NREL/TP-463-6154 • UC Category: 1321 • DE94000278

# A Fuel Cycle Assessment Guide for Utility and State Energy Planners

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*Columbia, Maryland*

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1617 Cole Boulevard
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A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

Prepared under Subcontract No. AAW-3-13003-01-103595

July 1994

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# ACKNOWLEDGMENTS

BCS, Incorporated, would like to acknowledge the valuable assistance of those involved in the process of developing and refining this guide. In particular, we would like to acknowledge: Gerald Duckett, Buffalo Coal; Jeff Fang, National Renewable Energy Laboratory; Frederick Florian, Osram-Sylvania; Alan Haymes, Maryland Public Service Commission; Frank Heinz, Maryland Public Service Commission; William Herrman, PEPCO; Jeffrey Meyers, Columbia Gas; Donald Milsten, Maryland Energy Administration; William Pino, BG&E; Kevin Porter, National Renewable Energy Laboratory; William Rever III, Solarex; Gerald Thorpe, Maryland Energy Administration, and Andrew Williams, PEPCO.

## PREFACE

In December 1991, a draft of the *Fuel Cycle Assessment Guide* was developed for the U.S. Department of Energy (DOE), Assistant Secretary for Energy Efficiency and Renewable Energy (EERE), Office of Utility Technologies (OUT), Integrated Resource Planning (IRP) Program. The objective of that report was to account for the potential impacts (costs and/or benefits) along the fuel cycle of energy technologies. It was designed to be a first step in

- Identifying the potentially broad scope of a fuel cycle analysis
- Developing a method for establishing research parameters around regionally appropriate fuel cycle analysis.

The draft guide provided an extensive array of potential environmental, social, economic, and technological impacts across all stages of the energy technology fuel cycle.

Early in 1992, the Maryland Public Service Commission (MD PSC) and Maryland Energy Administration (MEA) requested to have the draft guide implemented on a test case basis in the state of Maryland. They selected four energy technology case examples:

- Combined cycle gas turbine system
- Pulverized coal boiler
- Energy efficient lighting retrofit
- Demonstration of photovoltaics at an aquaculture center.

An initial working group was assembled. It was comprised of representatives from key Maryland agencies, utilities, and industry representatives for each of the four case example energy technologies. In addition, National Renewable Energy Laboratory staff members and representatives from the Maryland Department of Natural Resources also participated.

| Working Group Participants | |
|---|---|
| MD Energy Admin. | Osram-Sylvania |
| MD PSC | Solarex |
| MD Dept. of Natural Resources | Buffalo Coal |
| | Columbia Gas |
| PEPCO | Natl. Renewable Energy Laboratory |
| Baltimore Gas & Electric | BCS, Incorporated |

The objective of the project was to design a framework for initiating regionally appropriate fuel cycle analysis and incorporating the results into IRP or other energy-related planning. The individuals in this working group provided input to establish parameters around the analysis -- identifying those stages and impacts that were thought to be relevant and important to research. Briefly, the approach has been to

1. Scope out a wide range of environmental and non-environmental impacts (as shown in the draft guide).

2. Assemble IRP practitioners from state, utility, and industry organizations to identify the key stages and impacts of the fuel cycle -- effectively setting parameters around the analysis.

3. Conduct research to identify data resources for quantitatively or qualitatively measuring selected impacts.

4. Identify data gaps and research needs.

5. Revise the guide.

6. Finalize the guide.

The results of the research to characterize the four technology fuel cycles and identify data resources and gaps were provided in an earlier report, *Evaluation of the Fuel Cycle Assessment Guide for Framing a Fuel Cycle Analysis.* Based on that research and on practitioner inputs, preliminary revisions were made to the guide. These were presented in a second meeting where the IRP practitioners from the initial working group were reassembled. Their inputs on the earlier revisions were used to finalize the guide.

The evaluation of the guide resulted in several significant improvements that will help to enable states, utilities, and other users to implement structured and methodical fuel cycle research for a variety of alternative purposes.

