of these models.
3. Per capita and total risk are displayed by district, and the aggregated total risk, summed over all districts, is predicted by each risk model.

DATA CHARACTERISTICS

Some characteristics are beyond the specific module outputs which serve as inputs to the next stage of the model (discussed above). Data inputs consist of application-specific characteristics which can be assumed to be accurate, or at least strong estimates. In the emissions module, significant amounts of data are required, including plant type, firing rate, fuel type, control devices, load factors, operating schedule and other operational characteristics. In the air quality module, inputs consist of the receptor location with population-based receptor grids, and annual average climatology data for the location. Receptor location populations are defined in the exposure module and sub-populations can be defined here as well. Finally, in the risk module, the user must specify the incidence for various known dosage levels to estimate the incidence of various ailments. Data outputs are provided in tabular form and are used as both analytical resources and estimates of the health risks associated with each plant modeled. The depth and types of outputs consist of those direct and indirect impact data discussed above.

HARDWARE/SOFTWARE REQUIREMENTS

The model can be used on an IBM-compatible personal computer.

LABOR/TIME/COST REQUIREMENTS

The model is user friendly and does not require prior programming skills. The primary labor and time requirements consist of defining the framework and preparing the data inputs.

CURRENT UTILIZATION

The model is currently being used by EPRI members in evaluating emissions of alternative technologies.

STRENGTHS AND WEAKNESSES

One of the primary strengths of the model is that it uses quantifiable data elements and relevant reliable data sources. The model allows the user to estimate per capita and total health risks associated with a given power plant. This serves as a valuable tool in quantifying the total costs associated with the conversion stage of the selected fuel cycle and measuring the level to which costs should be incurred to preclude those health risks.

The primary weaknesses with the model are that it only accounts for one stage of the fuel cycle. In addition, the model only covers air emission impacts associated with electric generation. It does not cover the range of other environmental or economic impacts.

Because the model is both a control cost model and a risk assessment model, however, it could potentially be useful for analyzing both economic impacts and additional environmental impacts and the associated costs and benefits.

12. EFLOW, ENERGY FLOW MODEL FOR THE MEMBER STATES OF THE EUROPEAN COMMUNITY

Author: InnoTec Systemanalyse, Berlin
Source Organization: Commission of the European Communities, Directorate-General for Energy
Date Developed: 1987

PURPOSE

EFLOW is not a model for fuel cycle analysis in the sense that "total" costs are characterized or quantified. It is an energy flow model for quantifying specific and comprehensive energy flows from source to end-use. The methodological techniques and approach utilized in EFLOW, however, can be used in the design and implementation of a methodology for performing a fuel cycle assessment.

EFLOW was designed to serve as a standardized tool for analyzing future energy policy options in the European Community (EC). It is designed to allow for an expanded flow of information and statistics, as well as support energy and environmental analysis. In addition, it was the intention of the EC to use EFLOW in supporting Third World energy planning. As a planning and policy analysis tool, EFLOW was to assist in meeting EC energy goals, including reduction of the economy's dependence on mineral oil; ensurance of mutual support in times of energy shortages; stimulation of a better use of energy throughout the EC; and reduction of the dependency on imports by supporting the development of domestic resources.

FUEL CYCLE FRAMEWORK

The EFLOW fuel cycle spans from primary production or imports and passes through to end-use consumption. The flows are presented in three levels of detail -- synoptic, standard, and complex -- per user requirements. It organizes the energy fuel cycle into three segments:

1. Availability
2. Transformation
3. Final consumption.

The first segment, availability, shows the total amount of energy resources available to the EC or member states. The sum of these energy resources is composed of domestic production, recovered products and imports. Exports are then subtracted to provide "gross" inland consumption of primary energy resources. The second segment shows the transformation of primary products to final energy products (i.e. motor fuels) available for consumption. Energy losses during transformation and distribution are also shown in this segment. In the final segment, energy consumption flows are shown by sector and application. In addition, energy losses which occur during use are shown.

RESEARCH APPROACH/METHODOLOGY

EFLOW is a computer aided model for the performance of regional energy flow analyses. Energy flow analyses are performed through a set of complex formulas on the basis of published national energy balances. The results of the calculations are input-output matrices, which form the basis of energy flow diagrams. In addition to producing the energy flow diagrams, the input-output matrices can be used for statistical analysis; time series or regional comparisons; policy option simulations; and economic and environmental analysis.

EFLOW diagrams, in particular the complex version, show much of the realm of energy resources, consumable products and consumer applications. In addition, the interrelationships throughout the energy flow are exhibited. To describe the level of detail in the complex version of EFLOW, the entire network consists of 432 boxes (points in the flow) and 711 linkages. EFLOW does not incorporate storage or waste disposal/recycling stages of the energy cycle; nor does it incorporate exploration and pre-extraction processes. However, the model serves as an almost complete means which can be adapted without major efforts to include those stages.

EFLOW is designed to show comprehensive or specific energy flows and balances. It does not quantify energy costs or identify impacts along the fuel cycle. The network which EFLOW constructs, and the levels of products and end-uses shown, can be a useful framing tool for designing and implementing a fuel cycle assessment and in identifying and quantifying fuel cycle costs. The existing EFLOW network, or portions of it, can be expanded to construct a model of fuel cycle impacts.

As mentioned, EFLOW has numerous internal linear linkages. It does not contain multiple feedback linkages to develop back-end to front-end cause and effect relationships. Hypothetically, the model can be modified to incorporate feedback linkages and thus provide a better characterization of external total fuel cycle impacts.

DATA CHARACTERISTICS

All energy data from EC member countries come from the Eurostat Energy Statistics Yearbooks. One of the main advantages of relying on a single resource is the standardized nature of the data. (All data are presented in tonnes of oil equivalent.) Eurostat data tapes are transferred onto floppy diskettes for input into EFLOW. EFLOW does not utilize estimates or attempt to develop extrapolations of non-existent data which could be fed into the model. The application of the model for its current purpose is constrained by the availability of hard, published statistics.

Data outputs consist of input-output matrices containing all data for the various stages of energy production, transformation and consumption. Using matrix algebra, matrices can be converted to a common unit of measure (if necessary) for performing country or regional comparisons. The data can then be illustrated in the energy flow diagram for characterizing static or forecast energy flows.

If the user were to adapt EFLOW to include externalities, aggregated matrices could be used for ranking energy technologies or specific impact points within the network.

The EFLOW outputs cover each stage along the model's fuel cycle -- production to end-use -- and provide data for each point within the stages. The depth of the output is basically the depth of the network itself. Expansions to the network, given adequate data inputs, could provide additional depth to data outputs. If adapted appropriately, the network could include impacts such as air emissions for each point in the network.

HARDWARE/SOFTWARE REQUIREMENTS

The use of EFLOW requires a personal computer with a monitor, plotter, and printer. In addition, it requires the special Energy Flow Model software package, as well as special driver programs for the use of plotter and printer.

LABOR/TIME/COST REQUIREMENTS

In its current capacity, the model is designed to be user friendly and does not require previous computer skills. In addition, because all data are readily available from Eurostat, data research requirements are minimal. Data research, programming and analysis requirements will expand if and when the model is adapted to account for points beyond the current network.

CURRENT UTILIZATION

The EFLOW Model provides broad statistical information on the energy systems of EC countries. It has been utilized for development and forecast purposes of national energy systems. It is the intention of the EC that the model be available and implementable worldwide.

STRENGTHS AND WEAKNESSES

EFLOW is a comprehensive and logical network approach to developing input-output matrices. In spite of the complexity of the overall flows, the model is rather straightforward. Although the model is not a means of performing a fuel cycle assessment, the fuel cycle network it develops and the input-output matrices it constructs can be adapted for performing a comprehensive analysis of fuel cycle impacts.

13. INTERNATIONAL INPUT-OUTPUT ANALYSIS: COMPILATION OF CASE STUDIES OF INTERACTION BETWEEN ASEAN, KOREA, JAPAN AND THE UNITED STATES

Author: Shunichi Furukawa
Source Organization: Institute of Developing Economies (IDE)
Date Developed: 1986

PURPOSE

This multilateral input-output model was developed and applied to analyze international trading relationships and their effects. While the multilateral input-output tables used in this study are not implemented to perform a total fuel cycle analysis, the technique holds some important characteristics which can be considered for a total fuel cycle analysis application.

FUEL CYCLE FRAMEWORK

Again, this is not a model for performing fuel cycle analysis. However, this section will discuss the general framework of the model.

The model was used to determine total inputs, outputs and value added per industry, per trading relationship, for eight countries. The input-output tables assessed international trade data for eight counties over a one-year period. The data table components comprised supply/demand of goods and services and the resulting financial/economic transactions and effects per nation. The depth of each table was based largely on the quality and availability of the data. To streamline application, specific industry classifications and/or sectors can be aggregated.

RESEARCH APPROACH/METHODOLOGY

Transactions in the input-output tables are expressed in producers' prices using three industrial sectors. All values were translated into common currencies. The layout of multilateral input-output tables is basically the same as that of bilateral input-output tables, although multilateral tables are more complicated. The steps in the methodology for developing the tables are in two phases: preparatory work and estimation.

Preparatory Work

1. To establish a uniform input-output sector classification
2. To develop a working manual, including concepts, definitions, and methodology
3. To prepare a conversion system for the national input-output sector classifications, international trade classification, and the uniform sectoral classification.

Estimation

1. To compile national input-output tables based on national sector classifications
2. To separate transactions of domestic goods and imported goods
3. To decompose imported goods (using the import matrix) by country
4. To estimate the freight and insurance costs of international trade
5. To estimate the import sub-matrices valued at f.o.b. prices from those valued at c.i.f. prices
6. To estimate import sub-matrices valued at producers prices
7. Link all sub-matrices
8. Perform final adjustments and reconciliation.

DATA CHARACTERISTICS

To the extent possible, quantifiable data elements which show known costs/impacts should be utilized. These could be based on historic data or reflect expected outcomes in various scenarios based on historic relationships or patterns. These will need to be converted to a like basis for accurate summing and comparison.

HARDWARE/SOFTWARE REQUIREMENTS

These requirements will vary on how the model is modified for use in energy analysis. The primary requirement for this analysis would include an IBM compatible PC.

LABOR/TIME/COST REQUIREMENTS

The automated and labor requirements will vary based on the complexity of the analysis to be performed. Development of comprehensive multilateral input-output tables for total fuel-cycle analysis should be expected to require an extensive amount of time in preparation and testing of the methodology, component and data identification, data development, implementation and analysis.

CURRENT UTILIZATION

No known utilization at this time.

STRENGTHS AND WEAKNESSES

The primary strength of this application is its ability to isolate specific relationships. However, in the case of the total fuel cycle, specific relationships are not currently known in many cases due to a lack of data. The input-output technique provides no means of resolving those unknown relationships.

The input-output tables utilized for this study could potentially be adapted to perform a fuel cycle analysis. Multilateral input-output tables could be developed with specific "impact" or "cost" categories (i.e. air pollution, local employment, or agricultural injury) and detail the costs per specific energy technologies in specific applications for each phase of the fuel cycle. The depth of the analysis in terms of the extent of the fuel cycle and the level and type of direct and indirect costs/impacts to be analyzed depends largely on the purpose of the analysis and the availability and integrity of the data.

14. EMBODIED ENERGY AND ECONOMIC EVALUATION

Author: Robert Costanza
Source Organization: Coastal Ecology Laboratory, Center for Wetland Resources, Louisiana State University
Date Developed: 1980

PURPOSE

The author believes that energy requirements for the production of goods and services in the national economy are not adequately represented. In addition, the author believes that land, labor and capital requirements are interdependent. He has adapted input-output analysis to account for embodied energy in these U.S. goods and services, calculating direct plus indirect energy requirements. This requires an "ecological perspective" and the methodology can be utilized to determine "market values" where markets do not exist. The author explains that this is a means of internalizing all factors external to the existing market system and solving the natural resource valuation problem.

The results indicate a significant relationship between embodied energy and dollar output when labor and government are included as endogenous sectors. As more of the indirect energy costs are taken into account, the ratio of embodied energy to dollars becomes more nearly constant from sector to sector.

The results also indicate that with appropriate perspective and boundaries, market-determined dollar values and embodied energy values are proportional for all but the primary energy sectors. The required perspective is an ecological or "systems" view that considers humans to be part of, and not apart from, their environment.

The author states that for national policy purposes, "physical dimensions of economic activity are not separable from limitations of energy supply. The universally appealing notion of unlimited economic growth with reduced energy consumption should be put to rest."

FUEL CYCLE FRAMEWORK

This model is not designed for a fuel cycle analysis. Instead, the model seeks to account for the economic value of embodied energy input from natural resources. To account for the net flow of energy inputs to systems, as well as the interdependency of land, labor and capital, he has adapted the input-output model to include labor and government energy costs as well as solar energy inputs, thus accounting for the total (direct plus indirect) energy required to produce goods and services.

RESEARCH APPROACH/METHODOLOGY

The input-output technique for calculating embodied energy involves defining a set of energy balance equations (one for each sector) and solving the resulting set of simultaneous linear equations for the energy intensity coefficient vector, which is the energy required directly and indirectly to produce a unit commodity flow. The modifications to include labor and government in the model require expanding the transactions matrix to include two more sectors, households and government. These sectors receive goods and services from the other sectors in proportion to employee compensation, indirect business taxes, and some percentage of property type income. With household and government sectors considered endogenous, the GNP as currently defined is no longer the net input and output of the model. Personal consumption and government expenditures are now internal transactions, leaving gross capital formation, net inventory change and nest exports as the new net output.

From a physical perspective, the earth has one principle net input: solar energy. Fossil fuels and other natural resources represent millions of years of embodied sunlight. Environmental flows such as wind, rain and rivers represent sunlight in more recent origin. Using this perspective, the author holds that humans are products of millions of years of "solar powered R&D" and supported by agricultural processes reliant on solar energy.

Solar energy inputs were added to the model after accounting for the lower thermodynamic usefulness of direct sunlight in comparison with fossil fuels. Electricity represents an upgraded more useful form of energy than fossil fuel, requiring directly and indirectly more Btus of fossil fuel to produce 1 Btu of electricity. Fossil fuels represent an upgraded and more useful form than the solar energy that produced it. To account for the difference in quality -- relation of sunlight to fossil fuel -- an approximation was developed based on the conversion of sunlight to tree biomass to electricity in a wood burning power plant. This yielded a conversion factor of 2,000 Btu of solar energy per Btu of fossil fuel. The total solar input for the U.S. is estimated at 103×10^{18} Btu solar energy per year or the functional equivalent of 51.5×10^{15} Btu of fossil fuel per year. Solar energy was assumed to enter the economy through the agriculture, forestry, and fisheries sectors, according to their relative land areas. Selected embodied energy intensities were calculated for each of four possible alternatives:

1. Excluding labor and government energy costs and solar energy inputs
2. Including solar energy inputs
3. Including labor and government energy costs
4. Including both labor and government energy costs and solar energy inputs.

The results were put in a regression format to highlight relationships and for significance testing. The calculated energy intensity for each sector was multiplied by the sector's dollar output to yield the direct-plus-indirect energy input. This was used as the independent variable with total dollar output as the dependent variable.

DATA CHARACTERISTICS

Data used in the model were based on a 90-sector model of energy input and output that is maintained by the Energy Research Group at the University of Illinois. U.S. Bureau of Economic Affairs data also were used.

HARDWARE/SOFTWARE REQUIREMENTS

A description of the computer requirements to implement this model was not provided. Given computer advancements since this analysis was performed, it is likely that these requirements have changed significantly. Input-output models of this type can typically be run on a high-speed IBM compatible PC 486.

LABOR/TIME/COST REQUIREMENTS

As with computer requirements, a description of the labor, time and cost requirements to implement this model was not provided. It can be inferred that as with any input-output analysis of this kind, a significant amount of time would be required to establish/modify system parameters as well as perform research of available data bases to perform the analysis, and finally to implement the analysis.

STRENGTHS AND WEAKNESSES

As the results described above indicate, this model can be used to help verify particular policy stances or objectives. These results are a direct function of the system parameters established for the analysis. This illustrates that while input-output analysis can be an effective tool for identifying interrelationships between multiple factors, the results must always be considered in light of the system framework.

Decision-Aiding Tools

The following are brief overviews of several software packages that could be used to support impact analysis associated with implementation of alternative technology options or energy strategies. They include decision analysis and dynamic programming packages. Also included are examples of standard analytical techniques that could be considered.

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15. OPTIONS: ENERGY OPTIONS FOR LOCAL ECONOMIC DEVELOPMENT

Source Organization: Funded by Western Area Power Administration and the Iowa Department of Natural Resources, developed by Iowa Association of Municipal Utilities and Economic Research Associates

OVERVIEW

OPTIONS is a menu-driven decision support software package designed to evaluate community energy strategies. It enables a community to review a variety of energy investments and then select the mix of technologies that satisfies both energy efficiency and economic development goals. It can also assist utilities, government agencies or other planners and decision-makers in their planning and/or evaluation of energy management programs.

OPTIONS employs an algorithm known as "goal programming." This is an optimization technique that is based upon the linear programming concept. The goal programming technique allows policy makers to identify the mix of energy technologies which best satisfies multiple or competing community goals. Default input data are provided. It also uses input-output and benefit-cost analysis to evaluate individual technologies according to six different criteria or goals. Currently, goals include:

- Maximizing employment
- Maximizing energy bill savings
- Minimizing investment costs
- Maximizing net economic activity
- Maximizing electric utility benefits
- Minimizing the payback period of selected technologies.

Currently the package does not address environmental factors. However, software upgrades to account for environmental goals are anticipated by late 1993. Also, at that time, graphing and import/export capabilities should be available.

OPTIONS can be used on a micro-computer and requires only MS-DOS 2.11 or greater to run. The base software package costs $125 (as of this report date). Custom modifications can be made.

16. P/G% DECISION-AIDING SOFTWARE

Source Organization: Decision Aids, Inc.

OVERVIEW

Policy/Goal Percentaging (P/G%) is a multi-criteria decision-aiding software system. It can be used with micro-computer spreadsheet formats, including Lotus 1-2-3 or Excel. The software is relatively simple to use. P/G% also can be used to analyze and evaluate any decision that involves choosing among multiple options or actions. It can be used for analyzing problems that involve multiple criteria or goals to be achieved, measured in different units or scales. Also, P/G% is appropriate when an analyst or policy maker is confronted with numerous goals that must be achieved within a single problem solution, policy or budget allocation. In terms of public policy decision making, its algorithms can help direct users toward satisfying a set of constraints that may include trade-offs or conflicting objectives.

The package requires users to perform more algebra than other decision-aiding software. It uses part-whole percentaging to translate all of the data inputs into similar dimensionless measures, based on each alternative's contribution to the total variation within each criteria category. As profiled in this compendium, P/G% was used in comparing three electric power generating options in the state of Michigan. The software can be applicable during the entire life cycle of a program or policy, from conceptualization to outcome analysis. In addition, the algorithms are simple to understand and use. As of this writing, P/G% is available for $40 through Decision Aids.

17. PROFESSIONAL DYNAMO PLUS

Source Organization: Pugh-Roberts Associates, Inc.

OVERVIEW

Professional DYNAMO Plus (PD Plus) is a commercially available software package to be used as a tool for simulating continuous time-dynamic systems. The language is designed to facilitate the modeling and simulation of multiple variable feedback systems. The techniques available through PD Plus can potentially be utilized as part of total fuel cycle analysis activities.

PD Plus provides a multi-dimensional approach for analyzing systems dynamics. A wide spectrum of factors can be incorporated and simulated and it is structured to provide a versatile capability for sensitivity analysis. PD Plus allows the user to implement a model flow through identifying model variables and the causal links between those variables. The model can be analyzed using alternative scenarios for each to develop an understanding of the causal links and the overall behavior of the system.

There are three types of active equations in the system: Levels, Rates and Auxiliaries. Each equation type corresponds to certain properties that variables within a dynamic system possess. The levels are the elements of the system that give it dynamics; levels represent accumulations (integrations) and can only be changed over time. Rates determine how levels change over time. Auxiliaries are used to facilitate connections between levels and rates.

The depth and complexity of the model is largely up to the requirements of the user. However, this is a PC-based package and therefore is constrained by the operating capacity of the PC. On an IBM AT configured with an 80287 co-processor, PD Plus compiles at a rate of 750 - 1,000 equations per minute and simulates at a rate of 2,000 equations per second.

To a large extent the characteristics of the inputs and outputs are determined by the user. PD Plus requires the user to develop the algebraic equations which translate the causal effects in a feedback system, and input the data necessary for compilation and simulation. The system has no means, however, of compensating for poor data.

In terms of physical requirements, PD-Plus requires a minimum of Microsoft DOS version 2.0 or higher, a PD Plus master disk and supplementary disk, and formatted disks for storing models. Hardware requirements include an IBM personal computer (PC, XT, or AT) or a true hardware compatible, with a minimum 256K of memory. PD Plus supports several IBM printers and graphics cards.

Primary labor requirements are associated with data development, implementation, and analysis. PD Plus does not require a computer programmer, yet will require the systems dynamics modeling and data research skills necessary for total fuel cycle analysis activities.

PD Plus offers a straightforward method of identifying total fuel cycle interactions and quantifying cause and effect relationships. The system is constrained, however, by the data input for simulation and the model developed by the user.