**The guide is one component of a project to evaluate the use of fuel cycle analysis models and methods in IRP. Additional activities performed as part of this effort included**

- **Developing criteria to evaluate the data and models used in a fuel cycle assessment**
- **Providing results of fuel cycle research and data gaps for the four case examples**
- **Developing *Fuel Cycle Assessment: A Compendium of Models, Methodologies and Approaches.***

**The compendium profiles a variety of tools and techniques that could be considered for performing fuel cycle analysis or some component thereof. The evaluation criteria provide a point of measurement for assessing the usefulness of the data and models that would be utilized. Both of these components provided important assistance in refining the guide and can serve as useful resources in considering and implementing fuel cycle analysis within an IRP setting.**

Specifically, the refined guide is a structured tool providing

- An approach for assembling state, utility, and IRP constituents to collaboratively frame the fuel cycle analysis parameters and select valuation technique(s)
- A means for initiating fuel cycle research
- Excel 4.0 spreadsheets to calculate and store quantitative and/or qualitative data measuring specific impacts in each stage of the fuel cycle
- A range of additional applications of the guide and fuel cycle research
- A resource of potential data and analytical resources that can be used for utility, state, or federal planning activities.

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## LIST OF EXHIBITS

# SECTION 1. INTRODUCTION

## A. OVERVIEW

This document is intended to provide a framework for setting parameters, collecting data, and analyzing fuel cycles for supply-side and demand-side management (DSM) technologies. It is intended to provide users with an automated tool for entering comparative fuel cycle data that are meaningful to their state/utility integrated resource planning (IRP), collaborative, and/or regional energy planning activities. The guide outlines an extensive range of energy technology characteristics and environmental, social, and economic considerations within each stage of a fuel cycle. The guide is designed to be flexible, however, and permit users to focus on those specific stages/impacts relevant to the technology under evaluation and that meet the user's planning requirements.

While the guide provides a framework for data analysis, it does not provide the data or empirical structure for analysis. That is for the user to determine through relevant state or regional energy planning organizations.

The guide is one of a series of resource documents designed to assist in the application of fuel cycle assessment. The other documents include: *Fuel Cycle Assessment: A Compendium of Models, Methodologies and Approaches; Evaluation Criteria for Total Fuel Cycle Analysis Data, Models and Methodologies;* and *Evaluation of the Fuel Cycle Assessment Guide for Framing a Fuel Cycle Analysis*. These resource documents provide decision makers with the ability to identify, evaluate, and select from a range of analytical techniques, computer based models, and/or decision-making methodologies for performing fuel cycle assessment. Users can identify those tools that are most appropriate for their needs. The documents also will assist in identifying potential data resources for implementing the research and highlighting major gaps in fuel cycle data. These documents are available from:

National Renewable Energy Laboratory (NREL)
Mr. Blair Swezey
Principal Policy Advisor
1617 Cole Blvd.
Golden, CO 80401
(303) 231-7014

Some data resources that could be used to assist in a fuel cycle assessment are shown in Appendix A. Also shown in Appendix A are selected models profiled in the compendium.

## B. ORGANIZATION OF THE GUIDE

The guide is a workbook for framing a fuel cycle assessment and initiating the research process and is organized as follows:

**SECTION 2:** Fuel Cycle Assessment - A brief discussion of the fuel cycle and its applications and fuel cycle assessment.

**SECTION 3:** Implementing the Guide.

**SECTION 4:** Fuel Cycle Assessment Worksheets

- Summary worksheet for establishing research parameters around the fuel cycle analysis individually, and then reaching consensus in a group setting
- Detailed worksheets to the Guide.

**APPENDIX A:** Appendix A provides potential data resources for fuel cycle assessment and models, software tools, and techniques.

## SECTION 2. FUEL CYCLE ASSESSMENT

This section provides an overview of fuel cycle assessment, its objectives, and some of the complexities involved in implementing the analysis. It discusses the stages of the fuel cycle and general objectives of fuel cycle assessment. This section is designed to assist users frame their own analysis and develop objectives, as well as identify some of the key issues to be resolved prior to implementing a fuel cycle assessment.

### A. OVERVIEW

Fuel cycle assessment is the examination of market and non-market costs for any energy supply or demand technology option. The fuel cycle is different for each technology option -- comprising a varied series of stages and impacts. Typically, the fuel cycle includes exploration and extraction, raw materials processing, the production of the finished product, consumption, and waste disposal -- with transportation and storage activities occurring throughout the cycle. The fuel cycle can be defined generically, however, as follows:

> *The fuel cycle includes all direct and indirect actions and their associated costs of a technology option 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 societal or environmental, impacts that are not internalized in the market price of energy. The impacts can occur in economic, environmental, and social categories.*

Analysis of the fuel cycle allows for evaluation of the "total cost" associated with delivering a unit of energy. Total costs equal the internalized costs plus the unpriced externalities that occur throughout the fuel cycle. In some form, internalized costs include both direct and indirect costs attributable to energy. Examples of direct internalized costs include fuel, capital investment, personnel, operations and maintenance, transportation or transmission, waste disposal, and waste management. Examples of indirect internalized costs include private sector research and development (R&D), legal costs, and administrative costs. Externalities are those costs not represented in the market price of energy, such as the costs associated with land, air and water pollution, public sector costs, and impacts on human or animal health. Benefits accrue throughout a technology's fuel cycle and these also comprise total costs. Examples include supply reliability, employment benefits, and technological advancement.

A fuel cycle assessment allows the analyst to identify the components of the true total cost of selected supply- and demand-side energy technology options and provides a framework for appropriate qualitative and quantitative assessment of those components. Thus, all energy and conservation resources are placed on a "level playing field." This allows for a greater degree of fairness in comparing technology cost-effectiveness. In addition, an understanding of total fuel cycle costs supports energy planning and energy policy analysis activities.

## B. STAGES OF THE FUEL CYCLE

The following is the track of a multi-stage fuel cycle that can be applied for the analysis of supply-side and demand-side utility technologies. It falls into four primary phases -- raw materials phase, production phase, waste disposal phase (recovered and unrecovered), and post-operation phase. Activities associated with the transportation and storage stages are continuous throughout the fuel cycle. It is based on the standard steps and procedures that typically occur in transforming raw materials from the earth into consumable goods. The stages are