18. INFLUENCE DIAGRAMMING (INDIA)

Source Organization: Decision Focus Inc.

OVERVIEW

Decision Focus Inc. has developed the InDia software as an alternative to conventional decision analysis methodologies. InDia is an influence diagramming package which can be used for communicating the structure of a decision problem (or process), representing dependencies among variables, obtaining probability judgments, and finally as a means of solving a decision problem (or analyzing a process). The InDia package can be operated on an IBM compatible personal computer.

Standard Analytical or Modeling Techniques

The following are brief overviews of standard analytical or modeling techniques which could be used in evaluating socioeconomic or environmental impacts in support of decision analysis in energy planning and resource selection.

19. DYNAMIC PROGRAMMING

Dynamic programming is a multi-stage decision process in which the outcome at one stage affects the subsequent results and decisions at the next stage. Each stage represents a sub-problem or sub-process. Each sub-problem or sub-process, which may change from stage to stage, is a function of prior stage decisions. Together they comprise the overall problem to be solved or process to be analyzed. Dynamic programming could be a useful tool in performing a fuel cycle assessment in that the process of various direct, indirect and secondary impacts can be traced within each stage of the fuel cycle and through the progression of the fuel cycle.

The depth of dynamic programming applications are dependent on the boundaries established by the user, as well as the problem solving capacity and data resource limitations. Dynamic programming allows for analysis through each phase of the fuel cycle. In addition, it allows for the calculation, estimation, or analysis of direct, indirect and secondary fuel cycle effects and costs. Finally, internal linkages can be developed (when deemed necessary by the user) to assess impacts of later stages on previous stages. The dynamic programming approach involves several different concepts. These include:

- Decomposition of the process into a sequence of linked components or sub-processes.

- The approach is progressive. For example, the input (or state variable) in each stage of the process is a function of the system state upon transfer to that stage. And the system state is a function of the decision variable chosen from a range of alternatives during the previous stage, then flowing to the current stage. Thus a series of alternative inputs possible in one stage are dependent on the inputs and outputs from the previous stage.

- The transition function in the dynamic programming approach refers to how the stages are interconnected and the calculation of the system state varies from one stage to the next.

- The return in each stage (or through the total process) is that result of the decision which the user desires to measure (i.e. profit, emissions, or jobs created). Typically, the object of the dynamic programming approach is to minimize or maximize the return in each stage. This requires that in each stage the optimal solution be determined for each possible input state value. The optimal return for each stage is stored for use in defining the overall optimal decision.

There are numerous options, techniques and applications which can be employed in developing a dynamic programming approach to fuel cycle assessment. Crucial to the dynamic programming approach is the availability and integrity of the data to be used for basing decisions within each stage. Each stage must have sufficient data to develop and implement an optimization problem. Thus the integrity of the resulting input state value is a function of the validity of the data in previous stages.

To a large extent the boundaries established for analysis will depend on the availability of acceptable data.

20. MONTE CARLO SIMULATIONS

Monte Carlo simulation is a means of project analysis which allows the user to inspect all possible combinations of project variables and the entire distribution of project outcomes. Each step or stage of the project or application is modeled with equations representing each variable and the interaction of variables within and across stages. Within each step, the expected or range of probability of forecast errors must be defined for each outcome. Once the model has been constructed the user can simulate all potential outcomes, given the variable interdependencies and probability distributions. The probability of potential outcomes then can be calculated for each possible combination.

Monte Carlo is a useful technique for assessing the range of possible outcomes occurring through a fuel cycle. It is important in the sense that by simulating the entire range, it reflects the uncertainties inherent in total fuel cycle analysis. While the model can be as flexible as the user desires -- incorporating complex direct and indirect impacts through the fuel cycle -- as with any modeling effort, the output is only as good as the logic and data inputs utilized.

21. SOURCE RELEASE ASSESSMENT

Source/release assessment techniques are typically implemented to quantify (or estimate) and assess the incidental or accidental release of toxic chemicals or other hazardous materials. In developing a total fuel cycle analysis, this type of technique is applicable to determining toxic release, run-off or similar fuel cycle impacts in phases such as resource extraction, processing and transmission. Characteristics of this technique include:

- Monitoring to perform regular or ongoing sampling of an area near a risk source and to quantify or estimate harmful releases. Data can then be used to estimate historic or current releases/emissions or extrapolate potential releases/emissions from future activities.

- Accident investigation and performance testing to interpret the causes and sequences of events after disruptions in a system. Investigation and testing can be performed under controlled scenarios or conditions to predict expected outcomes for various situations.

- Statistical methods are used to analyze previously collected data and estimate the likelihood of a particular accidental release or hazardous event.

- Formal models of source systems to estimate releases.

22. EXPOSURE ASSESSMENT

Exposure assessment techniques are also used in risk assessment. These estimate or directly measure the quantities or concentrations of risk agents and any direct and/or indirect impacts realized by individuals, populations or ecosystems. For example, in performing a total fuel cycle analysis, exposure assessment techniques can be utilized to estimate the direct and indirect impacts associated with emissions. Exposure assessments which focus on a single or specific sets of risk agents are difficult and costly to perform due to the mobility number risk agents, exposure sources and impacted receptors. Characteristics of exposure assessment techniques include:

- Analogies with known information about other hazardous substances to infer and assess the transport and fate of hazardous substances under analysis

- Exposure monitoring such as personal monitoring or ambient monitoring, which will develop and assess samples for data development

- Exposure modeling to simulate the behavior of risk agents in the environment. Some types include atmospheric models, surface-water models, groundwater and unsaturated-zone models, multimedia models, and food chain models.

23. DOSE-RESPONSE

Dose-response assessment involves 1) determining the dose of a risk agent received by exposed populations and 2) estimating the relationship between different doses and the magnitude of their adverse effects. Dose-response techniques can also be utilized to assess specific environmental, health, agricultural or other impacts along each stage of the fuel cycle. The technique involves determining the dose, estimating the response and then extrapolating the data to develop dose-response curves for selected populations.

Risk characterization then takes the results of above analyses to develop risk probabilities for individuals or populations. The depth of analysis (i.e. the extent of the fuel cycle analyzed or the level of direct and indirect impacts and internal linkages) to be performed through these procedures is dependent on the user's specific objectives and ability to develop the necessary data and implement effective assessment processes.

Inherent in these risk assessment procedures are the costs and difficulties in developing accurate data. Uncertainty of specific data elements can be analyzed using sensitivity analysis or tests of statistical significance. Uncertainty is typically expressed using probability distributions, confidence intervals, or worst-case/best-case scenarios.

24. CHEMICAL MASS BALANCE MODELS

The chemical element signature of specific emission sources can be used to trace the relative contribution of each source type to the particulate matter measured in an ambient aerosol. The chemical mass balance method is based on the supposition that the observed concentration profile is made up of a linear combination of individual unique source profiles, each profile consisting of the relative composition of many chemical species. In order to apply the mass balance method, two data sets are required: air quality measurements, and chemically speciated source profiles.

25. TRAJECTORY MODELS

There are several trajectory models available on today's market. These models are based on the atmospheric diffusion equation, but use a moving-coordinate approach to describe pollutant transport. In these models, a hypothetical column of air is defined, bounded on the bottom by the ground and on the top by an inversion base, varying with time. After specifying a starting point, the column moves under the influence of prevailing winds and passes over emission sources (inject pollutant species). Chemical reactions may be stimulated in the column.

Some assumptions made in trajectory models tend to limit their utility. For example, some models consider only a single column of air, neglecting horizontal diffusion of pollutants. This assumption is most serious in a case where the air column passes near, but not over, large emission sources. The neglect of horizontal diffusion will result in missing the effects of these sources.

Another assumption that may limit model utility is that the column retains its vertical shape as it is advected by prevailing winds. Thus, the mean wind velocity is constant with height (wind shear). If a large fraction of the emissions inventory is via large point sources or if wind patterns display shear, neglect of wind shear effects can seriously impair reliability of trajectory model results.

26. GAUSSIAN MODELS

Gaussian models are the most widely used models in the regulatory community. Typically, all inert pollutants are considered and predicted for a one-hour average time period. Normal distributions of pollutants in horizontal and vertical directions are assumed. Sources and receptors analyzed are assumed to be located in either flat or gently rolling terrain, and uniform windflow is restricted to the horizontal direction. Other assumptions include:

- No wind sheer
- Continuous and non-varying sources
- Atmospheric stability conditions are invariant with height
- Dispersion coefficients were derived from studies in flat terrain
- Perfect reflection occurs if the plume intersects the ground surface.

B. TOTAL FUEL CYCLE AND LIFE CYCLE STUDIES

The following are profiles of efforts to identify and evaluate fuel cycle impacts. Typically, these efforts are broad in scale and incorporate environmental and non-environmental impacts in multiple stages.

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1. U.S. - EC FUEL CYCLE STUDY BACKGROUND DOCUMENT ON THE APPROACHES AND ISSUES: REPORT NO. 1 ON THE EXTERNAL COSTS AND BENEFITS OF FUEL CYCLES

Author/Contact: Russell Lee, ORNL
Source Organization: Prepared by: Oak Ridge National Laboratory (ORNL) and Resources for the Future (RFF), for the U.S. Department of Energy, Office of Policy, Planning and Analysis, and the Commission of the European Communities
Date Developed: In progress (started February 1991)

PURPOSE

In 1991 DOE and the EC began a major joint project to develop a comparative analytical methodology for eventually developing a range of estimates of external costs and benefits. These estimates will not be made at this point, however, and the present focus will be on marginal damages and benefits. The study will rely on secondary sources of information for eight supply-side fuel cycles for electric generation and four conservation technologies. The supply-side fuel cycles will be 1) coal, 2) biomass, 3) oil, 4) natural gas, 5) hydroelectric, 6) nuclear, 7) wind, and 8) photovoltaic. Four conservation options also will be evaluated, but the specific conservation technologies have not yet been selected.

A background document for the study was published in November 1992 which focuses on external costs and benefits of energy fuel cycles using the coal fuel cycle for several examples. It also discusses general fuel cycle analysis approaches and issues. Draft reports on four of the eight fuel cycles (oil, biomass, hydro, and natural gas) are being prepared for peer review. The draft coal report is currently undergoing peer review. Completion of the final reports is expected by the end of 1993. There are three principle objectives of the study. They are:

1. To create a unified conceptual design for quantifying the net costs and benefits, based on a damage-function approach.

2. To demonstrate an accounting framework that can be used to estimate a broad range of costs and benefits. Examples may include employment benefits, road damage, fatal accidents, or visibility.

3. To identify critical methodological issues and informational needs that will effect the expanded efforts to develop comprehensive assessments of the costs of energy use.

FUEL CYCLE FRAMEWORK

The general framework of the DOE/EC study is a social cost accounting of costs and benefits. An accounting framework is used to identify costs and benefits of each fuel cycle and quantify them if data are available. The overall process for implementing the accounting framework is to:

- Select the technology and a hypothetical location.
- Identify fuel cycle stages for each technology. The study looks at the generation stage and upstream stages, and to some extent downstream stages.
- Identify impact pathways and matrices/impacts cells.
- Estimate emissions from each fuel cycle stage (inputting available environmental impact data in the appropriate cells).
- Estimate physical impacts of emissions (inputting available physical impacts data, such as health impacts, in appropriate cells).
- Estimate the economic value of damages and benefits (inputting estimates of monetary damages associated with physical damages).

The DOE/EC study differentiates total energy cycle (TEC) analysis from fuel cycle analysis. It views TEC analysis as including all stages and activities of an energy cycle, including primary resource extraction and preparation, transport and storage, conversion, and end-use services. The authors see fuel cycle analysis as a component of TEC analysis, focusing on primary resource extraction and preparation, transport and storage, and conversion. With the exception of the conservation fuel cycles, the end-use stage of the energy cycle is excluded from this analysis.

In the supply-side fuel cycle studies, the primary emphasis will be upon fuel conversion for the generation of electricity. In each of the 12 studies, the fuel cycle stages evaluated will be specific to the technology. To date, only the background report is available. That report identifies coal fuel cycle stages as:

1. Coal mining - to include mine construction, mining of coal, waste water management, solid waste management, and post mining.

2. Coal cleaning and beneficiation - to include plant construction, treatment, waste water management, solid waste management, and decommissioning.

3. Coal transportation - to include facility construction, loading, transit, unloading, and decommissioning.

4. Generation - to include plant construction, generation, waste water management, solid waste transportation, solid waste management, and decommissioning.

5. Power transmission - to include construction and transmission.

The authors have mapped out, in matrix format, burdens and other residuals for coal fuel cycles into four groups consisting of air, water, solid waste emissions, and other burdens. Within each of these groups they have developed a second-tier matrix mapping out specific burdens/emissions, such as HC, CO, methane, sulfur and other burdens like noise, road use, and additional residuals. A third level matrix lays out impacts of burdens or endpoints in three general categories: ecological, health, and socioeconomic. The specific endpoints within each of these categories are:

<u>**Ecological**</u>	<u>**Health**</u>	<u>**Socioeconomic**</u>
Crops & Suburban	Cancer	Building Materials
Landscape	Asthma, Respiratory and Mortality	Land
Livestock	Neurological Effects	Water
Timber	Cardiovascular	Visibility
Commercial Fishing	Reproduction	Noise
Recreational Fishing		Public Services
Hunting		Other Quality of Life Effects
Recreation		
Biodiversity		

The three-level matrices are mapped out for each of the five stages of the coal fuel cycle and include cells for valuing the impacts.

RESEARCH APPROACH/METHODOLOGY

It is not the purpose of the DOE/EC to conduct original research in quantifying net costs and benefits. The project team is conducting a comprehensive review of existing literature, data/information, and models.

The Damage Function Approach (DFA) was selected as the method for guiding the study in assessing externalities. The DFA provides the greatest emphasis on the relationships between natural and economic science to reveal the sequence of marginal changes that result in damages. Report No. 1 presents the major tools to implement the DFA in the context of fuel cycle activities. These tools are necessary to name and quantify impacts, translate physical damages to quantities, and distinguish damages from external costs. Development of impact pathways for priority damages or benefits helps implement DFA accounting. In addition, when assembling the impacts into the accounting framework matrices, a message system is proposed to assess systematically the uncertainty and quality of the data.

The study will incorporate linear linkages to convey the cause and effect nature of energy production and emissions. However, the framework is static and does not incorporate any internal feedbacks. For example, impacts from coal mining remain static regardless of changes in energy consumption. While dynamic models would be desired, the authors found no existing model or analytical effort that captures the dynamic interactions of the energy, environmental and socioeconomic systems in enough detail to fully satisfy the information needs of estimating residual damages.

A preliminary assessment of methodological and information needs reveals a number of methodological concerns. For one, participants in the DOE/EC study indicate that scientific and economic data and models are inadequate in a number of areas to support damage estimates. In addition, there is concern over the issue of transferring estimates of externalities from one location or subpopulation to another without any modification. Often, externality values are site and application specific. Finally, there is significant uncertainty over the issue or appropriateness of aggregating damages and benefits to obtain an overall measure.

The study also has revealed a number of complex research and methodological issues. For example, one of the issues in identifying specific external impacts such as physical damages (e.g. road damages near a coal mining site), is the extent to which they are externalities. Only some portion of those damages may be externalities attributable to coal production. In addition, while those damages are not internalized into the market price for coal, they are paid for by society through taxes for road repair. Yet, to what extent are those benefiting from the coal generated power the same as those paying taxes? To what extent are road taxes being paid by those benefiting from employment effects of coal production?

CURRENT/PLANNED UTILIZATION

Report No. 1 is solely a background document to introduce the study approach and to discuss the major conceptual and practical issues. Priorities during this phase of the DOE - EC study are to:

1. Select, develop and demonstrate a rigorous methodology for estimating the damages and benefits for each of the fuel cycles through electricity generation

2. Undertake a state-of-the-art assessment of the most relevant scientific and economic literature;

3. Develop an economic framework capable of applying external cost estimates in a realistic PUC setting.

Follow-on efforts are likely to include the development of a data base and information system that can be accessed by PUCs and other users, and the extension of the methodology to distribution and end-use stages, including transportation.

STRENGTHS AND WEAKNESSES

The primary strength of the proposed DOE - EC approach is the extent to which social costs can be assessed. By identifying many of the direct and indirect costs associated with environmental impacts along nearly every phase of the fuel cycle, the framework is extensive in terms of data development and provides an almost comprehensive starting point from which to select costs and benefits which will be included in the analysis. However, the absence of internal feedbacks discounts the value of outputs and limits the flexibility and applicability of the framework for use in scenario development.

The effort seeks to develop a framework for evaluating 12 fuel cycles, yet it does not perform any original research. A number of frameworks have been developed already for evaluating particular fuel cycles. While these frameworks need modification, there is a more significant need for original research and methods/sources for conducting that research. Development of frameworks for less than 12 technologies and a reallocation of resources to identifying research sources and methods for primary research may be an alternative for allocating resources worth considering.

2. A TECHNICAL FRAMEWORK FOR LIFE CYCLE ASSESSMENT

Source Organization: Society for Environmental Toxicology and Chemistry (SETAC), Life Cycle Assessment (LCA) Advisory Group
Date: 1990 - ongoing

PURPOSE

In 1990, SETAC formed the LCA Advisory Group to develop a framework for performing LCA. The U.S. SETAC has a European counterpart also involved in the process. Since 1990, SETAC has sponsored a number of workshops held in the U.S. and Europe. The purpose of these workshops is to bring together experts and address LCA issues and techniques. The overall objective of the group is to develop a framework for addressing all stages of the fuel cycle and performing a case study. The focus has been on manufactured goods and processes but many of the issues and approaches translate for energy technology fuel cycle assessments in the utility sector.

A number of countries in Europe are already doing LCA in some form to evaluate certain product designs, manufacturing or other processes. Although the techniques have not been perfected, the general opinion of SETAC's European counterparts is that an incomplete LCA is better than no evaluation at all. SETAC members stressed that this policy should be seriously considered in the U.S. Moreover, while LCA may be perceived to be a complex, costly and long-term effort, it does not have to be. The LCA concept and some component of an LCA can be applied at a small scale by small businesses to support decision making. For example, it can build off of approaches to pollution prevention, recycling, waste reduction or greater streamlining and efficiency that are currently being implemented by many small businesses.

This profile reviews the first detailed document published by the group, "A Technical Framework for Lifecycle Assessment" (1991), which discusses the overall lifecycle analysis approach and issues. It also discusses the group's ongoing approach to addressing life cycle assessment.

FUEL CYCLE FRAMEWORK

The group defines LCA as "an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impacts of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements." The assessment includes all life cycle stages, including:

- Extracting and processing raw materials
- Manufacturing
- Transportation and distribution
- Use/re-use/maintenance

- Recycling
- Final disposal.

No one product or process is evaluated in particular. Instead, a general approach is developed.

RESEARCH APPROACH/METHODOLOGY

The group has developed a multi-year program to develop a detailed and reliable LCA framework addressing key issues. Some of these issues are:

- Scoping and boundary issues
- Goal definition
- Identifying appropriate conversion models
- Data quality
- Appropriate impact descriptors
- Valuation methods
- Utilization of results.

The group has framed LCA into three primary integrated components:

> **Inventory Analysis** - An objective data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases incurred throughout the life cycle of a product, process or activity.
>
> **Impact Analysis** - A technical, quantitative and/or qualitative process to characterize and assess the effects of the environmental loadings identified in the human inventory component. The assessment should address both ecological and human health considerations, as well as effects such as habitat modification and noise pollution.
>
> **Improvement Analysis** - A systematic evaluation of the needs and opportunities to reduce the environmental burden associated with energy and raw materials use and waste emissions throughout the whole lifecycle of a product, process or activity. This analysis may include both quantitative and qualitative measures of improvements, such as changes in product design, raw materials use, industrial processing, consumer use and waste management.

Each of these components is a function of Goal Definition and Scoping. The first stage of the LCA is inventory analysis. Inventory components are evaluated in terms of human health, ecology, resource depletion and social welfare. Using conversion models, impact descriptors are developed in each of those categories. These impacts are quantified by valuation models/methods. The outputs are used for ranking alternatives. Thus, the results of the life cycle assessment are in a functional form which can be used as part of an improvement analysis and/or decision analysis. Although only based in theory at this stage, the general model being discussed would look at the life cycle system. Within the overall system, three main groups of operations can be identified:

1. Operations responsible for the production, use, transportation and disposal of the product (the main processing sequence)

2. Production of ancillary materials, such as the packaging and machinery needed to process the raw materials that feed into the main processing or production sequence

3. The fuel production industries that supply the energy needed to drive the system.

To describe the performance of a system, the overall system must be divided into a series of subsystems linked to each other by balanced material flows. The systems are broken down to a level of detail such that each subsystem corresponds to some physical operation for which input and output data are available. As far as possible, input data that describe the performance of a subsystem, unique to the subsystem, should be derived from primary sources. In most cases, the manufacturing/processing/converting subsystems and the use/re-use/maintenance subsystems are unique to the system being studied. Data should be site, case and company specific, such as the operational data provided in site worksheets. These are preferable to industry averages. Once normalized input data for each of the component subsystems are available, linear sequence calculations can be performed by spreadsheet software on a personal computer. Large segments of material processing systems include linear sequences of operations; however, some segments are non-linear. The group suggests system iterations as the only acceptable method of dealing with non-linear networks. These iterations assign initial values to the system operators, calculate the system, substitute the calculated values for the initial values and recalculate the system.