Raw Materials Phase

1. Resource exploration and extraction
2. Raw materials processing

Production Phase

3. Manufacturing and construction
4. Transportation
5. Storage

Operation Phase

6. Conversion to electricity
7. Distribution/Transmission
8. End-Use (i.e., gas technologies, DSM technologies)

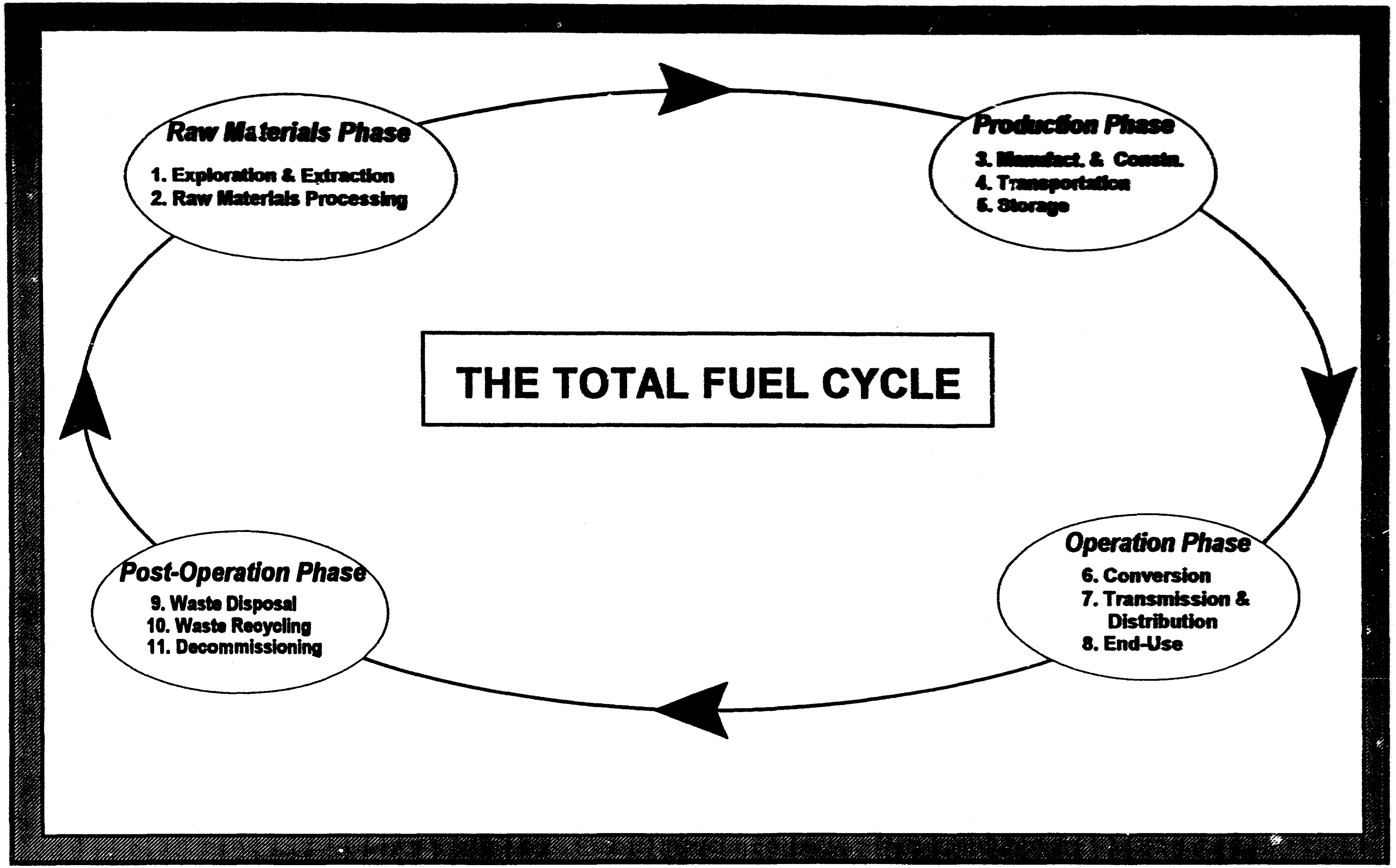
Post-Operation Phase

9. Waste disposal (unrecovered)
10. Waste recycling
11. Decommissioning/Retirement.

The fuel cycle is illustrated in Exhibit 1. 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.

Within the detailed worksheets to the guide, each stage has been briefly characterized. This is to assist the user in clearly identifying and defining the stages of the fuel cycle for the particular technology under analysis. It also will assist in ensuring that the identification of activities and impacts within each stage are clearly delineated and that related impacts are not omitted or double-counted. The definitions provided in the worksheet are to be used for guidance. Users may modify them as necessary for their specific application and objectives.

**Exhibit 1**



THE TOTAL FUEL CYCLE
Raw Materials Phase
1. Exploration & Extraction
2. Raw Materials Processing
Production Phase
3. Manufact. & Constr.
4. Transportation
5. Storage
Operation Phase
6. Conversion
7. Transmission & Distribution
8. End-Use
Post-Operation Phase
9. Waste Disposal
10. Waste Recycling
11. Decommissioning

## C. OBJECTIVES OF FUEL CYCLE ASSESSMENT

Much of the current popularity of fuel cycle assessment stems from the need to identify various environmental effects associated with the production of electrical power. Fuel cycle analysis has other policy and program analysis capabilities that are worthy of further explanation. *Fuel cycle analysis is a powerful framework for identifying and analyzing energy issues as well as government and private sector responses.* It also is unique in that it can provide a basis for the analysis of specific energy applications, utility plans, state or regional plans, or national strategic energy plans.

Environmental issues are the best known and are often regarded as the primary, if not only, rationale for fuel cycle analysis. By identifying all events in the process through which fuels move on their way to the end-user, the analysis provides a basis for identifying all the potential sources of impacts. This allows for the identification of impacts in stages upstream and downstream of the conversion stage rather than just at the point of conversion, which is the focus of most commonly studied sources of environmental impacts stemming from energy use.

*Research and development program planning can benefit from fuel cycle analysis.* The justification of R&D is a difficult process because of the sometimes problematic connection between the activities undertaken and the perceived problems to be solved. While these difficulties will never be fully resolved, fuel cycle analysis can provide a basis for selecting R&D activities. It provides an expanded view of how the technology being examined interacts with other technologies and markets. The analysis can be used to indicate subject areas or specific applications in which additional R&D could be expected to make the technology more competitive in the market place.

*The identification of market opportunities, especially niche markets, can benefit from the comparative use of fuel cycle analysis.* Emerging technologies must seek out markets or market segments in which they can compete early in their development. Fuel cycle analysis provides a common framework for examining all energy technologies and applications and thereby provides a basis for comparatively examining both primary and secondary energy uses at all production, transportation/transmission, end-use, and disposal nodes. By comparing the fuel cycle of one fuel with that of another, it may be possible to identify niche markets for emerging technologies that are currently not visible using traditional market analysis techniques.