The approach being developed by SETAC is still in its developmental stages and thus can be changed or refocused.

CURRENT UTILIZATION

There is no known current utilization of this approach as it is still in its developmental stages. However, a number of private sector, government and academic organizations are involved in the process.

STRENGTHS AND WEAKNESSES

The SETAC approach is not yet complete; therefore, it is difficult to draw conclusions on the strengths or weaknesses of the effort. Some of the strong points of the approach include the fact that a broad range of professional input is being included in the overall development. Thus, each individual is able to provide inputs based on experience developed in similar projects during their careers. Moreover, SETAC is approaching this activity in a methodical manner, accounting for the entire fuel cycle and addressing many of the critical issues. Without an identified application designed for this approach, however, it is difficult to envision where the overall effort/investment will lead and what applications will result. Moreover, the approach calls for case-specific analysis to ensure validity. It is true that in many cases resources will not be available for an extensive analysis. A subcomponent of this process then, should include a conceptual LCA approach.

C. PARTIAL FUEL CYCLE STUDIES

The following are profiles of approaches or methodologies implemented to evaluate components of fuel cycle impacts, such as the environmental externalities associated with electric generation.

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1. COMPUTERIZED TOOL FOR ENVIRONMENTAL ASSESSMENT OF ENERGY SYSTEMS: LIFE CYCLE ANALYSIS AND BIOMASS ENERGY

Source Organization: United Nations Environment Programme (UNEP), Stockholm Environment Institute (SEI)
Date: 1988 to present

PURPOSE

In 1988 UNEP and SEI began an effort to develop and disseminate methods for bringing environmental considerations to bear on energy development in developing countries. The objective of the effort was to:

- Build a stand-alone Environmental Data Base (EDB)
- Link EDB to the Long-range Energy Alternatives Planning (LEAP) System
- Implement intensive applications in collaboration with an African organization (ENDA)
- Disseminate the data and planning systems to developing country recipients.

The first phase of the effort is complete and the data base is in place. It is linked to LEAP and has been installed in a number of developing countries. User feedback is being obtained on the system and its operation. Among the suggestions being made by users is to provide a deeper understanding of environmental effects and an ability to track these effects throughout the full fuel cycle. Additional work is proposed for a second phase which could include development of life cycle (or fuel chain) analysis capability. The UNEP has not yet decided whether to fund a second phase of activities.

FUEL CYCLE FRAMEWORK

The EDB provides a comprehensive summary of the information linking energy production, conversion and consumption activities to:

- Air emissions
- Water emissions
- Solid waste
- Other occupational health and safety.

It is not a fuel cycle model or analysis, but is being considered for use in a fuel cycle analysis activity. Moreover, its linkage to LEAP (profiled in this compendium) allows for modeling capability.

RESEARCH APPROACH/METHODOLOGY

The EDB has a flexible structure which allows a user to store and access an extensive set of documented quantitative information about the environmental impacts of production and consumption activities. EDB can be thought of as a two-dimensional matrix. The rows of the matrix are source categories (energy demand, transformation, and extraction technologies). The columns are effects categories representing air, water, and solid waste emissions and direct health and safety impacts. For each combination of source and effect, information can be stored in the coefficients data base. This data base is the central component of EDB and contains the data on specific effects per unit of source activity. The coefficient data base is derived from over 50 literature sources of international origin and is augmented as new data becomes available. There are over 3,000 coefficient data entries.

CURRENT UTILIZATION

The LEAP/EDB system, or the EDB as a stand-alone, has been installed in over 30 organizations in over 20 countries. Generally, users consist of energy ministries, utility and industry organizations, and academic institutions. There are plans to make the data base available in all Latin American countries through cooperation with the Latin American Energy Organization (OLADE). The EDB/LEAP system has been used in national energy planning in countries such as Nepal.

STRENGTHS AND WEAKNESSES

The EDB as a stand-alone is a valuable tool for developing countries in that many governmental and non-governmental institutions in those countries can access the system free of charge. The system also is available to other institutions for a nominal charge. The EDB is an extensive data base, and its linkage to the LEAP provides significantly more analytical capabilities. EDB users have identified the extensive data and bibliographic resources in the data base as a major plus. In addition, users have pointed to the user friendliness of the system, on-screen conversion between physical units, and straightforward linkage between EDB and LEAP as advantages to the system. Similarly, users have expressed a desire for several improvements. These include a need for a deeper understanding of the nature of environmental effects; improvement in data for technologies that are being used in developing countries; identification of impacts other than air emissions; a desire for more biomass-related impacts since many developing countries are the targeted users; and incorporation of the ability to track environmental effects through the full fuel cycle.

2. ONTARIO HYDRO DEMAND/SUPPLY PLAN

Source Organization: Ontario Hydro, Environmental Studies and Assessments Department
Date Developed: Ongoing

PURPOSE

In late 1989, Ontario Hydro proposed a plan to meet the province's electrical needs for the next 25 years. That plan established objectives that included:

- Increased energy efficiency
- Getting the maximum use from existing generating and transmission facilities
- Developing economic hydraulic generation
- Encouraging purchases from non-utility generation
- Using major supply -- large-scale nuclear or fossil generating plants -- to meet the remaining requirements.

As part of the plan, Ontario Hydro began to look at components of fuel cycle impacts in response to the Canadian Environmental Assessment Act as well as in response to increasing concerns from environmentalists and the provincial government's commitment to environmentally sound energy production and consumption practices. In implementing this activity, the utility developed a number of reports evaluating demand-side and supply-side options and associated impacts. These include:

1. Environmental Impacts of Demand Management Options
2. Materials Relating to Environmental and Health Effects of Hydroelectric Development
3. Supply-side Environmental Effects of Ontario Hydro's Demand Management Plan
4. Demand/Supply Plan (25 year plan), and Environmental Analysis.

In the 1991 draft of the compendium, the ongoing Ontario Hydro plan was profiled. Since the 1989 start date, energy efficiency has improved and the economic situation in the province has changed, causing Ontario Hydro to revise its plans and scale back the current effort. The utility is no longer seeking approval of its large-scale nuclear or fossil generating plants. The current focus is on 1) demand management programs, 2) purchasing power from non-utility generators, and 3) expanding transmission capacity to carry purchased power.

Because the need to construct new generation facilities has been scaled back, so has the requirement to evaluate environmental impacts. Thus, some of the activities originally outlined in the Environmental Assessment have been scaled back or put on hold.

FUEL CYCLE FRAMEWORK

In 1989, Ontario Hydro released its *Demand/Supply Plan Report.* The Plan is the overriding report which establishes supply-side and demand-side measures to be implemented over a 25 year period (1989-2014) and which drives the environmental assessment. The plan is designed to respond to load demand and operational conditions over that time frame. The primary supply technologies are hydroelectric, nuclear and fossil fuels. The Demand Management Plan within the *Demand/Supply Plan Report* proposes these roughly 55 demand-side management measures or programs. Examples of some of the DSM measures in the Hydro Plan include:

Residential Sector	Commercial Sector	Industrial Sector
Audits	34W fluorescent	High Efficiency Motors
Renovation Advisement	Compact fluorescent	Energy Monitoring
Efficient Lighting	Daylighting Control	Customized Rebates
Time-of-use Rates	Ground Source Heat Pumps	EE Lighting
R2000 Homes	Audits	Off-peak Charging
High Efficiency Replacement Upgrades	Appliances	Load Controls
Efficient Appliances	Thermal Cool Storage	
Hi Efficiency Sentinel Lights	Streetlight Pilot	
	Lighting Redesign	

An *Environmental Analysis Report* accompanied the plan to provide a general discussion and assessment of its supply- and demand-side measures. The report overviews the environmental assessment activities that are taking place as part of the development of the plan. It only considers "full fuel cycle effects" that result from activities which 1) take place within Ontario and 2) are within the control of Ontario Hydro. Thus, numerous activities are excluded, including coal or uranium mining.

In addition, only direct impacts within "normal operating conditions" are evaluated. The analysis separates impacts into "natural environment effects" and "social environment effects." These projected impacts are those effects on the supply system resulting over the 25 year time frame from implementation of the DSM measures in the Demand Management Plan. In each of these categories, only the direct impacts are quantified or qualified. There are two types of natural environment effects quantified:

1. Resource use - the quantities of natural resources (coal, oil, natural gas, uranium, limestone, water and land) saved as a result of the DSM measures; and

2. Emissions/Effluents/Wastes - the quantities of wastes (to atmospheric emissions, water effluents, waste production) reduced due to deferred or delayed electric generation.

Social environment effects are discussed in a general manner as the report finds that these impacts are difficult to quantify with a high level of precision. In general, the study points to the dollar savings realized by consumers through reductions in electricity consumption; the increase in demand management employment; and the loss of jobs due to the absence of construction of large generating facilities.

RESEARCH APPROACH/METHODOLOGY

Research entailed the following processes:

1. Development of a set of natural and social environmental criteria for the generation and transmission components of the plan. The criteria should be tested for appropriate use or experience in other applications.

2. Evaluation of the environmental implications of the alternative plans using the criteria.

3. Consideration of mitigation/compensation to offset the potential environmental effects of the plans.

4. Determination of the environmental advantages and disadvantages of the alternative plans and identification of residual effects.

5. Identification of and comment on constraints and concerns outside Ontario Hydro's control.

6. Documentation of the process and findings.

The approach entailed development of a model for performing sensitivity analysis of alternative supply- and demand-side plans. Similar efforts that had been implemented in Canada and the U.S. were reviewed for their applicability.

In one of the analyses, the *Supply-Side Environmental Effects of Ontario Hydro's Demand Management Plan* was initiated by the Energy Management Branch of Ontario Hydro to develop a more quantitative environmental assessment of demand management initiatives set forth in the 1989 Ontario Hydro Plan. Supply-side effects refer to those environmental effects associated with the bulk electric and planning system, whereas the three broad categories that the DSM activities fall under include:

- **Load Reduction** - Primarily achieved through improvements in efficiency of electricity use.

- **Load Shifting** - Reducing system peak demand by shifting some electricity demand from high-use to low-use periods.

- **Peak Clipping** - Primarily achieved through Discount Demand Service Contracts, which offer customers a lower rate in exchange for an agreement to curtail electricity during peak demand hours.

The study evaluates the environmental and societal impacts of the total range of DSM measures proposed in the Demand Management Plan. The evaluation uses a median load growth case (2.5% annual demand growth) as the reference case and also analyzes two alternative scenarios which assume lower levels of demand management. For each of the three demand growth scenarios, the analysis uses emissions/use factors to project changes in environmental impacts over the forecast period. Comparative indices were then developed to compare estimates of resource use/emissions on a per TWh basis. The data outputs are the annual reductions in atmospheric emissions, water effluents, and waste produced over the course of the study.

As mentioned above, the study develops quantitative estimates for direct residual emission. Secondary impacts and non-emission impacts in the stages of the fuel cycle assessed are estimated and discussed more qualitatively.

The study is an integral part of the overall Ontario Hydro supply and demand 25 year planning process and has been used to demonstrate the extent to which Ontario Hydro planning processes reflect the goals and objectives of the Ministry of Energy and the political/environmental realities in the province.

CURRENT UTILIZATION

As discussed above, the need to construct new generation facilities has been scaled back. Thus, the utilization of the environmental analysis and the subsequent reports also has been reduced or put on hold.

Ontario Hydro originally planned to spend nearly $3 billion on demand-side management programs (with anticipated Canadian Ministry of Energy assistance) by the year 2000. That amount was increased to $6 billion in 1992. These activities are expected to result in demand reductions of up to 9,860 MW by the year 2000.

STRENGTHS AND WEAKNESSES

It is not possible to perform a comprehensive assessment of the strengths and weaknesses of the environmental analysis. Detailed analysis of societal supply-side impacts as well as natural and societal environment demand-side impacts are not yet available and may not be completed due to the change in focus of Ontario Hydro's plans. Some comments can be made, however, of the approach to determining supply-side environmental impacts. The Ontario Hydro studies use an approach for determining environmental and societal impacts that is organized and straightforward. If all pieces are assembled the approach should allow for a comprehensive environmental analysis. By analyzing the fuel cycle effects of each component of the 25 year Demand/Supply Plan separately, Ontario Hydro has developed an analytical framework that looks at some fuel cycle impacts from specific supply and demand technologies and programs. Moreover, one of the primary strengths of the analysis is that it is a response to a specific plan and set of activities. It is not a generic analysis of a "typical" technology fuel cycle. Thus, the output is more realistic, more valid and can be used to estimate actual outcomes and assist in real world decision making.

One of the primary drawbacks of the analysis for use by the larger audience outside of Ontario Hydro is that it will not cover renewable energy technologies other than hydroelectric in its supply report. These technologies are not part of the Demand/Supply Plan. Moreover, the analysis does not incorporate many stages of the fuel cycle or any secondary or indirect impacts, and it presents societal impacts in a very general sense. While this can be viewed as a drawback, it allows for output that is less clouded by highly uncertain or qualitative results. A similar point can be made with regard to not analyzing those externalities that are outside the scope of Ontario Hydro control or within the province. With further research and development of enhanced analytical techniques, however, the Ontario Hydro framework may provide a means of attaining better estimates of societal impacts.

The effort undertaken by Ontario Hydro appears focused and effective in assessing impacts from implementing demand-side management alternatives. An analysis which uses some form of this framework, however, will need to incorporate a broader set of operational, economic, environmental, political and social goals.

3. SOCIAL COSTS OF ENERGY PRODUCTION

Author: Contact person Peter Blair
Source Organization: Office of Technology Assessment
Date Developed: In progress

OVERVIEW

This effort is part of a larger project on renewable energy technologies. One component of the project is to investigate the social costs associated with renewable energy technologies as compared to conventional energy technologies. It is anticipated that cost estimates will be generated. The project is in its early stages and those estimates likely will not be developed until sometime in 1994. At this point very little information is available. Some initial project workshops may be held in mid-1993.

4. ENVIRONMENTAL COSTS OF ELECTRICITY

Author: Pace University Center for Environmental Legal Studies
Source Organization: New York State Energy Research and Development Authority and DOE
Date Developed: 1990

PURPOSE

This report, also known as the Pace report, was developed to review existing methods for quantifying the environmental externalities associated with electric generation. It also is a review of those methods which seek to account for environmental externalities in electric utility planning and resource selection.

It was not the purpose of the report to produce any original methodologies for quantifying environmental externalities or accounting for them in planning processes. The report is intended to assist utilities, government regulators, legislators, policy analysts and public interest groups in estimating the costs of the environmental impacts of electricity.

The Pace report also discusses many of the complex problems associated with accounting for externalities, including methods of valuation, boundary issues and uncertainty.

FUEL CYCLE FRAMEWORK

The report assesses externalities associated with specific technologies and emissions and augments that discussion with externality estimates from various sources. The technologies that are discussed in the report include:

- Coal plants
- Oil plants
- Natural gas plants
- Nuclear plants
- Renewable generation resources (hydro, solar, wind and biomass)
- Waste-to-energy facilities
- Demand-side management resources.

The Pace report does not address the entire fuel cycle. The report discusses measuring externalities in terms of direct fixed costs and direct variable costs associated with the stages from electric utility operations through waste disposal. Direct costs are defined as the net change in economic value resulting from the production, consumption or exchange of an economic good or service. Fixed costs are considered to be those one-time or ongoing environmental costs associated with plant construction, operation and decommissioning. Variable costs are considered to be those environmental effects which vary due to plant output.

A number of specific externalities are discussed in the report; most are environmental. Environmental externalities include global warming, sulfur dioxide, nitrogen oxides, ozone, acid deposition, particulates, land use and water pollution impacts, and electric and magnetic field effects. The effects of these impacts on specific receptors are also characterized and discussed.

Indirect costs and transfer costs are not considered in the report. These are the secondary impacts of environmental externalities (i.e. the economic benefits from a marina built at a reservoir created by a hydroelectric project). The authors identified several reasons for not including these costs, including 1) the tendency of indirect and transfer costs/benefits to cancel one another or transfer from one population to another in terms of overall economic value. The Pace report finds no evidence that alternative expenditure patterns would create a significantly different economic equilibrium; and 2) there is significant complexity in tracing all indirect costs. This complexity leads to increasing costs and an increasing potential for reductions in accuracy.

RESEARCH APPROACH/METHODOLOGY

In using secondary resources to assess environmental externalities associated with electric generation, the report uses the following five-step valuation process:

1. Ascertaining the pollution sources, the quantity of their harmful emissions and the constituents of the emissions that can cause environmental damages

2. Determining the dispersal of the emissions

3. Determining the populations exposed to the pollutants

4. Responses of the exposed populations to the pollutant

5. Determining the cost of that statistically expected outcome.

As mentioned, the report relies on numerous secondary sources of information for electric generation operations data and externality values.

CURRENT UTILIZATION

Currently, the report is used as a data and information resource among government agencies, utility planners, energy analysts and others involved in the study of environmental externalities from electric generating processes.

STRENGTHS AND WEAKNESSES

The Pace report is valuable in the sense that it is an extensive resource of data, technical information and methodological approaches for environmental externalities. Moreover, the report takes a sound analytic approach in identifying the parameters to bound the study and is articulate in its justification of those parameters. The report considers virtually the entire range of applicable resources and technologies. Some of these are presented in greater detail than others due primarily to a lack of available data.

The Pace report does not analyze the total fuel cycle and as such provides environmental cost estimates that are limited and potentially distorted. However, the report is an extremely useful starting point in the process of developing total fuel cycle analysis methodologies.

5. INTEGRATING ENVIRONMENTAL EXTERNALITIES INTO RESOURCE PLANNING AT NEW ENGLAND ELECTRIC

Author: Temple, Barker & Sloane (TBS)
Source Organization: New England Electric System (NEES)
Date Developed: 1989

PURPOSE

The purpose of this report is to document NEES methodology for incorporating environmental externalities into its resource planning process. NEES developed the methodology as part of its NEESPLAN II: 1990 and in response to Massachusetts D.P.U. 86-36-F, which ordered electric utilities in the state to consider environmental externalities in their planning processes. The objectives of the methodology are:

- Consistency with the state of the art, both in level of detail and degree of position
- Applicability to the range of options that would be considered as alternatives
- Objectives in application
- Consistency with NEES's planning structure
- Flexibility to be refined or replaced as NEES's experience with the topic grows.

The NEES team considered several alternative approaches being used to incorporate externalities. The Orange and Rockland rating and weighting approach was selected for modification to NEES's objectives.

FUEL CYCLE FRAMEWORK

NEES uses the same methodology for evaluating supply-side and demand-side options. The methodology is designed to be applied to all supply or demand technologies which NEES will need to evaluate over the near to long-term. A number of fuel cycle boundary issues were identified in developing the methodology. These included:

- The extent to which non-environmental externalities would be included
- Which stages of the fuel cycle to include
- How to efficiently categorize and assess the universe of environmental externalities.

The team conducted internal NEES interviews and group discussions, and reviewed alternative utility approaches to address these boundary issues. It was decided that only environmental externalities should be considered at this time, but the team indicated that non-environmental externalities are important and additional research will identify appropriate mechanisms for valuing and including them in planning. Until such mechanisms are developed, however, it was deemed inappropriate to include them. Moreover, the research that was performed identified the "operating" stages of the new resources as the primary stage of focus. Stages prior to operation are considered, as is decommissioning, yet the externalities associated with those stages receives lower priority. These decisions were driven largely by the difficulty in obtaining valid data for those stages. Specific "externality issues" evaluated include:

- Acid rain
- Global warming
- Land use
- Fuel issues
- Ozone
- Emissions to air
- Water use and quality
- Solid and hazardous waste
- Aesthetics
- Indoor air quality.

Within externality issues, there are "contributing factors" which make up the externality. For example, ozone is further broken out into VOCs, nitrogen oxides, and CFCs.

RESEARCH APPROACH/METHODOLOGY

The methodology uses a fairly straightforward worksheet approach. Externality issues are listed to the left of each worksheet and given a weight (i.e. global warming is weighted 9%). Within each externality issue, contributing factors are weighted (i.e. carbon dioxide is weighted 100% because it is the only contributing factor to global warming). To the right of each issue/factor is a 0 to 4 scale. Each issue/factor is rated 0 to 4 with 0 indicating the least environmental impact and 4 the greatest. The rating is multiplied by its weight to arrive at an issue score. The approach can be easily modified to include additional issues/factors or to eliminate existing ones. Different methods can be used to rate contributing factors. NEES uses different methods for rating contributing factors depending on the characteristic of the factor. The methods include:

- **Regulatory** - Derived from existing or potential legislation, to reflect the level to which the externality is within regulatory limits.

- **Range of Options** - Normalizes the ratings to cover a typical range of utility options.

- **Root Cause** - A more general assessment which is intended to "leapfrog" data and analytical problems.

- **Adjustment** - This method is used in conjunction with other methods to allow subjective adjustments to account for mitigating factors.

- **Grading** - Requires subjective assessments.

- **State of the Art** - Considers how well a factor is understood in rating.

- **Reference to Other's Work** - Uses ratings applied by others.

The list below shows each of the externaltiy issues and the methods used for rating their respective contributing factors.