A firm understanding of the fuel cycle contributes an additional benefit to energy policy and program analysis. *Fuel cycle analysis provides a schematic for the discussion of energy issues and policy alternatives.* This schematic offers the advantage of being able to place, within an agreed-upon context, the program elements, technologies, and options available to decision makers. This ability to locate the nexus of multiple programs or policies has the potential to establish an important rationality to energy policy and research. Coupled with regulatory analysis that identifies governmental actions, jurisdictions, and impacts, fuel cycle analysis provides a powerful and scientific approach to addressing energy issues.

## D. COMPLEXITIES IN THE ANALYSIS

There are a number of difficulties in performing a fuel cycle assessment. Some of the major complexities include the following:

- Establishing a geographical or political jurisdiction framework for analysis is a complex issue. Boundaries must be defined for the depth of externalities to be analyzed. For example, a boundary established to assess only direct impacts will consider only the direct cost of pollution (i.e., the cost of abatement), whereas secondary level boundaries will incorporate indirect costs such as health costs from emissions. An even deeper analysis will include tertiary impacts such as the cost of those health impacts on socio-economic systems.

- Many fuel cycle impacts are very site specific in nature. The surrounding ecosystem, weather patterns, population centers, and infrastructure can alter how the fuel cycle impacts occur and the effect they have.

- The temporal nature of fuel cycle impacts is another factor that must be addressed in implementing a fuel cycle assessment. Some impacts are one-time or temporary impacts. Examples include job creation associated with power plant construction or lighting retrofit programs, and mercury and polychlorinated biphenyl (PCB) disposal associated with lighting retrofits. Other impacts, however, are long-term or continuous; examples include emissions related to resource extraction, power plant emissions, and ash disposal.

- Data development can be a costly process and it may not be possible to achieve an acceptable level of validity within budgeting constraints. The selection of boundaries that will frame the analysis may be based largely on the ability and the cost of generating specific data elements. The level of analysis is important to render any comparative judgement regarding the use of a given energy technology.

- Another issue is the cost and complexity of assembling valid and comprehensive data to quantify externalities. Some of these data are known or estimates exist. For other data elements, however, no current resource exists and some data elements can only be expressed by qualitative measures. Moreover, each supply- and demand-side technology will have its own fuel cycle characteristics and thus varying externalities from stage to stage.

- Many impacts associated with energy resources are regulated. These include environmental impacts associated with oil and gas drilling, coal producer payments for mining-related health impacts, and emissions from utility generating stations. The measures that companies implement to comply with these regulations are generally incorporated in the price passed on to the customer in the next stage of the fuel cycle and, ultimately, to the final consumer (i.e., the utility ratepayer). Fuel cycle analyses must recognize that some impacts are already accounted for (partially or completely) by current regulation and avoid double counting these impacts. Also, it may be necessary to include in a comparative fuel cycle analysis, the level of regulation upon one technology option versus another and the extent to which regulation may have forced internalization of some of the costs of fuel cycle impacts.

- Another complexity is the method of valuation. Various techniques are available for qualitatively or quantitatively valuing specific fuel cycle impacts. These methods vary in their cost and complexity. Decision makers will need to evaluate these methods in terms of how their specific needs are best fulfilled within time and budget constraints.

In conducting research to develop this guide, a number of data resources were identified that could be used in performing a fuel cycle assessment. These included case-specific data from private sector manufacturers, producers of raw materials, or recyclers on impacts such as emissions, accidents, and employment. They also included state agency reviews of the environmental and socioeconomic impacts from power plant development. These are types of data that can be readily fed into the fuel cycle assessment and that may substantially assist in evaluating energy technologies on a broader scale. However, a number of data gaps also were identified. These gaps may or may not be filled easily or cost effectively. Users of the guide will need to assess whether or not to fill those gaps and at what cost.

## E. TECHNIQUES FOR QUALIFYING AND QUANTIFYING FUEL CYCLE IMPACTS

Estimating the costs and benefits associated with energy technologies can be very difficult. For example, how can a monetary value be placed on the visual impact of aquatic degradation to rivers or streams? It is unlikely that a single monetary value can adequately represent the social cost of that impact for all parties involved. To value impacts such as this requires techniques that are equitable and unbiased.

For other external costs such as atmospheric emissions from the direct combustion of fossil fuels, there are a range of available estimates to quantify and monetize their cost. These estimates account for the cost of controlling those emissions or valuing the associated physical damages. Many of these estimates have been published in literature that summarizes the environmental costs for selected generating technologies. Some state commissions used these estimates to develop monetized adders for specific externalities.

In developing estimates of external costs, whether quantitative or qualitative estimates, several techniques can be considered. The selection of a technique(s) should be a function of local priorities, the method in which the data are to be used, the scope of the research effort, and the resources available for performing the research. Exhibit 2 briefly describes some of the approaches.

In addition, *Total Fuel Cycle Assessment: A Compendium of Models, Methodologies and Approaches* (available through NREL) provides profiles of a number of analytical techniques, as well as models for performing the analysis. Selected models, software tools, and standard techniques for performing the analysis required to assess fuel cycle impacts are also listed in Appendix A. These include some of the models and approaches profiled in the compendium.

**Exhibit 2**
**Valuation Approaches**

**Contingent Valuation** - Contingent valuation models are direct surveys of consumers to elicit their valuations of direct, non-market fuel cycle impacts. These can include environmental impacts such as water degradation or smog. They can also include the valuation of social patterns that may be disrupted because of the location of a power plant or other facility. One approach to Contingent Valuation is "willingness-to-pay." Willingness-to-pay is the amount that individuals (and/or ratepayers) in the local area are willing to pay to avoid the specific externality. Willingness-to-pay can be measured through discussion and consensus in an expert round table or through demonstrated consumer behavior.

**Ranking and Weighting** - This is a multi-attribute decision-making method for systematically evaluating environmental and non-environmental externalities. Each of the effects of interest is identified, organized, and weighted in terms of importance. The external effects from each resource alternative are measured (in physical terms where possible) and the severity of each effect is given an interval score (i.e., 0 = no effect, ... 10 = severe adverse effect). The sum of the weighted scores is used to perform the evaluation of the environmental and non-environmental impacts of each technology alternative.

**Dose-Response** - This method can be used to measure the biological impacts from increases in a particular type of human activity. Examples include health effects associated with atmospheric emissions; direct kills to species or loss of habitat from waste disposal; ecosystem impacts from flow variation or thermal impacts; the effect of land/biomass use on environmental disasters such as floods or landslides; and attitudinal responses to aesthetic effects.

**Description and Characterization** - This is a more qualitative approach to valuing impacts. A brief summary of the impact is performed based on historic data, literature reviews, or professional judgment. Based on these characterizations, the impact can then receive a measure (i.e., numerical ratings, positive/negative measure +,0,-).

**Hedonic Pricing** - Hedonic pricing is a technique for measuring the implicit price for resource attributes or characteristics associated with an environmental good; the price of the non-market good is given as a function of the quantities of various characteristics such that the coefficient on those characteristics represent implicit prices.

## F. UTILIZING THE RESULTS OF FUEL CYCLE RESEARCH

When the results have been assembled from the completed worksheets, they can be used to augment IRP or energy planning processes.

The results of fuel cycle research can be used to assist in a variety of activities. From a state perspective, they can be used to assist in the review of integrated resource plans or in the development of state energy strategies. Federal or industry research organizations can use the results of fuel cycle analysis to identify areas that will improve the technology. In addition, economic planners may want to assess the economic costs/benefits of various energy technology fuel cycles to maximize the economic opportunities that particular technologies or energy programs represent.

Exhibit 3 identifies some of the potential applications of fuel cycle analysis in this guide. Many of these were identified by state, utility, and industry representatives during the evaluation of the guide in the state of Maryland. As it illustrates, fuel cycle analysis offers a variety of applications and benefits. These include

- Augmenting current IRP activities such as site evaluation and the fuel cycle assessment of selected technologies (e.g., at the back-end of the IRP process). Also, it could be used for evaluating bids received for purchased power agreements.

- National, regional, or state energy policy analysis and planning

- Evaluation of alternative R&D funding options and prioritization of those options based upon key criteria.