Issue	Method
1. Acid rain	Regulatory
2. Global warming	Range of Options
3. Land use	Range of Options
4. Fuel issues	Root Cause
5. Ozone	Regulatory, Range of Options
6. Emissions to air	Regulatory, Root Cause
7. Water use and quality	Grading, Range of Options
8. Solid and hazardous waste	Range of Options, Adjustment
9. Aesthetics	Reference to Other's Work
10. Indoor air quality	State of the Art

Weights were applied to issues and contributing factors using one or more of various approaches. These included regulatory, expert polling, judgment, and multiplicative.

CURRENT UTILIZATION

NEES representatives were contacted in March 1993 to discuss the current status of this methodology. These representatives indicated that the methodology was used by NEES for approximately two years. The model was well received and reportedly adopted by other utilities. The used of the approach was discontinued upon passage of Massachusetts D.P.U. 91-131, which regulates specific externality values to be applied to emissions and makes the methodology irrelevant. The DPU values are being contested, and if regulations are revised NEES may revisit this methodology as an approach for assessing external impacts.

STRENGTHS AND WEAKNESSES

The NEES methodology provides a straightforward method to evaluate those externalities for which full-costing is difficult or unrealistic. It can be applied to any technology, and externalities that are assessed can be modified to meet user needs. Moreover, the level of assessment can vary by externality. For example, those externalities which can be quantified with greater validity can be weighted higher than those for which data are not available and which may require a more general method of rating. In addition, this approach can be implemented for valuing costs and benefits along the total fuel cycle to the extent to which qualitative/quantitative data or expert judgment are available.

6. SOCIAL COSTS OF ENERGY CONSUMPTION

Author: Olav Hohmeyer
Source Organization: Fraunhofer Institute, FRG
Date Developed: 1989

PURPOSE

The purpose of this effort was to develop an understanding of the magnitude of hidden costs associated with electricity production from conventional and renewable energy technologies and to evaluate the differences. The effort was commissioned because of an increasing understanding of the external costs associated with nuclear energy and combustion of fossil fuels. For example, social costs were borne by individuals outside the Chernobyl area for years following the nuclear accident there. In addition, more than 50% of trees in Germany have shown damages from fossil fuel combustion. The "questionable" reliance on internal cost mechanisms has driven analyses of the type Hohmeyer presents. The author believes that incorporating social costs will make renewable energy systems more competitive with conventional technologies and thus accelerate deployment and improvements in the technologies and their efficiencies.

FUEL CYCLE FRAMEWORK

This Hohmeyer study estimates the environmental and economic costs/benefits associated with electricity generation from conventional and renewable resources. While the focus is on the electric generation (conversion) stage, impacts associated with other stages of the fuel cycle are incorporated. These impacts are presented as "gross" social effects. They are not explicitly itemized on a stage-by-stage basis or considered as "fuel cycle" effects.

The impacts evaluated in this analysis included both environmental and non-environmental externalities and the direct and indirect impacts associated with them. Most of the impacts assessed are those that can be monetized or quantified. Specifically, Hohmeyer considered four primary areas of social costs. These included:

- Environmental effects, including effects on human health
- Depletion of non-renewable resources
- General economic effects, such as changes in gross value added or employment
- Subsidies paid by government agencies either directly or indirectly, including research and development on energy technologies.

In each of these areas, there are various single effects which comprise the gross effect. For example, specific environmental damages were estimated for noise, flora, fauna, materials damages, and climatic impacts resulting in human health effects, crop loss or flooding.

Hohmeyer considered a number of other social effects but did not include them in his analysis because they could not be quantified or monetized. These include:

- The psycho-social costs of serious illness or deaths as well as the costs to the health care system
- The environmental effects of the production of intermediate goods used for investments in energy systems and the operations of these systems
- The environmental effects of all stages of the fuel cycle (specifically in the case of nuclear energy)
- The full costs of climatic changes
- The environmental risks of routine operations of nuclear power plants
- Any hidden subsidies for energy systems provided under other titles.

The results of the analysis are considered minimum net external costs due to the fact that additional costs such as those listed above cannot be estimated with validity.

RESEARCH APPROACH/METHODOLOGY

The Hohmeyer approach compared the external costs of electricity using four classes of generating technologies as examples: wind energy, photovoltaics, nuclear reactors (excluding breeder reactors), and fossil fuel combustion.

The approach utilized an input-output model to estimate and forecast employment and trade effects. Each iteration included numerous assumptions for technical and economic forecasts of each of the technologies. A net-effect analysis was performed to assess the positive versus negative effects in arriving at the given output. Outputs consisted of forecasts for changes in savings, imports, gross value added, employment effects, and government costs due to unemployment.

In estimating environmental damages associated with these technologies, the author has used decision trees to identify impact pathways and cause-effect relationships. Impact pathways for each energy resource follow from the conversion stage and the technology used to the polluted media/pollutant and finally to specific environmental damages.

All estimates of damages/effects were based on the best available data on total impact (i.e. total environmental loss/effect, resource depletion, or economic effect). Monetized values were based on those data using the estimated percentage of the loss attributable to electric generation (i.e. for CO_2 pollutants, what percentage resulted from combustion of fossil fuels for electric generation).

In each case, a range of estimates was provided in deutsche marks (D) per kWh. Specific outputs included:

	Fossil	Nuclear	Photovoltaic	Wind
Environmental Effects	0.0114-0.0609	0.0120-0.12	(-)0.0044	(-)0.0001
Depletion Surcharge	0.0229	0.0591-0.0623	(-)0.0052-(-)0.0104	(-)0.0026-(-)0.0055
Goods/Serv. Publicly Supplied	0.0007	0.0011	--	--
Monetary Subsidies	0.0032	0.0014	--	--
Public R&D Transfers	0.0004	0.0235	--	--
Economic Net Effects	--	--	+0.0240-(+)0.0665	+0.0053-(+)0.0094
Avoided Costs	--	--	+0.0535-(+)0.1188	+0.0535-(+)0.1188
Total	0.0386-0.0881	0.0971-0.2083	+0.068-(+)0.171	+0.056-(+)0.123

CURRENT UTILIZATION

The results of Hohmeyer's work are being used to evaluate U.S.-based approaches for externalities assessments.

STRENGTHS AND WEAKNESSES

This study provides an extremely valuable resource of data on the environmental and economic costs/benefits associated with electricity generation. The data provide detailed estimates of specific types of impacts and how those estimates are derived. While the study is specific to the FRG, similar techniques can be undertaken in other countries, and/or the data can provide a baseline with which to evaluate other methodological outputs. The primary weakness of the study is that it only looks at the electric generation stage of the fuel cycle. It makes no attempt to consider or forecast internalized costs and does not perform a technology comparison based on total costs. It must be stated, however, that this was not the intent of the study or within its funded capacity.

The study relied on extensive amounts of data specific to the FRG. Although the quantitative and monetary results are based on the administrative and economic situation of Germany and are not directly applicable to other countries, the general approach is valid for any market-oriented economy. A similar national analysis for the U.S. would be dependent upon the same level and quality of economic/environmental impact quantifications. The data presented in most cases consist of ranges at the lower end of societal cost estimates.

7. COMMUNITY ENERGY CHOICES: THE GOAL PROGRAMMING CONCEPT AS AN ECONOMIC DEVELOPMENT ASSESSMENT TOOL FOR UTILITY/COMMUNITY-BASED ENERGY MANAGEMENT PROGRAMS

Source Organization: Iowa Association of Municipal Utilities; and Economic Research Associates
Date: 1988

PURPOSE

This study was performed to develop and test the use of a goal programming model. The specific application of the model is to help communities develop a strategy for economic development through energy efficiency.

The application of this model was in Iowa. The impetus for the project was the fact that the Iowa economy suffered through a cycle of stagnation and decline during the 1980s. As a result of this decline, Iowa suffered a net population loss of 80,000 (3 percent) between 1981 and 1987. In addition, small businesses in nearly all sectors of the economy left the state or closed down. This impacted local utilities, forcing them to spread their fixed costs to fewer ratepayers. In addition, much of the energy costs incurred by Iowans left the local economy. These included payments for gas, coal, and hydroelectric power. If local resources are used to reduce energy payments in general and payments to external sources in particular, total community expenses decline, more dollars are available to reinvest in the community, and payments for local resources for energy efficiency that substitute payments for external energy resources also are reinvested in the economy. The state sought to reduce its use of energy and substitute local resources for energy imports to the state. The goal programming concept was designed to achieve this.

FUEL CYCLE FRAMEWORK

While this was not a fuel cycle analysis, it included evaluations of a number of the impacts that can be included in a fuel cycle analysis. The impacts evaluated were strictly economic. Environmental impacts were not evaluated. This study did not make a explicit effort to look at the fuel cycle of a technology; however, particular stages of the fuel cycle were implicitly evaluated. These included manufacturing and installation of energy-efficient devices. The study evaluated impacts associated with 15 efficiency technologies/activities. These were:

1. New energy-efficient homes
2. Weatherization in existing homes
3. Installation of energy-efficient appliances
4. Installation of efficient residential lighting
5. Use of home water heater blankets
6. Setting thermostats back
7. Replacing home air conditioners
8. Rewinding industrial motors

9. Installation of cogeneration units
10. Installation of commercial insulation
11. Weatherstripping businesses
12. Using energy management systems
13. Using efficient air conditioners
14. Replacing business lighting
15. Replacing street lighting.

RESEARCH APPROACH/METHODOLOGY

Three specific tasks were performed to adapt the model to energy planning for a test case small town in Iowa. In the first task, goals were defined and prioritized. The goals identified in this study, in order of importance were:

1. Employment gains - 20 or more job years
2. Utility bill savings - $100,000 or more annually
3. Investment cost - $300,000 or less
4. New economic activity - $1.5 million
5. Payback period - Less than five years.

The second task was to create a brief economic profile for each of the communities to be analyzed. Finally, data are collected on the energy technologies to be analyzed.

Collected data were input and the model was run to solve for the set of goals. Input data include estimated investments in six of the 15 energy efficiency measures.

1. Weatherization in existing homes ($250,000)
2. Installation of energy-efficient appliances ($1,250)
3. Installation of efficient residential lighting ($8,000)
4. Use of home water heater blankets ($24,000)
5. Setting thermostats back ($3,750)
6. Weatherstrip businesses ($12,500).

This goal programming tool is a mathematical model. Similar to the linear programming algorithm, it solves for a set of choices that best meets multiple goals. It is different from linear programming in two ways. Where linear programming seeks to achieve one objective, goal programming seeks to satisfy multiple objectives. Second, goal programming operates on the principle that better decisions can be made if emphasis is given to achieving minimum levels of satisfaction for multiple objectives rather than maximizing a single gain.

The results of the model showed that with the level of investment specified for each of the six technologies, the employment and investment cost goals were met. The energy savings, economic activity, and payback goals were exceeded.

CURRENT UTILIZATION

This particular application was for the Iowa Association of Municipal Utilities. The model has been enhanced and is now available in a goal programming software package called OPTIONS. It has been used by local jurisdictions and municipal utilities in Iowa for planning and analysis purposes.

STRENGTHS AND WEAKNESSES

This decision analysis, goal programming model focuses strictly on economic factors. It helps fill a gap that exists in many utility decision-making processes. This is a technique that can be considered for augmenting many of the environmental modeling activities currently in place. Its application in Iowa during an economic downturn revealed the public and political forces impacting decision making. To the extent that local jurisdictions or states can reduce their external dependence on energy resources, promote local economic growth, maintain energy services, not hinder national energy, economic or environmental objectives, or impinge on the economic or environmental well being of another state, this appears to be a valuable strategy.

8. MICHIGAN ELECTRICITY OPTIONS STUDY (MEOS)

Source Organization: Michigan Department of Commerce
Date: 1987

PURPOSE

The MEOS represents a cooperative effort to strengthen and broaden the electric resource planning capabilities in Michigan. Its primary purpose was to develop tools and expertise required to perform integrated assessments of electricity resource options. Specifically, trade-offs associated with a wide range of supply-side and demand-side options were identified and evaluated. Elements evaluated included cost, potential for reducing electric demand or increasing generation capacity, reliability, environmental impacts and socioeconomic effects.

FUEL CYCLE FRAMEWORK

There were 13 supply options and 19 demand-side resources evaluated in this analysis. They included options for life extensions for existing plants, fuel conversions for existing plants, transmission improvements, power purchases, lighting, building shell improvements and others. This activity was part of an integrated planning process in the state and not an explicit fuel cycle analysis. The total fuel cycle for these technologies was not evaluated. This decision was made due to the extensiveness of data requirements and the fact that many fuel cycle impacts occur outside of Michigan. A general assessment of impacts associated with the exploration and transportation stages of the coal, gas, oil and nuclear fuel cycles was made and briefly included in the analysis.

The MEOS included analysis of environmental and socioeconomic costs. The extent of that analysis, however, was limited by the availability of data. Examples of "social costs" that were analyzed include:

- Selected air emissions
- Waste disposal
- Indoor air quality.

Examples of "social costs" that were not analyzed include:

- Human health impacts from environmental emissions
- Impacts to agricultural products resulting from environmental emissions.

RESEARCH APPROACH/METHODOLOGY

An Integrated Planning Model (IPM) was developed to conduct the MEOS integrated analysis. It is a computer-based linear programming model designed to select a mix of supply and demand options which would satisfy an assumed set of electricity requirements at minimum economic cost. The IPM does this by minimizing the discounted sum of capital and operating costs over a 30-year planning period, subject to specified scenario and operating constraints. The IPM consists of two submodels:

1. **Integrated Resource Planning Model** - This uses mathematical algorithms to select investments in resource options and to dispatch these options in such a way as to minimize long-term systemwide costs. Model outputs include the amount and timing of option investments; the capacity and generation from supply-side options; the capacity and generation displaced by demand-side options; fuel use by type; total capital and operating costs; power plant emissions; and other cost and performance information.

2. **Electric Utility Financial Model** - This uses the outputs from the first model to develop financial and rate information and accounting indices (interest rate coverage ratios) which are used as proxies for regulatory accounting measures. Outputs of this model include total revenue requirements, income statements, balance sheets, and average electricity rates.

The IPM generates numerous data outputs which can be used in the overall decision-making process and in further evaluation of the resource mix that the model identifies. Examples of data outputs include:

Overall System Information
- System capacity and demand
- Peak load displaced
- Out-of-state purchases and sales
- Transmission and distribution losses

Capacity and Energy Generation by Resource Category
- Capacity and generation by fuel type
- Non-utility capacity and generation
- Displaced non-utility generation

Resource Option Additions
- By year, utility, non-utility and demand-side options added
- By year, the percent of demand-side option programs selected, and the cumulative and incremental energy displaced

Economic and Other Costs
- Environmental measures by year and type of pollutant
- Total fuel cost by plant type and year
- Demand-side option costs by program, sector, and type of costs
- Marginal energy costs by load segment, year, and season

Two approaches were combined to assess environmental impacts associated with each of the technology options. The first approach was to perform a quantitative assessment of environmental characteristics or outputs from each resource option; and then to tabulate or aggregate those outputs.

These data were combined with a qualitative environmental assessment based on previous research and expert judgment. A working group approach was implemented to perform the qualitative assessment. Each working group used the environmental output data augmented with professional expertise and other available information to draw conclusions on the overall environmental and socioeconomic impacts associated with the supply-side and demand-side options. Individual working groups were conducted for each category of technology options.

CURRENT UTILIZATION

This was a large one-time study conducted with the Michigan Public Service Commission, Michigan Energy Office, and others. It was the first time that a systematic approach was used to evaluate DSM options. The effort was successful in terms of teambuilding and bringing together diverse interests in working group formats. Results of the analysis and the model outputs were used to assist energy decision making in the state.

STRENGTHS AND WEAKNESSES

One of the strengths of the Michigan approach is that it combined a quantitative approach with a qualitative approach to evaluate the results. Through the working group, the qualitative approach brought together a diverse set of experts and interests to ensure that a wide range of views and issues could be addressed. The primary drawback of the approach was that only minimal social costs were identified and evaluated.

9. ESTIMATING ENVIRONMENTAL COSTS AND BENEFITS FOR FIVE GENERATING RESOURCES

Author: ECO Northwest, Ltd., Shapiro and Associates, Inc., and Seton, Johnson, and Odell, Inc
Source Organization: Bonneville Power Administration
Date Developed: 1986

PURPOSE

The Bonneville Power Administration (BPA) commissioned this effort to develop monetized estimates of significant environmental effects likely to accompany the use of specific generating technologies. The purpose was to develop a generic methodology using available models and data resources to estimate environmental costs associated with each of the resource options. The methodology was designed to allow BPA to assess future environmental costs in levelized mills per kWh for alternative generating facility sizes, types and locations.

FUEL CYCLE FRAMEWORK

This effort evaluated environmental effects for five types of electric generating resources/technologies. These were:

1. Cogeneration from biomass (12 MW)
2. Cogeneration from municipal solid waste (10MW)
3. Geothermal (10 MW)
4. Solar Central Stations(100 MW, solar thermal and photovoltaic)
5. Wind (35 MW).

BPA identified a general five-stage fuel cycle. The stages are: 1) extraction, 2) transportation, 3) construction, 4) operation and 5) decommissioning. The analysis of impacts within each of these stages varies by technology. For example, solar and wind resources have no extraction or transportation component in the BPA fuel cycle. Geothermal resources have a minimal transportation component because the resource is typically used on the site where it is extracted. Thus, BPA does not consider impacts associated with those stages for those technologies. In addition, BPA does not include the effects associated with the manufacture of materials and equipment used in the facilities (e.g. solar panels) or the transmission of that energy once it is generated.

BPA included in its analysis a very broad array of potential fuel cycle impacts. These included:

- Air quality
- Water quality, quantity and use
- Flora and fauna
- Noise
- Land use

- Natural resources
- Risk of explosion and hazardous emissions
- Socioeconomic characteristics
- Occupational health and safety
- Aesthetics
- Light and glare
- Recreation
- Cultural resources.

Within each of these categories, there are specific impacts which can be evaluated.

RESEARCH APPROACH/METHODOLOGY

The overall methodology that BPA used in implementing its analysis followed six general steps, as follows:

1. Characterizing the generic generating resources by type, size, and location

2. Identifying and describing the potential environmental effects associated with each phase of the fuel cycle of a generating resource, including extraction, transportation, construction, operation, and decommissioning

3. Determining which effects are significant enough to warrant detailed economic analysis

4. Describing and estimating the magnitude of the significant environmental effects

5. Estimating the economic value of the physical effects

6. Calculating the present value of the expected environmental effects for each generating resource.

As discussed above, five generating resources were identified. Operating characteristics were assumed in some detail, including capacity factors, plant size, average annual output, and expected plant life.

In addition, the range of *potential* impacts associated with each resource was identified. BPA then implemented a screening system to reduce the number of potential impacts to only those significant enough to be evaluated in the model. BPA used a common definition of significance: "an effect is significant if it is likely to contribute a significant percentage of total environmental effects." Those effects determined insignificant would be incorporated only by means of a general discussion on how they affect the total environmental impact. The three-step screening process used expert judgment and experience to:

1. Determine whether the effects occur at all
2. Assess whether the existing effects were environmentally significant
3. Assess whether the environmentally significant effects were economically significant.

When the magnitude of an effect was uncertain, those effects remained on the list. Similarly, if an effect had negligible environmental impacts, yet public concern was high, that effect also was included in the model. The result of the screening identified seven types of affects which had the potential for resulting in significant environmental costs or benefits. These included:

- Air quality
- Water quality
- Land productivity
- Solid waste
- Endangered species
- Aesthetic qualities
- Cultural values.

BPA used various modeling techniques and approaches to estimate impacts for low, expected and high-case scenarios.

In analyzing air quality, emissions from the five facilities were estimated. A simplified Gaussian plume model with assumptions about population density was then used to estimate likely exposures. Available information about dose-response functions used to estimate final effects on health and dollar values was then assigned, based on a thorough review of relevant economic literature on the value of increased risk of mortality and morbidity.

The study estimated that the expected value of effects on water quality approach zero. The cost of externalities on water supplies was assumed to be effectively the cost of treatment over a five- to ten-year period. When standard treatment and other mitigation costs were discounted using a rate of 3 percent, the cost approached zero in most cases. Moreover, the analysts felt that the likelihood of contamination was negligible.

Estimating and valuing the potential changes in land productivity was limited to the changes that might result when biomass fuel is removed from the forest to fire a 12 MW biomass cogenerator, rather than burned as slash. Two techniques were used to estimate the value. The first considered the cost of mitigation (i.e. the cost to restore nutrients in the land) and the marginal cost of fertilizer was used as the value. The second used the estimated present value of an acre of timber as a result of estimated changes in productivity. Both techniques showed the value of land productivity impacts to be negligible.

In the absence of better data and models, the valuation method for the environmental cost of solid waste was assumed to be the avoided cost of landfilling. In terms of aesthetic qualities, cultural values and endangered species, analysts felt that the methodologies and resources available were insufficient to quantify these impacts.

All estimates of the value of different environmental effects were then discounted over the expected plant life using a 3% discount rate (BPA standard). Of the potential significant externalities analyzed, air emissions were found to have the highest cost. All of the effects that were found to be significant occur only during plant operation; no significant impacts were found during the construction stage of the fuel cycle.