**Exhibit 3**
**Potential Applications of the Fuel Cycle Assessment Guide**

| APPLICATION | OUTPUTS |
|---|---|
| ***Integrated Resource Planning***<br><br>**The guide can be implemented to augment current IRP activities including:**<br><br>- **the collaborative process**<br>- **site evaluations for new generating stations**<br>- **comparative analysis of selected supply/demand technologies**<br>- **review of bids for non-utility power**<br>- **utility strategic planning.** | ▸ **Provides a comparative analysis of fuel cycle activities and processes**<br><br>▸ **Provides a comparative analysis of economic, environmental, and social impacts (in each stage of the fuel cycle for selected technology options)**<br><br>▸ **Augments cost and performance data** |
| ***Energy Planning and Policy Analysis***<br><br>**The guide can be applied by state, regional, or national energy organizations in developing energy strategies.** | ▸ **Augments justification for potential changes in policy direction or new policy goals**<br><br>▸ **Can be used for identifying priority technologies or programs for state, regional, or national promotion** |
| ***R&D Program Screening and Prioritization*** | ▸ **Strategic mapping of R&D pathways correlated to organizational objectives (i.e., environmental or economic objectives)**<br><br>▸ **Input into R&D long- and mid-term strategic planning processes** |

## SECTION 3. IMPLEMENTING THE GUIDE

The implementation process is straightforward and is designed to ensure that the fuel cycle assessment effort is responsive to regional priorities and can be used within established planning frameworks.

Steps essential to implementation include

1. ***Identify and assemble participants in the IRP/fuel cycle assessment working group and define the technology application. (See page 19)***

2. ***Establish fuel cycle assessment research parameters using the summary worksheet contained in the guide. (See page 23)***

3. ***Review the responses to the worksheets and reach a consensus on the definitions and parameters to be used in the detailed analysis.***

4. ***Begin the fuel cycle research process using the detailed worksheets. (See page 12)***

5. ***Perform comparative fuel cycle assessment for decision processes.***

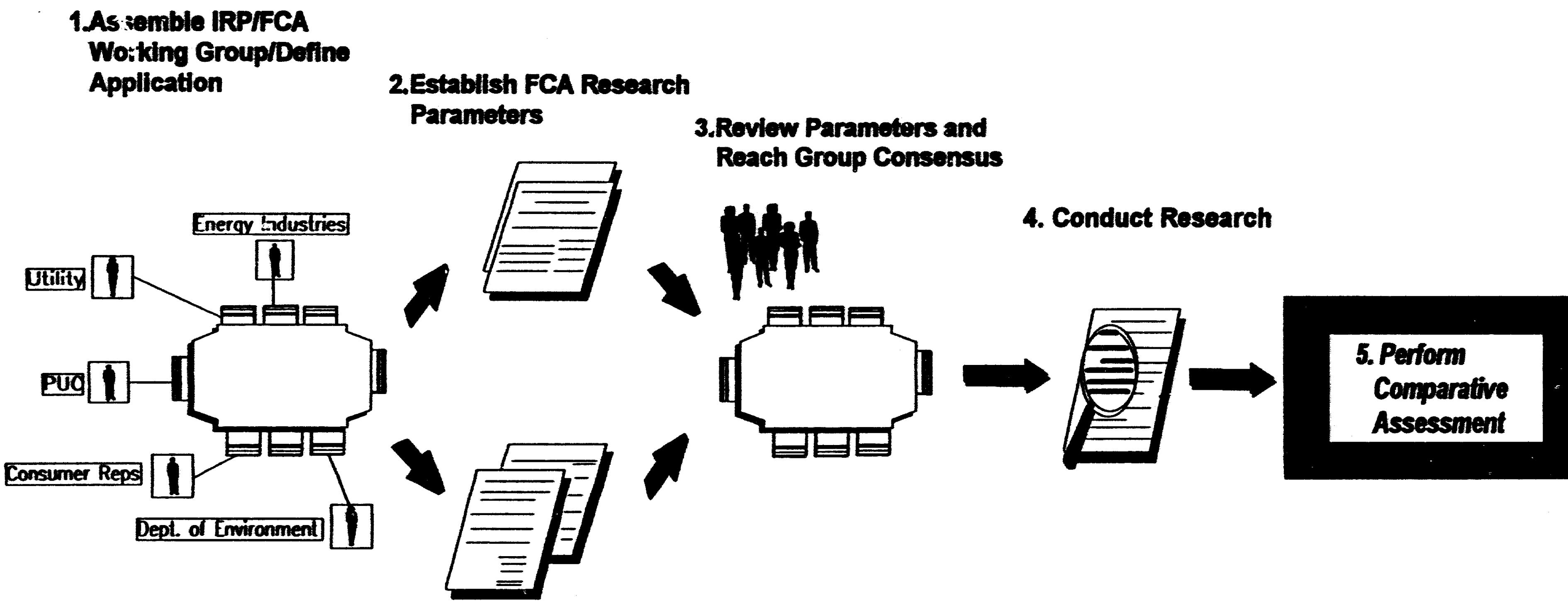
Each of these steps is described in detail below. (Exhibit 4 illustrates an approach to framing fuel cycle analysis.)