BPA did not perform any primary data research. Existing data resources and models were used to generate estimates for the BPA case studies. All environmental cost estimates were levelized using a discount rate of 3%. Net benefits were illustrated as negative costs. Much of the data used in the analysis of cogeneration and geothermal resources were based on known data from existing generating stations in Oregon and California.

The analysis showed that only the effects on air quality will have a significant impact on the levelized costs of the five resources evaluated. These are primarily health impacts. Some benefits were identified, such as waste reduction in the cogeneration of municipal solid waste. The solar and wind resources were found to have insignificant environmental impacts.

CURRENT UTILIZATION

The results developed in this analysis continue to be used by BPA. They support overall environmental cost evaluations performed as part of resource planning. The results are also used in developing externalities adders, which are used in resource selection.

STRENGTHS AND WEAKNESSES

A number of beneficial aspects of this effort can be translated to other approaches. The screening process is a straightforward method for focusing the specific impacts to be evaluated. In addition, the BPA study utilized specific techniques which could apply in evaluating externalities in the conversion or other stages of the fuel cycle. The BPA study incorporates a number of assumptions which should be considered prior to defining boundaries in implementing a fuel cycle analysis. Moreover, it utilizes data sources and modeling techniques which could be useful in a fuel cycle analysis. One drawback of the BPA effort is that while it considers various stages of the fuel cycle, impacts are not assessed explicitly on a stage-by-stage basis.

10. SOCIOECONOMIC IMPACTS OF POWER PLANTS

Author: Denver Research Institute and Browne, Bortz & Coddington
Source Organization: Electric Power Research Institute
Date Developed: 1982

PURPOSE

The purpose of this study was to develop an understanding of the socioeconomic impacts from power plant siting, construction and operation. The methodology for performing this included a review of 12 case studies of different power plant projects. EPRI funded the effort because of a growing concern and regulatory response to socioeconomic impacts. EPRI felt there was a lack of knowledge to help predict impacts. The specific objectives were:

1. To develop a comprehensive data base on the socioeconomic impacts of power plant construction

2. To evaluate approaches to socioeconomic impact assessment

3. To provide a better understanding of the extent and nature of these impacts.

FUEL CYCLE FRAMEWORK

This study was a life cycle analysis of power plant socioeconomic impacts. The emphasis was on coal-fired power plants which represented 9 out of the 12 case studies. One study plant was oil-fired and two were nuclear.

The case studies accounted for multiple stages of the fuel cycle and focused primarily on the power plant rather than the resource. Stages evaluated included siting, construction and operation stages of the power plant. It did not account for decommissioning.

The study established several sets of boundaries. The initial set established geographical boundaries as study parameters. A geographical boundary of 60 to 70 miles (95 to 110 kilometers) was established based on analysis of historic data/patterns for a series of associated subfactors, such as commuting time for employees, physical barriers (i.e. lakes, deserts, bridges, traffic), population concentrations, labor union jurisdictions, and indigenous regional labor force.

A number of direct, indirect and secondary impacts were analyzed to translate the causal factors (power plant construction and/or operation) into local area impacts. The direct impacts focused on public sector impacts; housing impacts; and family, population and employment effects. The indirect impacts focused on employment factors such as in-migration and secondary employment. Secondary impacts included income effects, retail effects, and local purchasing by the plant.

RESEARCH APPROACH/METHODOLOGY

The research project was carried out in two phases:

> **Phase I** - Review of present impact assessment models; review of the socioeconomic impact assessment literature; development of a structure for case study analysis; identification of study phenomena; selection of case study locations; and preparation of a Phase I report. Descriptions of most of the models reviewed follow this profile. These models include: REAP, SIMPACT, BREAM, BOOM I, HARC and Social Economic and Assessment Model. No one model was selected, but each of these were used in helping develop a consistent data base relative to socioeconomic impacts and factors affecting their distribution.
>
> **Phase II** - Preparation of 12 case studies, analysis of case study data, and preparation of case study reports.

The analysis relied on historical data associated with each of the 12 power plants to complete the case study and to project direct and indirect impacts. For data such as project timing, wages, capital investment, and local purchasing estimates, performance data were utilized.

Anticipatory studies were prepared for relatively straightforward projections of impacts based on only one scenario. However, the use of computer-assisted models to perform multiple scenarios was suggested. This would help handle unanticipated events, changes in plans, or data uncertainty.

CURRENT UTILIZATION

The study was a 1982 EPRI effort to respond to societal and regulatory concern over the socioeconomic impacts of power plants. Its current utilization is primarily as a resource document.

STRENGTHS AND WEAKNESSES

The primary weakness of this study in terms of performing a total fuel cycle analysis is that it makes no attempt to investigate the direct or indirect environmental impacts for plant siting, construction and operation. However, the study is impressive in that it utilizes a number of approaches to develop comprehensive social impact estimates, such as employment, housing, etc., which are lacking in many studies on the externalities of energy production.

MODEL DESCRIPTIONS

The following are descriptions of selected models reviewed during this project. A brief overview of these models is relevant for the compendium for the same reasons that they were reviewed for

EPRI initially. These models represent tools and approaches which could be modified and assess the socioeconomic impacts of power plants. These models are: REAP, SIMPACT, BREAM, HARC, Social Economic and Assessment Model (SEAM), Socioeconomic Impact Assessment (SIA) and BOOM I.

1. REAP ECONOMIC - DEMOGRAPHIC MODEL

PURPOSE

Developed by Authur D. Little and North Dakota State University for the state of North Dakota, 1979. This is a economic and demographic model for performing assessment of integrated socioeconomic impacts associated with various forms of development in North Dakota. It has been used in developing environmental impact statements. It was evaluated for use as a tool for assessing the socioeconomic impacts of power plants.

RESEARCH APPROACH/METHODOLOGY

The model is designed to assess socioeconomic impacts from various forms of development. This could include hydropower project development or other large-scale development projects. To track and account for these impacts, the REAP model contains six major interactive components. These are:

1. **Economic module** - An input-output model is used to project employment, income, and gross business volume under both baseline and impact conditions.

2. **Demographic module** - A cohort-survival routine projects population and labor force using vital rates and non-employment-related migration from local and state data.

3. **Interface module** - This module compares labor demand and availability by job type and computes needed in- or out-migration. Worker characteristics from survey data determine population changes due to migration.

4. **Residential Allocation** - This is a gravity model with separate coefficients for each worker type. It allocates project related workers to city and county of residence. Baseline workers are allocated based on historical trends.

5. **Service requirements model** - National or state ratios are applied to in-migrating population to estimate requirements for education, medical, and criminal justice services. Housing patterns of project related workers as determined from survey data are used to project demand for housing.

6. **Fiscal Impact** - Cost functions for capital and operating costs of various services are applied to in-migrating population. Revenue functions based on additional income, retail sales, real property, business volume or population.

DATA CHARACTERISTICS

Data requirements to implement the model were extensive. Data outputs included projections for:

- Employment by type for multi-county regions, counties and cities
- Population for counties, cities and regions. Populations also were provided by age and sex for counties.
- Gross business volume, personal income and retail sales for regions (functional economic areas)
- School enrollments by district
- Requirements for medical and criminal justice services by region
- Housing requirements by type for counties and cities
- Public sector costs and revenues by type for cities, school districts, counties and state government.

STRENGTHS AND WEAKNESSES

The study developed comprehensive social impact estimates such as employment, population effects, public services, public revenue, private income and business activity. These are crucial, yet lacking in many studies on the externalities of energy production. In addition, the study provided a wide range of outputs with considerable geographic detail. Multiple projects were easily handled and the user could alter a number of parameters, including project schedule, inflation rate, and rates of several taxes. The ability to readily alter parameters permitted analysts to assess the level of uncertainty associated with various impact estimates. The primary drawbacks were that data requirements were extensive. This would be a particularly important limitation if the model were to be modified for application on a national level. In addition, computer CPU and storage requirements were significant at the time this model was first implemented. No indication was provided as to labor, time and cost requirements. To modify this model for national-level analysis would require significant effort, however, and these requirements can be inferred to be extensive.

2. SIMPACT

PURPOSE

This model was developed by Arthur D. Little for U.S. Steel to determine socioeconomic, economic and environmental impacts resulting from new plant projects during their construction phase and for ten years of operation. One specific application of the model was to assess a U.S. Steel project and its impacts on the Ohio-Pennsylvania region. There are no known current uses.

RESEARCH APPROACH/METHODOLOGY

The model is an integrated impact assessment input-output design, which has been considered for use in determining socioeconomic impacts of power plants. It can be used as a component of a broad-based fuel cycle analysis. Model parameters include a range of direct and indirect socioeconomic impacts. These include employment, demographics, infrastructural impacts, public sector impacts, and environmental impacts.

This model develops projections for an impact area and 11 sub-areas. It contains seven modules and provides outputs for associated characteristics of socioeconomic impacts. The seven modules and associated outputs are:

1. **Economic-Demographic** - Uses multipliers from regional input-output tables and population-to-employment ratios to project employment, payroll, gross business volume, investment, and land requirements for 18 sectors. Demographic projections include 20 occupation groups, seven income categories, six age groups and six household size categories.

2. **Private Infrastructure** - Includes projections of housing requirements (10 categories) and health facilities (three categories).

3. **Social Infrastructure** - Includes projections of requirements for schools, fire protection, law enforcement and streets.

4. **Utility Infrastructure** - Includes projections for requirements for water, sewer, and solid waste facilities.

5. **Physical Impacts** - Projects five categories of air emissions, wastewater by economic sector, land requirements and runoff water.

6. **Fiscal Expenditures and Finance** - Projects public service costs for each local jurisdiction affected by the project.

7. **Fiscal Revenue** - Projects changes in revenues for each local jurisdiction and for state government.

DATA CHARACTERISTICS

The model requires extensive collection and analysis of local data in implementation of site-specific analyses. It generates a strong range of data outputs which include:

- Employment, payroll, gross business and volume and investment for 18 sectors
- Population by age, income, occupation and household size
- Ten categories of housing requirement
- Public service requirements
- Public sector costs and revenues
- Environmental effects, including land requirements, air pollutants, emissions, waste-water runoff, and water.

STRENGTHS AND WEAKNESSES

One of the major advantages of the model is that it emphasizes detailed disaggregation of projected impacts. Moreover, it includes broad coverage of economic, demographic, public service, fiscal and environmental impacts. Conversely, implementation of this model may require extensive collection and analysis of local data and the incurrence of that expense. In addition, the model is limited in that its projection horizon is short -- ten years beyond construction. As with the other socioeconomic impact models, however, SIMPACT provides a means of projecting impacts beyond environmental characteristics. While the 10-year horizon may be short (especially when considering greenhouse gas emissions) the model still provides a basis for analyzing incrementally timed project (or fuel cycle) impacts.

3. BUREAU OF RECLAMATION ECONOMIC ASSESSMENT MODEL (BREAM)

PURPOSE

This was developed by Mountain West Research Inc. for the U.S. Bureau of Reclamation, Denver, Colorado, 1978. The model has been used to ascertain the economic and socioeconomic impacts of several Bureau of Reclamation projects, including the LaVerkin Springs Water Quality Project.

RESEARCH APPROACH/METHODOLOGY

The model contains five major submodules:

1. **Demographic** - This module uses a cohort-survival technique with county or state vital rates adjusted for national trends. Race-specific vital rates are allowed.

2. **Economic** - In this module, income multipliers are used to estimate non-basic income and employment. Multipliers are derived from county-level data with productivity adjustments based on national trends.

3. **Construction Worker** - This module allows for separate characteristics and separate demographic treatment of temporary construction workers.

4. **Labor Market** - Balances supply of labor from cohort-survival module, and demand for labor from economic module. Unemployment controls in-or out-migration. Migrants' characteristics are from surveys or regional data. A non-employment related migration component can be specified.

5. **Spatial Allocation** - Uses gravity model to allocate project workers to communities. Other population components are allocated using historical shares or community growth trends.

DATA CHARACTERISTICS

Implementation in a given area requires substantial data collection and the model does not include public service requirements or fiscal impact requirements. Specific model outputs include:

- Employment by type, at the county and city level
- Income at the county level
- Total population, as well as population by age and sex at city and county level.

STRENGTHS AND WEAKNESSES

The model can be useful as part of total fuel cycle analysis for specific power plant, refinery, barge terminal or other relevant energy facility construction studies. In addition, it provides detailed economic and demographic projections for local areas. Economic analysis accounts for inter-county dependencies and the hierarchy of trade centers. The primary weakness of this study in terms of performing a total fuel cycle analysis is that is makes no attempt to investigate the direct or indirect environmental impacts for plant siting, construction and operation. In addition, its analysis for socioeconomic impacts executes for a maximum of two counties only in any given run.

4. HARC, BATTELLE HUMAN AFFAIRS RESEARCH CENTERS

PURPOSE

This model was developed by Battelle for DOE as part of nuclear waste repository site identification and development activities. It assessed the potential socioeconomic impacts resulting from alternative nuclear waste repository siting activities.

RESEARCH APPROACH/METHODOLOGY

The model emphasizes the demographic effects of large-scale projects and consists of five major components. These include:

- A demographic component where a cohort-survival procedure was used to project baseline population.

- An economic component where employment multipliers were used to project non-basic employment.

- A labor market component where local labor availability was computed using national labor force participation rates. The comparison of labor supply and demand leads to estimates of the number of required in-migrating workers. Labor force turnover was also simulated, leading to additional in- and out-migration throughout the period of project operation.

- A special allocation component using a gravity model to allocate workers between site county and surrounding counties. The factors considered include distance, present population and housing availability.

- A public and social service component. Service requirements are estimated by applying given standards to projections of project-related population.

DATA CHARACTERISTICS

Examples of model outputs included population by age and sex, county-level employment by type, and public and social service requirements. Model projections were given at five-year intervals.

STRENGTHS AND WEAKNESSES

The model's demographic analysis took explicit account of work force turnover, and geographic allocation of project workers takes housing availability into consideration. In addition, the study can potentially provide insights into development of a technique for estimating some of the socioeconomic impacts through the fuel cycle, and in particular through the fuel cycle of large-scale energy production facilities. These socioeconomic impacts and population effects are unaccounted for in many of the current techniques addressing environmental impacts of electric generation or specific energy technology fuel cycles.

Some major weaknesses of the model included the fact that projections are provided only at five-year intervals and only for a given county of interest. Moreover, the use of national labor force participation rates may be unrealistic for some rural areas.

5. SOCIAL AND ECONOMIC ASSESSMENT MODEL

PURPOSE

The model was developed by Argonne National Laboratory in 1978. This was a national-level model developed by Argonne to assess the social and economic impacts associated with major development projects. The model was applied to assess several projects nationwide, including power plant construction and operation projects in West Virginia and North Dakota.

RESEARCH APPROACH/METHODOLOGY

The model contained a data base for all U.S. counties, as well as four major modules. The modules include:

- Impact projections using employment multipliers, and construction worker characteristics
- Spatial allocation using linear programming algorithms and data from construction worker profiles
- Public costs with national and regional service requirements standards applied to the in-migrating population and costs calculated from service requirements
- A demographic (cohort-survival) module.

DATA CHARACTERISTICS

Very little local, site or project-specific data are required. Specific data outputs of the model include direct and indirect employment by county and subcounty areas; county-level population characteristics, including age, sex and race; available labor force by county; housing requirements by county and subcounty; and public sector costs and service requirements.

STRENGTHS AND WEAKNESSES

The study can potentially provide insights into development of a technique for estimating some of the socioeconomic impacts through the fuel cycle and in particular through the fuel cycle of large-scale energy production facilities. These socioeconomic impacts and population effects are unaccounted for in many of the current techniques which address environmental impacts of electric generation projects or specific energy technology fuel-cycles. The Argonne model contained a nationwide data base which allowed for rapid implementation in any area. Data research and input activities were further streamlined due to the fact that very little local or project-specific data were required.

While there are some advantages to utilizing a nationwide data base, this aspect of the model also leads to one of its primary weaknesses. For example, the use of national data or standards (i.e. public service needs) may produce unrealistic results for some local areas or projects.

6. SOCIOECONOMIC IMPACT ASSESSMENT: A METHODOLOGY APPLIED TO SYNTHETIC FUELS

PURPOSE

This was an integrated impact assessment model developed for DOE. Its intention was to construct a "cookbook" approach for projecting and analyzing community development in mining regions. The model was used to estimate community, county, state and regional impacts from mining projects. It was used specifically for areas in Indiana, Illinois, and Kentucky.

RESEARCH APPROACH/METHODOLOGY

This was a community development model which consists of author-specified ratios and standards taken from mining-dominant counties or large-scale energy construction projects. These were then applied to estimate economic, demographic, social, land use, and fiscal impacts associated with development projects.

DATA CHARACTERISTICS

Specific model outputs include:

- Employment impacts such as secondary employment, employment income, per-capita and per-household income, retail sales and service receipts.

- Demographic and social impacts, including total population, school enrollment, health needs, housing requirements, protective services and other social services.

- Land use impacts such as land requirements for commercial, industrial and residential development, schools, parks, open space and other community facilities.

- Local government impacts, including capital and operating costs for public facilities, roads and utilities, and public services. The model also provides estimates for property taxes and other local revenues likely to be generated by private residential and non-residential development.

STRENGTHS AND WEAKNESSES

No computer is necessary and data research and implementation processes are not labor intensive. The study can potentially provide insights into development of an cost-effective technique for estimating some of the socioeconomic impacts through the fuel cycle of large-scale energy production facilities. These socioeconomic impacts and population effects are unaccounted for in many of the current techniques that address environmental impacts of electric generation projects or specific energy technology fuel cycles.

The model was easy to apply and no computer was necessary. The model permits the user to refine subelements so it can be applied to site-specific assessments. The basic data source was the Bureau of Census. The data were consistent, accessible and economical to obtain.

The primary weaknesses of the model were that impact estimates were gross rather than net impacts. For example, it does not provide a quantitative estimate of population influx, net growth in secondary economic activity, increases in capital spending, debt service or local revenues. The relationships between variables are static and the model does not estimate impacts for multi-county regions or municipalities.

7. BOOM I MODEL

PURPOSE

Developed at Los Alamos National Laboratory in 1976, this model incorporates systems dynamics features to simulate interactions among key subsectors and variables. Examples of past applications include an integrated impact assessment at Rock Springs, Wyoming, and analysis for coastal zone impact.

RESEARCH APPROACH/METHODOLOGY

The model contains approximately 48 parameters organized into the following five major subsectors:

- **Power Plant** - Workforce and construction cost data are used to calculate secondary employment and changes in the tax base.

- **Retail Trade and Service** - Investment determines service employment and depends on income and distance from trade centers. Adverse boom town conditions (shortages of housing and public facilities) may constrain investment.

- **Housing** - The need for mobile and permanent housing is determined by workforce characteristics and preferences. Construction of permanent housing may be constrained by adverse boom town conditions.

- **Migration** - The number of in-migrants depends on employment and the fraction of jobs held by heads of households. Employment in other basic sectors is assumed constant. Average family size of construction workers may decline under adverse boom conditions.

- **Public Sector** - Aggregate public service capital per capita requirements determine public costs. Investment in plant, housing and retail sector determines revenues. Bonding and tax rate changes are incorporated.

DATA CHARACTERISTICS

Specific outputs of the model include employment, housing and population for the community being analyzed; aggregate public service costs; aggregate local tax revenue; aggregate state transfers; and capital requirements, bonding capacity and local tax rate.

STRENGTHS AND WEAKNESSES

Primary strengths of the model include limited requirements for local data. It includes a number of important interrelationships among sectors. For example, construction worker productivity is a function of adverse boom town conditions. The numerous feedback mechanisms in this model are one of its major strengths and may enable more realistic estimates of some impact dimensions.

The primary weakness of this study in terms of performing a total fuel cycle analysis is that it makes no attempt to investigate the direct or indirect environmental impacts for plant siting, construction and operation. In addition, outputs apply only to a single community. There is no spatial allocation of impacts, and some key parameters are based on judgment or intuition.

However, the study is impressive in that it utilizes a number of approaches to develop comprehensive social impact estimates such as employment, public services, public revenue, private income and state transfers, which are lacking in many studies on the externalities of energy production.

11. FUEL CYCLE ANALYSIS FOR FOSSIL ENERGY SYSTEMS: COAL COMBUSTION

Author: W.L. Greenstreet, R.L. Carmichael
Source Organization: Oak Ridge National Laboratories (ORNL)
Date Developed: 1981

PURPOSE

This report was prepared by ORNL for DOE. It is a compendium of information available to describe the coal fuel cycle. The objectives of this analysis were to 1) examine in detail each of the elements of the fuel cycle for coal combustion, and 2) assemble information on the technological status, economics, and efficiencies for coal combustion technology.

The primary overall intent of this effort was to provide a basis for identifying issues and to establish needs and priorities for research, development and demonstration. The report does not project external fuel cycle costs.

FUEL CYCLE FRAMEWORK

This study overviews the coal combustion fuel cycle in the traditional sense. While it provides insights and techniques for analyzing processes and internalized costs along the fuel cycle, it does not discuss the "total" fuel cycle. The stages of the fuel cycle that were covered include:

- Coal Mining: exploration, underground mining, surface mining, and surface mine reclamation.
- Coal Transportation: rail, truck, barge, slurry pipeline.
- Coal Preparation.
- Direct Combustion: conventional and fluidized bed combustion.
- Environmental control: for coal mining, preparation and transportation; conventional and fluidized bed combustion. This includes waste disposal and/or utilization.

Each of these stages and the technology options within them are described in detail and internalized costs are included. A variety of external impacts are discussed in this report. These vary from stage to stage. These impacts are not quantified in this report.

RESEARCH APPROACH/METHODOLOGY

For each stage of the coal combustion fuel cycle, ORNL has described in detail the activities that take place for each of the technology options available for that stage (i.e. rail, truck, barge or slurry pipeline within the transportation stage). This includes a brief review of material available to evaluate processes and activities within that stage and an examination of issues and problems associated with that stage. For each stage, economic data from secondary sources are provided.

This effort also included energy requirements within each stage of the fuel cycle. This was performed to evaluate the energy efficiency of various options within each stage.

Environmental impacts associated with each of the technology/process options were discussed in general, but estimates were not provided. Nor were sources of information assessed.

DATA CHARACTERISTICS

This report relies on a number of secondary sources for internalized fuel cycle costs. Data from these sources are presented in the report. This effort did not seek to generate new data or develop projections and no new data are presented.

CURRENT UTILIZATION

This report has primarily been used as a reference document to identify research needs for fuel cycle analysis, as well as to obtain detailed characterizations of the stages of the coal fuel cycle and the technologies and processes used in the exploration, processing and combustion of coal.

STRENGTHS AND WEAKNESSES

This report does not assist directly in the evaluation or body of information on external impacts in the coal fuel cycle. It is, however, a highly detailed description of the fuel cycle and each of the various technologies and processes that can be used within that fuel cycle. This can be highly beneficial in framing a fuel cycle analysis effort. In addition, it identifies a number of potential data sources for quantifying coal fuel cycle activities and costs.

In addressing externalities, the study discusses the technology and internalized cost aspects of environmental control measures, as well as waste disposal and/or recycling. This discussion and the data presented could provide insights for analyzing technological processes along the fuel cycle.

In addition, the sections on environmental control and waste disposal and/or recycling could assist in developing cost-of-control of other measures of economic costs of specific externalities.

12. TOSCA: THE TOTAL SOCIAL COST OF COAL AND NUCLEAR POWER

Author: Linda Gaines, R. Stephen Berry, and Thomas Veach Long II
Source Organization: Resource Analysis Group, Committee on Public Policy Studies and the Department of Chemistry, University of Chicago
Date Developed: 1979

PURPOSE

The purpose of this computerized model was to develop an analytical tool for reconciling both the debate and the data over coal versus nuclear power. The model was intended to be simple so it can be used by a wide audience for a variety of policy problems.

FUEL CYCLE FRAMEWORK

TOSCA accounts primarily for the electric generation stage of the coal and nuclear fuel cycles. Where data or indirect impacts are significant, it will also account for other stages such as mining. However, its representation of stages prior to and following the electric generation stage (such as mining or recycling) are inconsistent, due largely to uncertainty in the data.

The model calculates both direct and indirect costs associated with electric generation. However, the model does not consider costs which are negligible or uncertain. For example, land reclamation at coal mining sites was estimated to be less than 5% of fuel costs for mining and thus are not considered. Direct costs in the model are those internalized in the cost of power, including initial capital investment, operation and maintenance costs, and fuel costs. Indirect costs accounted for in the model include financial costs; human health and safety; spent fuel costs and associated emissions; safeguards; and accidents.

RESEARCH APPROACH/METHODOLOGY

The methodology follows an approach that allows the user to calculate the total social cost of a technology. The first step in calculating the total social cost is to identify those costs that make significant contributions. As noted above, these can include direct (internalized) and indirect (external) costs. The method for quantifying direct costs is straightforward. The identification and quantification of indirect costs can be defined by the user based on user-defined importance/relevance of indirect costs, and availability of data to value those costs. The following briefly describes how the model deals with indirect costs.

1. **Indirect Financial Costs** - These include public and private sector investments in electric technology research and development; property damage from pollution which is assumed to be directly proportional to fuel consumption; and heat loss which could translate to atmospheric warming and potentially impact marine and agricultural industries.

2. **Human Health and Safety** - Human health and safety costs are calculated for pollution and operating safety and spent fuel storage hazards. The model applies a value (which can be adjusted by the user) of $1 million per human life.

3. **Spent Fuel Costs/Emissions** - The model assumes fossil fuel health hazards from pollution to be cumulative and to rise linearly with the amount of fuel consumed. The model incorporates two equations for accounting for spent fuel social costs. The first calculates the cost to be proportional to the amount of fuel used, assuming that the residues remain a hazard and must be monitored for leaks in perpetuity. The second calculates the net cost for fuel storage and monitoring, assuming that some portion of spent fuels can be recycled.

4. **Accidents** - Costs are also input for accidents at nuclear power plants and the cost for safeguards from terrorism or sabotage.

All costs with the same functional form affect the total cost in the same way. Fuel costs and property damage, for example, are proportional to the number of plants in service. Thus, a higher assessment of the costs of property damage is equivalent to an increment to fuel costs. In addition, the model does incorporate several internal linkages to reflect what changes in electricity demand or cost factors will have on plant operation and total costs.

DATA CHARACTERISTICS

Many of the equations developed for measuring specific cost variables or explaining cause and effect relationships can be adapted to specific user needs. Data and other inputs will need to be developed for each application, based on available historic data or estimates. Users can assign values to specific indirect costs, such as values for human life based on their analytical requirements.

LABOR/TIME/COST REQUIREMENTS

The model likely could be reprogrammed to be run on a personal computer, which would require minimal hardware and software. Programming, data research, and analytical skills would be proportional to the complexity and comprehensiveness of the model application.

CURRENT UTILIZATION

The model was developed in 1979 for use in policy analysis efforts. It is not being used at the present time.

STRENGTHS AND WEAKNESSES

TOSCO is a straightforward approach for calculating fuel cycle costs. Although the application provided was for coal and nuclear power, the model can be adapted to other applications. While the model is not comprehensive in its accountability of the total fuel cycle or all indirect costs, it is efficient in that it does not consider costs externalities perceived to be minor in their effect on total social costs but which may require significant research and analysis to develop and justify.

13. A GUIDE TO THE PREPARATION OF THE SOCIAL WELL-BEING ACCOUNT: SOCIAL ASSESSMENT MANUAL

Author: Stephen J. Fitzsimmons, Lorrie I. Stuart and Peter C. Wolff, Abt Associates Inc.
Source Organization: Bureau of Reclamation, U.S. Department of Interior
Date Developed: 1975

PURPOSE

The *Social Assessment Manual* was prepared for developing a comparative evaluation of future beneficial and adverse social effects likely to occur as a result of implementing various water development plans or as a result of not implementing a plan. However, much of the manual is devoted to materials and procedures necessary to prepare a social well-being account in multiple objective planning. The manual was developed on contract for the U.S. Bureau of Reclamation as a potential method of evaluating large-scale projects. The social well-being account is designed to illicit all of the various beneficial and adverse effects for a number of impact components. It can be used as part of an overall feasibility report or strategic plan. In addition, it can be used as a data development tool or as input to an Environmental Impact Statement.

FUEL CYCLE FRAMEWORK

The technologies evaluated in the manual are those related to large-scale water development projects, such as reservoirs, dams or hydroelectric facilities. The manual does not evaluate these projects on an explicit fuel/life cycle stage-by-stage basis. Yet the user is to look at the project as a whole in completing the manual.

The manual includes a large number of impacts that could be evaluated in determining an overall societal impact assessment. There are five categories of impacts and 35 subcategories in total. Within these subcategories, there are literally hundreds of items (potential impacts) which could be evaluated. The five categories and examples of subcategories include:

1. Individual, Personal Effects
   - Life, Protection and Safety
   - Health
   - Family and Individual

2. Community, Institutional Effects
   - Demographics
   - Government Operations and Service
   - Recreation

3. Area, Socioeconomic Effects
   - Employment and Real Income
   - Transportation
   - Communications

4. National Emergency Preparedness Effects
   - Water Supplies
   - Power Supplies
   - Scarce Fuels

5. Aggregate Social Effects
   - Quality of Life
   - Relative Social Position
   - Social Well-Being

RESEARCH APPROACH/METHODOLOGY

There are five general steps in preparing the social well-being account:

- Describe each project in terms of activities, functions, impact areas and project schedule.

- Describe the total project area in terms of history, present-day characteristics, and life-style.

- Identify or estimate the future impacts and their beneficial and adverse social effects for each plan.

- Compare the effects of each plan in terms of individual and personal effects, community and institutional effects, area socioeconomic effects; national emergency preparedness effects, and aggregate social effects.

- Recommend a specific plan (or no plan) as the optimal choice in terms of future beneficial or adverse effects.

The validity of the results of the social well-being account is directly related to the quality of the data input to the assessment and the method and sources utilized for acquiring that data. The manual recommends a number of primary and secondary sources, as well as historical documents which can be used in data development. Primary sources include interviews with local residents, local business and labor leaders, and local government officials. Secondary sources include research into government and other data sources, as well as local newspaper files and municipal records for historical data/information.

Utilizing the worksheets provided in the manual, data and information are collected for several hundred variables as components of beneficial and adverse effects. These variables are grouped into the five categories listed above. Descriptive measures of impacts are identified and each is rated on a five-point scale ranging from very positive to very negative.

The responses are then aggregated under each category for each alternative. Descriptions are made of specific trade-off options resulting from direct vs. indirect effects; short-term vs. long-term effects; geographic distribution; and special groups affected. Based on aggregate results, the optimal alternative (or no alternative) is selected in terms of its long-term impacts and beneficial/adverse effects.

CURRENT UTILIZATION

The manual was used in 1975 for the U.S. Department of Interior, Bureau of Reclamation. Its current use is primarily as a reference document.

STRENGTHS AND WEAKNESSES

In terms of performing a fuel cycle assessment, the manual provides a useful technique for evaluating in detail potential impacts and their adverse or beneficial effects. In addition, it identifies many variables that could be accounted for in performing a broad-boundary assessment.

One of the primary weaknesses of the manual and its technique relates to the validity of the data and the absence of measures to account for uncertainty. The focus of the data research effort and the sources utilized, if a function of researcher decisions, could be inherently biased. In addition, many of the data collected are based on subjective opinions or are not comprehensive in their representation. Therefore, weighting criteria or some other measure to account for uncertainty should be utilized for more reliable results.

14. THE SOCIAL COST OF PRODUCING ELECTRIC POWER FROM COAL: A FIRST-ORDER CALCULATION

Author: M. Granger Morgan, Barbara Rose Barkovich and Alan K. Meier
Source Organization: University of San Diego
Date Developed: 1973

PURPOSE

The methodology had its origin at the University of California. It was developed in response to the growing public awareness that the market price of many goods and services does not adequately reflect the societal or external diseconomies of their production. It includes techniques for estimating some fuel cycle costs based on existing data. The methodology is intended to identify the optimal mix of production and controls when social costs and control costs are both at a minimum.

FUEL CYCLE FRAMEWORK

The methodology investigates the fuel cycle of one technology -- electric power from coal. The analysis only accounts for the extraction and conversion phases of the coal fuel cycle, which is where the authors feel that social costs are the greatest. Transportation and differential transmission costs are not treated. The methodology considers ash disposal to be only a minor problem. This as well as other waste disposal processes are not considered.

The methodology attempts to value social costs from the extraction and conversion stages of the coal-to-electricity fuel cycle. In the extraction stage, it places social costs under three general categories:

1. Land use costs
2. Health and safety costs
3. Human environmental costs.

Cost estimates are presented in mills per kWh under three alternative scenarios:

- Cost to control at optimal level
- Total societal costs with optimum controls
- Uncontrolled or baseline costs.

Several aspects of land use costs are discussed. Recovery or reclamation costs in $/acre are presented as curves on a two-dimensional cost-time surface. Estimates are provided for both agricultural land and forest land. Estimates are based on author-derived calculations using a variety of public and private sector data sources. Similar methods are used for quantifying environmental impacts from land subsidence, acid water drainage, and refuse storage. Health and safety costs consist of lower boundary reimbursement costs for death or illness, and the cost of control for mine safety. These costs are then measured against the coal production to arrive at a mill per kWh figure.

RESEARCH APPROACH/METHODOLOGY

The methodology uses a combination of both the damage-function approach, as well as the cost of control approach, to measure social costs from coal-to-electricity conversion. With these measurements, the methodology looks at emissions, including sulfur oxides, nitrogen oxides and particulates. It uses available estimates of emission damage costs and control costs to develop societal cost estimates from conversion in mills per kWh.

The methodology provides measures and calculation techniques rather than a fuel cycle analysis methodology. Thus, the costs derived are static and the methodology does not provide internal linkages.

The calculations used in the methodology are based on the best available public and private sector data sources. While the quality and extent of data has improved substantially since this methodology was developed, many of the techniques could still be valid. The data outputs consist of specific social cost categories under three scenarios, discussed above. The totals of these costs for each scenario (mills/kWh) are:

- $\geq 3 \pm 1$ for optimal level of control costs
- $\geq 4.5 \pm 1.5$ for total societal costs with optimal controls
- $\geq 11.5 \pm 2$ for "uncontrolled" or baseline costs.

The methodology allows strictly for straightforward calculation of social costs. It does not incorporate any methods for assessing policy implications or for drawing broad conclusions on the basis of the costs which are derived.

CURRENT UTILIZATION

This methodology is not being used at the present time.

STRENGTHS AND WEAKNESSES

This methodology uses numerous valid data sources in developing calculations for societal costs. Moreover, it utilizes data that were available at the time it was written to quantify specific costs. It does not provide detail on the basis for how and why particular calculations were formulated. Nor does it provide estimates or any measure of discussion on many other societal costs in the extraction and conversion stages, as well as for the many costs incurred through other stages of the fuel cycle.

15. A MODEL ELECTRIC POWER AND CONSERVATION PLAN FOR THE PACIFIC NORTHWEST

Author: Michael Shuman and Ralph Cavanagh
Source Organizations: Bonneville Power Administration and Pacific Northwest Regional Council

PURPOSE

This is a methodology for analyzing some of the more significant generic environmental impacts of electric generation resources. The methodology was developed in response to Regional Act mandate (Section 3(4)(B)), which states that "such quantifiable environmental costs and benefits as the (BPA) administration determines, on the basis of a methodology developed by the Council... are directly attributable to such measure of resources."

FUEL CYCLE FRAMEWORK

This methodology was implemented to evaluate five supply-side and demand-side technologies. These are:

1. Coal-fired generation
2. Nuclear generation
3. Wind power
4. Solar water heating
5. Residential weatherization.

The fuel cycle framework is based on the principle that "virtually every environmental impact is shrouded in uncertainty" and that uncertainty or disputes about the impact's likelihood or magnitude should not preempt its quantification. Large uncertainties should be captured in the "range" of damage estimates and not in the choice of which impacts to quantify. This methodology attempted to assign values to many impacts typically left unquantified.

For the coal and nuclear fuel cycles, three general fuel cycle stages are evaluated. These include fuel extraction, fuel transport, and plant operation. Generic public damages and occupational environmental damages to human health and property are assessed. Impactors assessed include nuclear accidents, radionuclide emissions, nuclear weapons proliferation, and carbon dioxide. These impactors are translated into health effects in terms of immediate and latent deaths and immediate and latent injuries for each stage of the technology fuel cycle. They are also translated into property damages and human life values. Each is monetized on a mill per kilowatt-hour basis.

Totals are shown below:

	Total Cost (mills/kWh)	
Impact	**Coal**	**Nuclear**
Nuclear Accidents:		
Health Effects	--	0 - 20.5
Property Damage	--	0 - 0.6
Radon Release		
Health Effects	--	0.5 - 165.4
Weapons Proliferation		
Health Effects	--	0 - 112.6
Property Damage	--	0 - 2.1
Climate Change		
Health Effects	0 - 123.6	--
Property Damage	0 - 0.4	--
Human Live Valuation	0.3 - 82.8	0 - 1.2
Total	0.3 - 206.8	0.5 - 302.4

In addition to these impacts, other impacts are considered for each of the fuel cycles, including the solar and wind fuel cycles. Non-land intensive applications are considered; thus, environmental impacts from extensive land use are not incorporated into the analysis. The focus is primarily on:

- Material requirements of steel, nonferrous metals, concrete, glass and plastics
- Occupational effects of employment, fatalities and lost work days
- Air emissions, including particulates, oxides of sulfur, oxides of nitrogen, carbon monoxide and gaseous flourides.

The environmental costs of renewable and conservation technologies range from 0 - 1.2 mills per kWh. The authors state the environmental costs of weatherization programs are negligible (essentially zero), yet they do not identify the fuel cycle and associated costs and benefits for weatherization systems.

Due to the cost of developing valid estimates, many environmental impacts of centralized electric generation technologies have not been incorporated. These include water consumption, recreation losses, fish and wildlife mortality, aesthetic damage, and impacts from transmission and distribution facilities. In addition, environmental impacts already reflected in energy prices are not incorporated to avoid double counting. Examples include land use (which is already incorporated into capital costs) and the fact that workmen's compensation accounts for a portion

(25%) of the social costs of job-related deaths, injuries and illnesses (and are thus internalized in market prices).

RESEARCH APPROACH/METHODOLOGY

The research relied on a number of academic and institutional sources for data and information. These sources were reviewed and considered in development of value ranges for each of the impacts. Examples of sources include the British Health and Safety Executive Annual Review of Energy and others. At the onset of the analysis, a broad range of impacts are to be assessed.

Wherever possible, dollar figures are expressed in 1980 dollars. The methodology assumes that low discount rates are appropriate, based on the theory that society prefers a dollar of damage in the future to a dollar of damage today. For property damage, a one percent discount rate is used. To account for environmental impacts that result in injury or premature death, a discount rate of zero is used. Human life is valued at $300,000 to $3,000,000 and a human injury is valued at $30,000 to $300,000.

The next step is to identify environmental impacts that should not be counted. These include those already internalized into the market price of energy. Finally, once these parameters/assumptions have been made around the analysis, research of available sources is performed to develop ranges of data for valuing impacts.

CURRENT UTILIZATION

There is no known current use of this particular approach by the source organization.

STRENGTHS AND WEAKNESSES

This approach sets broad initial objectives for the extent of impacts to be incorporated in the analysis. However, in the final analysis, many of these impacts are not included. A limited number of data sources are identified and used in this effort.

D. TECHNICAL RESEARCH PAPERS

This section provides brief descriptions of technical papers that have been developed relevant to the subject of fuel cycle assessment and related methodological issues/approaches. It is an example of some of the technical papers written on the subject and is not intended to be a complete collection.

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1. APPLICATIONS OF DECISION-AIDING SOFTWARE: LEAST-COST UTILITY PLANNING

Author: Thomas Stanton
Source Organizations: University of Illinois at Urbana-Champaign and the Policy Studies Organization
Date: 1992

OVERVIEW

This text was written to discuss the use of decision-aiding software applications in a variety of decision analysis and decision-making circumstance, including government decisions, personal decisions, legal decisions, cross-national decision-making, political strategies, and other applications. The focus of this profile is on a section of the text that discusses the use of decision-aiding software in least-cost utility planning.

The author states that these tools must overcome the criticism that they are imperfect. They are a first generation of decision tools, however, and with use they will be continuously improved and refined. In addition, the author states they are necessary. With little oversight he notes, "regulators have essentially allowed public and private utility companies to dictate public policy about energy supply systems ... without a clear articulation of decision effects." These models are a necessary tool for providing direction, leadership and oversight in energy policy.

Rational comprehensive decision making is said to require: 1) an exhaustive list of goals, 2) an exhaustive list of means, 3) a full comparison of means and goals, and 4) the selection of the optimum means. However, decision support tools allow information and decision-making costs to be reduced by using relatively inexpensive microcomputer analysis techniques and by only including relevant data inputs. The underlying concept behind these models is that:

- They will accurately depict a broad range of the impacts of decisions about energy systems.

- Energy systems have significant implications for many important social and economic factors. Least-cost energy system planners should not ignore these indirect or external costs.

- Models do not propose policies or take the place of policy analysts or decision makers. They are simply a means of increasing information resources that allow decisions to be made on a more complete body of information.

Computer models are especially useful for public policy making because they reduce labor and time requirements and are low cost. Moreover, they assist in addressing five key methodological problems found in decision making:

1. **Data Gaps** - Problems may be presented where multiple data/information elements are not available. Decision-aiding and other models allow the user to resolve uncertainties through analytical techniques such as "what-if" analyses. This assists modelers in learning how missing data or various assumptions affect outcomes of their analyses.

2. **Multiple or Conflicting Goals** - Models may not directly solve for this problem or reconcile conflicting goals; however, they do allow users to cost-effectively conduct analysis that addresses multiple goals, including objectives that are measured in different units.

3. **Time Constraints** - When dealing with numerous alternatives and impacts or other complexities, computer models provide a cost-effective means of performing the necessary calculations quickly.

4. **Policy Constraints** - Computer models can be instructed to solve problems within a given set of constraints and those constraints can be mathematically moved, tightened or loosened as needed.

5. **Output Formats** - Models can use prescribed formats, graphics, etc. to speed and simplify communication of results.

The author describes two particular decision-aiding software packages and examples of their applications. These are a goal programming (GP) and P/G%. A GP package (OPTIONS) and P/G% are both described in this compendium, as are example applications. Thus, they will not be described further in this profile.

2. ENVIRONMENTAL TRADE-OFFS ASSOCIATED WITH VARIOUS ENERGY PATHWAYS: A TOTAL ENERGY CYCLE ANALYSIS APPROACH

Authors: Marylynn Placet and Ken Humphreys
Source Organization: Pacific Northwest Laboratory
Date: 1991

OVERVIEW

This paper describes an approach for conducting total energy cycle (TEC) analysis and discusses the issues and problems associated with its implementation. The underlying basis of this paper is that increased understanding and concern over environmental impacts has made it important to assess the environmental tradeoffs associated with various energy technology options and pathways.

The authors take a TEC approach (primary resource extraction; transport and storage; conversion and processing; product transportation, storage and distribution; and end-use service), which they define as more broad than a traditional fuel cycle approach (primary resource extraction; transport and storage; conversion and processing). A broad approach allows for a more equitable comparison of impacts, inclusion of end-use technologies and evaluation of all ancillary impacts related to total energy cycle activities/processes.

Each energy technology has a distinct pathway through all or most of the stages of the TEC. This approach allows comparison of energy options with only subtle technological differences, as well as options with clearly distinct differences and pathways. The TEC approach follows three general steps:

1. Characterize the application to be analyzed by identifying the feedstock, technology option and end-use application.

2. Identify the pathway(s) options for any feedstock or end-use application that can have multiple pathways. For example, an assessment of biomass feedstocks for use in transportation applications can include numerous pathways. There are various alternatives of biomass feedstocks, transportation and conversion options, and end-use transportation technologies.

3. Take inventory of all impacts associated with each pathway element. All primary and secondary impacts should be identified and those that are determined significant should be objectively characterized.

Implementation of a TEC analysis as discussed in this paper will present numerous complexities. These include:

- Data gaps
- Addressing various levels of uncertainty
- Defining the boundaries of the analysis
- Estimating changes in conditions over time
- Using the results.

The authors hold that while the development of a consistent environmental analysis framework would require resolution of some challenging analytical issues, the benefits of broad adoption would be tremendous.

3. QUANTIFYING AND COMPARING FUEL CYCLE GREENHOUSE GAS EMISSIONS: COAL, OIL AND NATURAL GAS CONSUMPTION

Publication: Energy Policy, July/August 1990
Author: Deborah Wilson, Visiting Research Scientist, Department of Environmental and Energy Systems Studies, Institute of Science and Technology, Lund University, Lund, Sweden.

OVERVIEW

This paper contains a discussion and analysis of many relevant fuel cycle concepts, boundary issues, and emissions levels which could be useful in framing a total fuel cycle analysis effort. It was written in response to recent calls for switching from coal and oil to natural gas, based on the expectation of fewer greenhouse gas emissions. The author addresses the concept that these calls do not account for the fuel cycle; nor do they account for emissions of greenhouse gases other than CO_2.

The paper discusses the fuel cycles of the three fossil fuel technologies (coal, oil and natural gas) in terms of emission occurrences and levels. It develops a comparison of the emissions for those technologies in six basic stages of the fuel cycle: 1) production, 2) refining, 3) transportation, 4) combustion, 5) end-use, and 6) services. The paper addresses the emissions of methane, nitrous oxide, nitrogen oxides, carbon monoxide, tropospheric ozone and chlorofluorocarbons. It also discusses the greenhouse gas properties of each. Estimates of the emissions of each greenhouse gas in each stage of the fuel cycles are required for quantifying the CO_2 equivalent emissions from fossil fuel cycles.

There are two rationales for comparing the climatic effects of greenhouse gas emissions. The long-term view holds that due to the time lag between the emissions of some gases, such as $C0_2$, and their total climatic impacts, the effect of today's emissions will not be felt until long into the future. The near term view focuses on buying time by reducing emissions of gases with large near term greenhouse forcings, such as methane. In order to compare greenhouse forcings of $C0_2$, CH_4 and N_2O, the author states that it is necessary to put them into common units.

In comparing the technologies based on a three-point evaluation methodology, the author found that natural gas is "less offensive" than either coal or oil on a megajoule basis over the long term. For example, half the near term CO_2 equivalent forcings for natural gas over the short term were found in the production and distribution stages of the fuel cycle, with the other half resulting from combustion. Over the long term, leakage is reduced to about 1% of production -- cutting total emissions roughly in half. While similar reductions in emissions for coal mining and oil production are also exhibited, combustion-related emissions for those technologies hold steady and remain significantly higher than those for natural gas over the long term. The three-point methodology was designed to:

1. Include emissions from the complete fuel cycle for each of the fuels
2. Include CO_2, CH_4 and N_2O emissions

3. Evaluate both near and long-term greenhouse forcing effects.

Energy efficiency is a driving factor in determining the greenhouse forcing that results from the use of large-scale energy conversion technologies, compared with the power that is produced. Conversion efficiency advantages available today in natural gas technologies widen the gap in greenhouse forcing comparisons between oil and coal technologies.

4. CONTINGENT VALUATION STUDY OF THE ENVIRONMENTAL COSTS OF ELECTRICITY GENERATING TECHNOLOGIES

Author: Shepard C. Buchanan
Source Organization: Bonneville Power Administration
Date Developed: 1990

OVERVIEW

This paper discusses the use of a survey approach in implementing the contingent valuation method for estimating environmental externalities associated with electric generation. The survey approach is designed to estimate society's willingness to pay to avoid externalities associated with specific generating technologies. A similar method could potentially be applied to specific environmental and non-environmental impacts along the fuel cycle. This method could be used in valuing those impacts, as measured by society's willingness to pay to avoid or reduce them.

The survey implemented by BPA asked respondents whether or not they would be willing to pay to avoid specific generating technologies. If so, it asked, how much, and if not, why. The values produced by the study were not used to determine resource environmental costs on a $/kWh basis, but rather on a general basis for use in a planning context.

5. A FRAMEWORK FOR EVALUATING ENVIRONMENTAL EXTERNALITIES IN RESOURCE PLANNING: A STATE REGULATORY PERSPECTIVE

Author: Dr. Daniel Violette and Ms. Carolyn Lang; Dr. Philip Hanser
Source Organization: RCG/Hagler, Bailly, Inc.; EPRI
Date Developed: 1990

OVERVIEW

This paper discusses the concept and surrounding issues of incorporating environmental externalities into utility resource planning. The Appendix to this paper, "Economic Damage Cost Approaches for Valuing Environmental Damages," overviews four approached used to perform direct damage assessment. Each of these approaches could be applied in some or all stages of the total fuel cycle. The four approaches are briefly described below:

Travel Cost Methods - Travel cost methods are one approach for estimating externalities at recreational sites. Historically, most applications of the travel cost method have focused on use-related values associated with eliminating or adding recreational sites. New developments have increased the applicability of the technique to encompass estimating the use-related value of a site with different levels of characteristics, such as water quality or fishing. The most significant strength of this method is that it is based on actual decisions of individuals. Moreover, it has received professional acceptance.

Hedonic Price Method - The hedonic price method (HPM) has been used to examine damages from air pollution in urban areas. The method's essence is to gather data on goods and products actively traded in markets and use that data to estimate an implicit price for the natural resource injury in terms of the reduced value for the privately marketed good or service. The most common application of HPM has been to estimate the impact of air pollution on residential property values. This method relies on observed individual choices, but there are many assumptions inherent in the method that are flawed. For example, the reduced value of a marketed good or service assumes no other contributing factors.

Operations Research Methods - Operations research encompass a set of analytical techniques, such as simulation modeling, used to optimize or solve decision problems. These techniques are versatile, yet they require extensive review and validation, and often large data sets.

Contingent Valuation Methods - This method uses survey techniques and hypothetical markets to directly elicit individual willingness to pay for different levels of natural resources. It can be used to value human health effects from contaminated drinking water, or recreational or aesthetic impacts. It is the only method discussed that estimates option or preservation values, and is the most appropriate technique for estimating unavailable data.

6. MONETIZING EXTERNALITIES IN UTILITY REGULATIONS: THE ROLE OF CONTROL COSTS

Author: Paul L. Chernick and Emily Caverhill
Source Organization: PLC, Incorporated
Date Developed: 1990

OVERVIEW

This paper provides an overview of four basic approaches used to estimate environmental externalities. These are:

1. Estimating the relative physical, chemical or toxicological potency of various pollutants

2. Polling of experts or inputs from other relevant persons

3. Directly estimating the environmental effects of a pollutant, and the valuation of each of those effects

4. Determining the implied societal value of reduction of the pollutant from the maximum cost society has committed to pay for reductions of this pollutant.

The authors discuss in detail their preferred technique for incorporating externalities into utility planning in the near term: implied valuation through the estimation of the marginal cost of abatement.

The marginal control cost represents the highest cost which society has explicitly demonstrated a willingness to pay to eliminate current or future reductions of an externality. Under this method, the costs of control provide direct information on the societal value of emission reductions under two theoretical approaches. The first approach is that the cost of required control measures serves as an estimate of the price that society is willing to pay to reduce the pollutant. The second approach is that the costs of required controls may directly establish the social benefits of reducing emissions defining the direct pollution control cost that can be avoided by an exogenous reduction in emissions.

While implied valuation through estimating the marginal cost of abatement is discussed in terms of electric generation (e.g. the conversion stage of the fuel cycle) it can be applied to other stages of the fuel cycle as well. Cost of control, or, in another form, cost of waste or hazard management, can serve as a proxy of the cost of many types of externalities throughout the total fuel cycle.

7. REVERSIBILITY AS A WEIGHTING FACTOR IN INTEGRATED LEAST-COST PLANNING METHODS

Author: Susan Hedman
Source Organization: Center for Global Change, University of Maryland
Date Developed: 1990

OVERVIEW

This paper describes a least-cost planning methodology that uses weighted, scaled scores instead of monetization. The weighting scheme attempts to capture the degree to which different types of externality costs are reversible. In 1989 the Center for Global Change developed a methodology for the Vermont Agency for Natural Resources that was designed to determine which of several electric power supply and demand-side management scenarios could meet the future needs of Vermont residents at the lowest total economic, environmental, and social cost.

The methodology used a matrix to list over 20 weighted factors (internalized and externalized) associated with each technology. Full fuel cycle and conversion-to-electricity impacts for each of these factors were then quantified. For those factors which could not be quantified, a score was assigned based on a 0-to-100 scale. Using the weights applied to each factor, a weighted score was calculated for each technology. The weighting scheme reflected the severity and reversibility of each impact, with the more irreversible impacts given a larger weight. The general effect of the reversibility weighting scheme is to increase the relative costs associated with irreversible commitments to large, centralized electric plants that rely on nonrenewable fuels when these options are compared with more flexible incremental investments in smaller, decentralized, renewable energy technologies and demand-side measures.

8. PROGRESS IN INTEGRATED ENERGY-ECONOMY-ENVIRONMENTAL MODEL SYSTEM DEVELOPMENT

Author: Yasukawa, Mankin, Sato, Tadokoro, Nakano and Nagano
Source Organization: Japan Atomic Energy Research Institute
Date Developed: 1987

OVERVIEW

The Integrated Energy-Economic-Environmental Model System was developed for providing analytical tools for the system analysis and technology assessment of nuclear research and development. One aspect of these models is their application for fuel cycle systems analysis. This paper provides an overview of each model in the system and discusses the developmental status of each. The system models include:

1. The Macro Energy-Economy-Environment Model Group, which contains five models for analyzing, evaluating, projecting and estimating present and future impacts, performing scenario analyses, and performing technical assessments.

2. The MARKAL model, which analyzes technological aspects of energy systems, environmental control technologies, and energy system emissions.

3. The E-I/O(TRANS) Model, a multi-sectoral energy economy interaction model to analyze structurally the long-term evolution of energy-economy systems.

4. The JALTES Models, which facilitate the study of long-term reactor strategies and analyze in detail nuclear fuel cycle systems.

5. A cost-benefit risk assessment model group and data base, which analyze various aspects of the fuel cycle as well as data bases on energy, environmental data, and technology characteristics.

The system does not include models or techniques for risk assessments. Nor does it include the dose-response conditions or data bases necessary for conducting these assessments. As developed, the system is designed to evaluate nuclear energy systems, although it could be modified for other applications.

9. EXTERNALITIES AND INTANGIBLES

Author: Cynthia M. Crane
Source Organization: Pacific Gas and Electric Co.
Date Developed: 1985

OVERVIEW

This series of papers discusses techniques for incorporating externalities into the market price of energy. Reductions in emissions from new participants in a conservation program were calculated. Yet none of the methodologies reviewed were sufficient for monetizing the value of improvements in air quality. An input-output model was used to quantify employment benefits (and disbenefits) received by PG&E ratepayers through the administration of conservation and load management programs. A third paper presents estimates of oil import premiums. The oil import premium measures the social costs incurred by society from imported oil purchases. The paper used the results of the Energy Modeling Forum Working Group on World Oil Issues, 1982.

10. THE ECONOMICS OF NATURAL ENVIRONMENTS: STUDIES IN THE VALUATION OF COMMODITY AND AMENITY RESOURCES

Author: John V. Krutilla and Anthony C. Fisher
Source Organization: Resources for the Future
Date Developed: 1985

OVERVIEW

This paper describes an approach which, at the time, represented a "first-generation" effort to incorporate the noncommercial or amenity resources of natural environments into the body of economic theory and application. It examined hydropower development in Hells Canyon in terms of the preservation benefits associated with the High Mountain Sheep site. The authors realize that all of the benefits from preservation cannot be measured. Thus, the approach adopted was to determine how large the benefits from preservation must be in order to at least equal the benefits from development. One can then determine whether the preservation benefits equal or exceed this amount.

To quantify the value of the developmental benefit, a single-discounted, present value sum of the total time stream of benefits from the development project was calculated. This accounted for the fact that the role of the hydroelectric facility in the regional power system may change as the system evolves over time, thus changing the annual benefits of the facility over that time. It also accounted for technological advances in alternative sources of power, which can lessen the benefits of hydroelectric development.

To find the value of preservation benefits, a simulation model was run to take into account the growth in demand over time as a function of the increase in population, income and changing tastes. Initially, the rate of growth in annual benefits will be the result of a combination of demand growth (i.e. recreationists), along with a higher willingness to pay as a function of increases in income. As capacity is reached, the growth in annual benefits will occur only as a result of increases in willingness to pay.

Aspects of this cost-benefit technique can be applied to total fuel cycle analysis in the sense that many of the indirect and secondary costs and benefits along the total fuel cycle are not easily quantified. By measuring the known social costs against the known social benefits, however, one can form a basis for evaluation and decision. In addition, this technique measures the benefits and costs over time. This is a crucial component of total fuel cycle analysis in that technological development will change the internalized costs of energy over time. Concurrently, changing societal and ecological realities will create constantly changing values and willingness to pay for societal and environmental fuel cycle externalities. This approach requires significant analytical, modeling, and research expertise. In addition, it will require programming skills for computer simulation.

11. COMMUNITY-LEVEL IMPACT PROJECTION SYSTEM

Author: University of Texas Center for Energy Studies
Source Organization: Texas Energy Advisory Council
Date Developed: 1979

OVERVIEW

This paper describes a model developed for the Texas Energy Advisory Council to project community-level impacts resulting from Texas Lignite projects.

The model contains four major submodules, each providing specific outputs. The employment submodule uses an export-based technique to estimate changes in business-serving (indirect) and household-serving (induced) employment. The population submodule is based on a cohort-survival routine, using five-year age cohorts. Regional baseline population projections are used as control totals for community population projections. Population is provided by age and sex. The spatial allocation submodule uses a gravity model approach, and the public service costs submodule uses a per-capita approach to project costs by type.

One advantage of the model is that it is based almost exclusively on secondary data rather than estimates or tertiary sources. Yet, while the model projects public service costs, it does not project public service revenues, and this limits its planning and analysis usefulness.

12. ENVIRONMENTAL IMPACT ASSESSMENT

Author: Marian Blissett, Ed.
Source Organization: Engineering Foundation, LBJ School of Public Affairs, University of Texas at Austin
Date Developed: 1976

OVERVIEW

This text includes a section on "Matrix Techniques in the Evaluation of Environmental Impacts." Matrix techniques call the user to apply scaled ratings to a number of fuel cycle impact variables per energy technology/per stage. These techniques are very flexible, however, and can be used to measure an infinite number of variables and relations. Matrix techniques can be used for several functions, including:

1. Concentrating and displaying in readily understandable form large numbers of individual primary or first-order actions of a major program or fuel cycle to be evaluated

2. Providing a checklist and guide in the preparation and review of fuel cycle analysis as to topic outline, which will help avoid omission of key elements that could later be challenged

3. Presentation of individual first-order actions in reduced format to specify the overall character of the fuel cycle

4. Expedition of review of the fuel cycle impacts by indicating clearly and concisely the relative emphasis assigned to specific impacts

5. Facilitating decision processes during or after a fuel cycle analysis by emphasizing which actions will have the least impact.

Outputs of the matrix technique provide overall results of given technologies in terms of variable impacts. They thus serve as a means of scoring specific technologies. Some of the limitations of the matrix technique include the omission of indirect or secondary impacts from the scoring process, the difficulty in rating intangibles, and the inability to adequately represent the often complex interrelationships between variables.

Matrix techniques are currently utilized for a variety of analytical and evaluative purposes. In some instances they have been used as a means of evaluating utility solicitations for independent power. They can take on many forms and are easily adaptable to decision processes at hand.

13. CAPITAL COEFFICIENTS AND DYNAMIC INPUT-OUTPUT MODELS, "DEVELOPING *EX ANTE* INPUT-OUTPUT FLOW AND CAPITAL COEFFICIENTS"

Author: W.H. Fisher and C.H. Chilton
Source Organizations: Columbia Laboratories, Battelle Memorial Institute
Date Developed: 1975

OVERVIEW

The authors believe that conventional methods of constructing input-output tables are flawed. "Most input-output tables have been generated from collected statistics by conventional (ex post) methods. These cannot suffice either for forecasts of input-output relationships or for years in which the statistics were not collected. Moreover, the very nature of the ex post method assures that the tables are out of date by the time they are completed."

In response, the authors developed an alternative (ex ante) method of constructing input-output tables with direct coefficients generated from judgmental estimates. The authors feel this approach has many advantages, including relative speed of construction and lower cost over the traditional approach. Crucial elements in the ex-ante method involve selection of the experts from whom judgmental data are to be obtained, field interviews with experts, and the post-interview generation of the coefficients. The depth of this approach is limited only in terms of the user's ability to identify and obtain expert judgment and implement the computations.

This approach to an input-output table is made via the development of direct coefficients. Direct coefficients indicate the proportions in which purchased inputs and values added are combined to create output. First, sectors must be defined. Most sectors are made up of many establishments using many different technologies. Such a sector's coefficients are weighted composites of several "pure" coefficients. Once the sector's coefficients have been defined to the experts' satisfaction, the total dollar values of the final demands that each productive sector must supply are estimated. The remaining operations produce the dollar flow matrix.

14. BENEFIT COST AND POLICY ANALYSIS: AN ALDINE ANNUAL ON FORECASTING, DECISION MAKING, AND EVALUATION

Author: Haveman, Harberger, Lynn, Niskanen, Turvey, Zeckhauser, and Wisecarver
Date Developed: 1974

OVERVIEW

The purpose of the Aldine annual is to reproduce a series of articles in both benefit-cost and policy analysis. The particular focus of 1973 annual is on broad efficiency and equity impacts of major policy alternatives. The first section is devoted to articles on the analysis and evaluation of public investment and resource management activities. Cost-benefit analysis is frequently used to compare energy technology alternatives and fuel cycle impacts. It is a straightforward tool for evaluating specific decisions, investments or policies. These analyses also support policy development and analysis activities. In performing a total fuel cycle analysis, cost-benefit techniques can be an important element for micro-level data development and analysis applications. For example, to calculate the overall cost of toxic releases from petroleum exploration processes, the environmental costs of those releases should be calculated as should the economic benefits resulting from the development of a response industry. Alleviation techniques can then be measured in terms of their cost to implement, the improvement to the environment, and the potential negative impact on industries, which may provide economic benefits.

One application published ("The Economics of Flood Alleviation," D.N. Chambers and K.G. Rogers) presents a cost-benefit methodology applicable to total fuel cycle analysis. The focus of the article is to assess the tangible and intangible costs resulting from a potential flood and then estimate the benefits of flood alleviation. The analysis considered a number of direct and indirect impacts/costs realized by economic sectors. In looking at direct impacts in the residential sector, for example, a sample was developed of homeowners inundated by the flood. They were surveyed on their financial losses as well as the level of inundation received (water depth and exposure time) Data were then extrapolated for the remaining population. Similar analysis was performed for retail and industrial facilities. In looking at indirect impacts, estimates were made of the value of services ceased or reduced due to the flood. For example, the consequence of disrupting education or the consequences resulting from lack of access to hospitals and other medical facilities were assessed. In addition, impacts on utilities and emergency services were valued, as were the economic impacts associated with traffic disruption, increased commute time, agriculture and recreation. One method suggested for measuring intangible costs such as distress or inconvenience was to multiply the quantifiable costs by a factor of two, given that the level of intangible costs will be proportional to physical damage. The depth of the analysis considered which impacts, if minimized, would result in a lower cost to society from the flood. Similarly, total fuel cycle analysis can consider costs/benefits which are feasibly calculated and significant in the analysis of overall fuel cycle impacts.

15. "THE DYNAMICS OF SOLID WASTE GENERATION," TOWARD GLOBAL EQUILIBRIUM: A COLLECTION OF PAPERS

Author: Jorgen Randers and Dennis L. Meadows
Source Organization: Wright-Allen Press, Inc.
Date Developed: 1973

OVERVIEW

This provides a description of a dynamic model of solid waste generation. The model accounts for the dynamics of political, social, economic and technical interactions in projecting the size, composition, and rate of solid waste flows. In addition, it was used to simulate various policy effects. The model used the DYNAMO computer language. Similar dynamic systems models can be developed and implemented for specific energy technology fuel cycles.

In developing the model the user must first define his goals or the questions the model is supposed to answer. This sets the direction of the modeling task. Second, parameters must be established to set boundaries around the analysis. As with any total fuel cycle analysis, the extent to which indirect or secondary impacts can be valued is limited. Thus, for results of higher integrity, model boundaries should be realistic. This is where the framework for analysis is set and where assumptions are defined. Third, the system (or fuel cycle) is laid out complete with positive and negative feedback loops showing causal relationships between variables.

16. <u>SOCIETY AND THE ASSESSMENT OF TECHNOLOGY</u>, "COST/BENEFIT ANALYSIS IN TECHNOLOGY ASSESSMENT STUDIES"

Author: Francois Hetman
Source Organization: OECD, Paris
Date Developed: 1973

OVERVIEW

The author seeks to place technology assessment in a social and economic perspective to define its scope and outline various methodological approaches it has evoked. Two of the primary methodologies discussed are cost/benefit analysis and full social cost assessment of technology. The text provides a step-by-step methodology for performing a cost/benefit analysis, as applied to measuring social impacts, and presents criteria and techniques for evaluating results. In the section of full social costing, the text provides a number of techniques for estimating full social costs. These include the Delphi method, relevance trees, event evaluation and review, relevance matrices, and cross-impact techniques.

17. THE SOCIAL BENEFITS AND COSTS OF ELECTRICITY GENERATION AND END-USE TECHNOLOGIES

Authors: Michael DeAngelis and Samuel Rashkin

OVERVIEW

This paper presents a qualitative methodology for incorporating externalities in the evaluation of electricity generation and end-use technologies. The qualitative methodological approach this paper describes may offer some useful applications for fuel cycle assessment. The six-step methodological approach follows:

Step 1 **Identify all Societal Costs** - These fall under three general categories: government subsidies, external costs, and private costs.

> **Government Subsidies** - These account for expenditures targeted to one or more energy technologies. They represent a conscious decision to provide direct support, but may not be the result of comprehensive planning. They include R&D support, other government program support, tax expenditures, loans and loan guarantees, military support (i.e. Persian Gulf presence), and inventory support (i.e. SPR).
>
> **External Costs** - These reflect indirect costs that result from the use of specific energy technologies, including environmental clean-up costs, health and safety costs, economic development, supply reliability and security, and system operation (i.e. impact of the technology on the electricity supply system).
>
> **Private Costs** - These include capital, operations and maintenance, and fuel costs.

Step 2 **Assign Cost Weighting Factors** - The relative importance of the various cost categories above can vary significantly. Analysis is necessary to determine appropriate weighting factors based on relative degrees of impacts. In some cases these impacts can be measured to assign weights. In other cases, expert opinion such as the Delphi process can be used.

Step 3 **Collect and Analyze Data** - The paper provides no techniques for developing data. However, it suggests that primary sources in the public and private sector should be used. Where hard data do not exist, qualitative estimates can be used based on professional judgment.

Step 4 **Develop the Cost Matrix** - The matrix should allow for a cross comparison of all societal costs identified in Step 1 relative to each energy technology.

Step 5 **Assign Matrix Cost Impacts** - Magnitude values of energy technology cost impacts should be provided for each cell of the matrix based on the research data collected in step 3. The cells would contain both the raw qualitative or quantitative score and the weighted score. The aggregate of the weighted scores will then serve as a final comparison for each technology.

Step 6 **Compile Final Results** - Use the matrix information to assist in determining energy technology decisions. Results should be qualified based on the degree that cost impacts are derived from documented quantitative data.

V. GLOSSARY

Cohort-Survival - This is an alternative approach for projecting future population. The technique involves dividing the area population into age-sex groups (cohorts). Appropriate rates for mortality and fertility are then applied to each cohort, and individuals in each cohort are reallocated to the next higher age group in each period.

Control Cost - The cost of reducing or avoiding an environmental impact at its source.

Decision Trees - A means of displaying a set of alternative sequential decisions and the possible outcomes from those decisions. For use in activities such as process analysis or strategic decision making.

Decommissioning - The process of removing an operating unit from service including dismantle.

Delphi Method - Based on informal techniques of surveying and reconciling judgments, insights and expectations of persons who are considered experts in the field under study. Typically used to derive a picture of future events.

Direct Cost/Benefit - A cost/benefit that can be economically traced to a single source object.

Discount Rate - Rate used to calculate the present value of cash flows.

Dose-Response - A quantitative relationship between the dose of a substance and an effect caused by the substance.

Dynamic Systems Analysis - Analysis of complex direct and indirect interactions between dependent and independent variables over time. Often used in analysis of alternative scenarios.

Externalities - Direct or indirect costs/benefits resulting from process activities which are not reflected in the market prices of goods and services developed through those processes.

Fixed Cost - Costs that remain constant in dollar amount as the volume of output or production changes.

Fuel-Cycle - The sequence of activities associated with transformation of a raw material into a consumable product (i.e. exploration through consumption).

Gaussian Statistical Distribution - A commonly occurring statistical distribution characterized by a bell shape and having a mathematical representation in the form of a mean and a variance. Also known as a normal distribution.

Gravity Model - The use of population and distance as variables to determine patterns of spatial interaction. Frequently used to determine the area of primary site influence via prediction of settlement and commuting patterns of plant workers.

Indirect Cost/Benefit - A cost/benefit that is not directly traceable to production of a good or service but is associated with the production/use of that good or service.

Input-Output Model - Typically used to analyze interdependence among industries at the regional or national level. It is especially useful for analyzing, forecasting, or planning business and/or economic activities.

Net Present Value - The present value of future cash inflows less the present value of future cash outflows.

Opportunity Cost of Capital - Expected rate of return that is foregone by opting for one project or investment decision over a reliable and secure alternative.

Present Value - The discounted value of future cash flows using an agreed upon discount rate or opportunity cost of capital.

Sensitivity Analysis - A method used to examine the behavior of a model by measuring the variation in its outputs resulting from changes to its inputs.

Total Fuel Cycle Analysis - The process of evaluating the series of interrelationships and interdependencies from process activities of the fuel cycle. Typically referred to in terms of quantifying or qualifying the internalized and externalized costs and benefits of energy technology fuel cycles.

Variable Costs - Costs that vary in total as the level of production or output changes.

Willingness-to-Pay - The amount that an individual would pay to achieve a different amount or quality of a good or service.

VI. BIBLIOGRAPHY

Abt Associates Inc., *A Guide to the Preparation of the Social Well-Being Account: Social Assessment Manual*, Bureau of Reclamation, U.S. Department of Interior, 1975.

Arthur D. Little, North Dakota State University, *REAP Economic-Demographic Model*, 1979.

Arthur D. Little, *SIMPACT*, U.S. Steel, 1979.

Battelle, Seattle, *HARC, Battelle Human Affairs Research Centers*, 1978.

Bauer, Raymond A., Gergen, Kenneth J., *The Study of Policy Formation*, 1968.

Belzer, D.B., Kellog, M.A., Shankle, D.L., Pacific Northwest Laboratory, "Policies to Reduce Energy Use and GHG Emissions in the Commercial Sector" Draft Report, December 1989.

Blissett, Marian, *Environmental Impact Assessment*, Engineering Foundation, LBJ School of Public Affairs, University of Texas, 1976.

Brealey, Richard and Myers, Stewart, "A Project is Not a Black Box: Monte Carlo Simulation," London School of Business, Mass. Institute of Technology, 1984.

Buchanan, Shepard C., "Contingent Valuation Study of the Environmental Costs of Electricity Generating Technologies," *Electricity Journal*, 1990.

California Energy Commission, prepared by Regional Economic Research, Inc., "Valuing the Environmental Impacts of Alternative Energy Resources," 1991.

Chernick, Paul, Caverhill, Emily, "Monetizing Externalities in Utility Regulations: The Role of Control Costs," PLC, Inc., 1990.

Cohrssen, John J., Covello, Vincent T., *Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks*, Executive Office of the President of the U.S., 1989.

COMPLEAT, A Planning Tool for Publicly Owned Electric Utilities: Final Report, America Public Power Association, September 1990.

Costanza, Robert, "Embodied Energy and Economic Evaluation," Coastal Ecology laboratory, Center for Wetland Resources, Louisiana State University, 1980.

Crane, Cynthia M., "Externalities and Intangibles," Pacific Gas and Electric Company, 1985.

DeAngelis, Michael, Rashkin, Samuel, "The Social Benefits and Costs of Electricity Generation and End-Use Technologies."

Denver Research Institute, Browne, Bortz & Coddington, "Socioeconomic Impacts of Power Plants," Electric Power Research Institute, 1982.

Denver Research Institute, "Socioeconomic Impacts of Western Energy Resource Development, Vol. II Assessment Methodologies," 1979.

ECO Northwest, Ltd., Shapiro and Assoc. Inc., Seton, Johnson and Odell, "Estimating Environmental Cost and Benefits for Five Generating Resources," 1986.

Electric Power Software Center, Electric Power Research Institute, *Air Emissions Risk Assessment Model*, 1988.

Eto, J.H., Lawrence Berkely Laboratory, Applied Science Division, "An Overview of Analysis Tools for Integrated Resource Planning," *Energy, The International Journal*, March, 1990.

Fisher, Anthony C., Energy and Resources Group, University of California, Berkely, *Resource and Environmental Economics*, 1981.

Fisher, W.H., Chilton, C.H., *Capital Coefficients and Dynamic Input-Output Models*, "Developing *Ex Ante* Input-Output Flow and Capital Coefficients," Columbia Laboratories, Batelle Memorial Institute, 1975.

Ford, A., *BOOM I Model*, Los Alamos National Laboratory, 1976.

Forrester, Jay W., "Counterintuitive Behavior of Social Systems," *Toward Global Equilibrium: A Collection of Papers*, Wright-Allen Press, Inc., 1973.

Furukawa, Shunichi, "International Input-Output Analysis: Compilation of Case Studies of Interaction between ASEAN, Korea, Japan and the United States, 1975," Institute of Developing Economies, 1986.

Gaines, Linda R., Berry, Stephen, "TOSCA: The Total Social Cost of Coal and Nuclear Power," Committee on Public Policy, University of Chicago, 1979.

Gilbert and Newbery, "Regulation Games," University of California, Berkeley, Department of Economics, June 16, 1988.

Greenstreet, W.L., Carmichael, R.L., "Fuel-Cycle Analysis for Fossil Energy Systems: Coal Combustion," Oak Ridge National Laboratories, 1981.

Haveman, Harberger, et al., *Benefit Cost and Policy Analysis: An Aldine Annual on Forecasting, Decision Making and Evaluation, 1973*, 1974.

Hedman, Susan, "Reversibility as a Weighting Factor in Integrated Least Cost Planning Methodologies," Center for Global Change, University of Maryland, 1990.

Hetman, Francois, "Cost/Benefit Analysis in Technology Assessment Studies," *Society and the Assessment of Technology*, OECD, 1973.

Hohmeyer, Olav, "Social Costs of Energy Consumption: External Effects of Electricity Generation in the Federal Republic of Germany," Fraunhofer Institute, 1988.

Holtzman, Samuel, Strategic Decisions Group, *Intelligent Decision Systems*, 1989.

Huettner, David A., Center for Economic and Management Research, University of Oklahoma, "Net Energy Analysis: An Economic Assessment," *Science*, Vol. 192, (4235), April 9, 1976.

InnoTec Systemanalyse, Berlin, *EFLOW, Energy Flow Model for the Member States of the European Community*, 1987.

Krutilla, John V., Fisher, Anthony C., "The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources," Resources for the Future, 1985.

Lee, Moore, and Taylor, "Dynamic Programming," *Management Science*, Wm. C. Brown Publication, 1985.

Maag, Douglas R., *Including Societal Benefits in Rates for Cogeneration and Small Power Production: A Methodology and Handbook*, Ohio Public Utilities Commission, June 1990.

McMahon, James E., Lawrence Berkely Laboratory, Energy Analysis Program, "Policy Elements for Reducing Carbon Emissions in the Residential Sector."

Morgan, M.G., Barkovich, B.R., "The Social Cost of Producing Electric Power from Coal: A First-Order Calculation," University of San Diego, 1973.

Moskovitz, David, NARUC, *Profits and Progress through Least-Cost Planning*, November 1989.

Mountain West Research Inc., *BREAM, Bureau of Reclamation Economic Assessment Model*, U.S. Bureau of Reclamation, Denver, CO, 1978.

Murphy/Williams Consultants, "Socioeconomic Impact Assessment: A Methodology Applied to Synthetic Fuels," U.S. Department of Energy, 1978.

NARUC Proceedings, "National Conference on Environmental Externalities," October, 1990.

Oelert, G., F. Auer, K. Pertz, "Economic Issues of Renewable Energy Systems."

National Coal Council, "Special Report on Externalities", May 21, 1992.

Ottinger, Richard, *Environmental Costs of Electricity*, Pace University Center for Environmental Legal Studies, 1990.

Putta, Sury, N., "Weighing Externalities in New York State," New York State Department of Public Service, 1990.

Quinn, James Brian, "Technology Forecasting," *Harvard Business Review*, March-April 1967.

Randers, Jorgen, "DDT Movement in the Global Environment," *Toward Global Equilibrium: A Collection of Papers*, Wright-Allen Press, 1973.

Randers, Jorgen, Meadows Dennis, L., "The Dynamics of Solid Waste Generation," *Toward Global Equilibrium: A Collection of Papers*, Wright-Allen Press, 1973.

Sandia National Laboratories, Meridian Corp., "A Manual for Determining the Cost-Effectiveness of a Solar Vaccine Refrigeration System," U.S. Department of Energy, 1988.

Shuman, Michael, Cavanaugh, Ralph, "A Model Electric Power and Conservation Plan for the Pacific Northwest."

Stenehjem, E., *Social and Economic Assessment Model*, Argonne National Laboratory, 1978.

Temple, Barker, and Sloane, "Integrating Environmental Externalities into Resource Planning at New England Electric," 1989.

U.S. Department of Energy, Office of Conservation and Renewable Energy, *Characterization of U.S. Energy Resources and Reserves*, December 1989.

U.S. Department of Energy, Office of Conservation and Renewable Energy, *Climate Change Reference Book.*

U.S. Department of Energy, Office of Conservation and Renewable Energy, Utility Systems Division, "Methodology for Performing A Total Fuel Cycle Analysis as Part of Integrated Resource Planning," Draft Briefing, July 1990.

University of Texas Center for Energy Studies, *Community-level Impact Projection System*, Texas Energy Advisory Council, 1979.

Valuing Emission Reductions for Electricity Report 90, California Energy Commission, November 21, 1989 (includes a summary appendix of SCAQMD Teir I control measures).

Viollette, D., Lang, C., Hanser, P., "A Framework for Evaluating Environmental Externalities in Resource Planning: A State Regulatory Perspective," RCG/Hagler, Bailley; Electric Power Research Institute, 1990.

Whitney and Whitney, *Investment and Risk Analysis in the Minerals Industry*, 1981.

Wilson, Deborah, "Quantifying and Comparing Fuel-Cycle Greenhouse-Gas Emissions: Coal, Oil and Natural Gas Consumption," Dept. of Environmental and Energy Systems Studies, Institute of Science and Technology, Lund University, 1990.

Yasukawa, Mankin, Sato, et al., "Progress in Integrated Energy-Economy-Environmental Model System Development," Japan Atomic Energy Research Institute, 1987.

APPENDIX A

ADDITIONAL AIR QUALITY AND HEALTH IMPACT MODELS

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ADDITIONAL AIR QUALITY AND HEALTH IMPACT MODELS

Model Name	**Model Type**	**Damage Function Pollutants Modeled**
Buoyant Line and Point Source	Gaussian Plume	NO_x,SO_2,CO,PM
Climatological Dispersion Model	Gaussian Plume	NO_x,SO_2,CO,PM
Gaussian Plume Multiple Source Air Quality Algorithm (RAM)	Gaussian Plume	NO_x,SO_2,CO,PM
Industrial Source Complex Short-Term (ISCT)	Gaussian Plume	NO_x,SO_2,CO,PM
Industrial Source Complex Long-Term (ISCLT)	Gaussian Plume	NO_x,SO_2,CO,PM
Multiple Point Gaussian	Gaussian Plume	NO_x,SO_2,CO,PM
Single Source Model (CRSTER)	Gaussian Plume	NO_x,SO_2,CO,PM
Offshore and Coastal Dispersion Model (OCD)	Gaussian Plume	NO_x,SO^2,CO,PM
COMPTER	Gaussian Plume	NO_x,SO_2,CO,PM
SHORTZ	Gaussian Plume	NO_x,SO_2,CO,PM
LONGZ	Gaussian Plume	NO_x,SO_2,CO,PM
Models 3141 and 4141	Gaussian Plume	NO_x,SO_2,CO,PM
MULTIMAX	Gaussian Plume	NO_x,SO_2,CO,PM
Multi-Source Model (SCSTER)	Gaussian Plume	NO_x,SO_2,CO,PM
Pacific Gas and Electric PLUMES Model	Gaussian Plume	NO_x,SO_2,CO,PM
Plume Visibility Model (PLUVUE II)	Gaussian Plume	NO_x,SO_2,PM,O_3
Point, Area, Line Source Algorithm (PAL)	Gaussian Plume	NO_x,SO_2,CO,PM

APPENDIX A
ADDITIONAL AIR QUALITY AND HEALTH IMPACT MODELS
(Continued)

Model Name	**Model Type**	**Damage Function Pollutants Modeled**
Maryland Power Plant Sting Program Model (PPSP)	Gaussian Plume	NO_x,SO_2,CO,PM
Rough Terrain Diffusion Model	Gaussian Plume	NO_x,SO_2,CO,PM
SCREEN	Gaussian Plume	NO_x,SO_2,CO,PM
Shoreline Dispersion	Gaussian Plume	NO_x,SO_2,CO,PM
Fugitive Dust Model (FDM)	Gaussian Plume	PM
COMPLEX I/II	Gaussian Plume	NO_x,SO_2,CO,PM
VALLEY	Gaussian Plume	NO_x,SO_2,CO,PM
Mesoscale Transport Diffusion and Deposition Model for Industrial Sources (MTDDIS)	Gaussian Plume	NO_x,SO_2,CO,PM
Mesoscale Puff Model (MESOPUFF II)	Gaussian Plume	NO_x,SO_2
Air Resources Regional Pollutant Assessment (ARRPA) Model	Gaussian Segmented Plume	SO_2
AVACTA II	Gaussian Segmented Plume Segment/Puff	SO_2
Reactive Plume Model (RPM II)	Numerical, Lagrangian Photochemical Plume Model	SO_2,NO_2,CO,O_3
PLMSTAR Air Quality Simulation Model	Numerical, Lagrangian Photochemical Plume Model	SO_2,NO_2,CO,O_3
Photochemical Box Model	Numerical Box Model	O_3,NO_2,CO
Empirical Kinetics Modeling Approach (EKMA)	Numerical Box Model	O_3

APPENDIX A
ADDITIONAL AIR QUALITY AND HEALTH IMPACT MODELS
(Continued)

Model Name	Model Type	Damage Function Pollutants Modeled
Regional Acid Deposition Model (RADMII)	Numerical, 3-D Photochemical Grid Model	O_3,NO_2,SO_2,CO
Acid Deposition and Oxidant Model (ADOM)	Numerical, 3-D Photochemical Grid Model	O_3,NO_2,SO_2,CO
Sulfur Transport Eulerian Model (STEM II)	Numerical, 3-D Photochemical Grid Model	O_3,NO_2,SO_2,CO
Regional Oxidant Model (ROM)	Numerical, 3-D Photochemical Grid Model	O_3,NO_2,SO_2,CO,PM
Regional Transport Model (RTM III)	Numerical, 3-D Photochemical Grid Model	O_3,NO_2,SO_2
Caltech UAPM	Numerical, 3-D Photochemical Box Model	SO_2,NO_2,CO,O_3,PM
Urban Airshed Model (UAM)	Numerical, 3-D Photochemical Model	SO_2,NO_2,CO,O_3
Livermore Regional Air Quality Model (LIRAQ)	Numerical, 3-D Photochemical Model	SO_2,NO_2,CO,O_3
Integrated Model for Plumes and Atmospheric Chemistry in Complex Terrain (IMPACT)	Numerical, 3-D Photochemical Model	SO_2,NO_2,CO,O_3

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