1. ***Identify and assemble participants in the IRP/fuel cycle assessment working group*** - Participants can include representatives from state agencies such as the public service commission, energy authorities, environmental agencies, and representatives for potential energy consumers. They can also include representatives from utilities and others in the energy industry. The group will assemble to review the objectives of the fuel cycle assessment effort, evaluate the overall process, and discuss any modifications to the process.

   The specific supply and/or demand-side technology(s) being evaluated will be defined using the technology application worksheets (p. 18).

   Also, summary total fuel cycle worksheets (p. 21) will be provided to each participant and instructions will be given on how they are to be completed.

## Exhibit 4
## Approach to Performing Fuel Cycle Analysis



2. ***Establish fuel cycle assessment research parameters using the summary worksheets in the guide*** - The purpose of this activity is for each of the working group members to individually complete the summary worksheet for establishing fuel cycle research parameters. Individually, each member will identify

   a) The stages that he/she believes should be included in the research

   b) the environmental, social, or economic impacts that he/she believes should be included in the analysis.

   This worksheet was not included in the original draft of the guide; however, the value of such a worksheet became clear during the process of refining the guide.

   The objective of this activity is to obtain expert input for establishing boundaries around the research and analysis -- starting from a broad scope and then focusing down to high priority stages and impact categories.

3. ***Review the responses to the worksheets and reach consensus on the definitions and parameters to be used in the detailed analysis*** - The working group will reassemble to review the individual inputs and reach a group consensus on

   a) Research parameters - which stages/impacts should be included in the fuel cycle research process

   b) Criteria impacts - which fuel cycle impacts or research needs are of highest priority

   c) Valuation technique(s) - which techniques are to be used in measuring the impacts qualitatively or quantitatively

   d) Weights (if any) - to be applied to the criteria impacts.

4. ***Begin the fuel cycle research process using the detailed worksheets*** - This entails identifying and gathering data and using the detailed worksheets of the guide to conduct the research process. The guide provides detailed worksheets which reflect a broad overview of potential fuel cycle impacts. The specific worksheets to be used will depend on the stage/impact boundaries agreed upon in Step 3.

   The worksheets shown in the guide provide "examples" of types of impacts that may occur in each stage (i.e., land requirements for coal mining). These are to assist in describing the particular impact category. Users must identify the specific impacts that are to be evaluated. (See Appendix A for potential data resources.)

5. ***Conduct comparative assessment for decision processes*** - Assemble the data collected, evaluate the worksheet results, and use the results for the specific

application selected (e.g., collaborative process, R&D prioritization, IRP, etc.). This requires identifying locally appropriate applications of the Guide and designing and testing methods for using the results.

When the Guide was tested in Maryland, representatives from state agencies, utilities, and the energy industry were assembled to evaluate the Guide as a tool for implementing FCA within an IRP setting. All of those that participated in the evaluation and refinement of the Guide indicated that the results of fuel cycle assessment could be useful in resource assessments, IRP processes, the collaborative process, as well as in establishing R&D priorities.

# FUEL CYCLE ASSESSMENT WORKSHEETS

# SUPPLY AND DEMAND TECHNOLOGY APPLICATION WORKSHEETS

***The following worksheets are to be completed by the IRP/FCA working group participants. Their purpose is to provide guidelines for clearly defining and describing the specific technology and application that is being evaluated. The characteristics of the specific supply or demand-side system(s) under consideration impact the approach to implementing the fuel cycle analysis, the nature of the fuel cycle, and the fuel cycle impacts to be analyzed.***

## Supply Technology Application

| *Overview:* | *Description* |
|---|---|
| Location/Acreage – | |
| System type/Supplier – | |
| Prime mover/Back-up — | |
| System size – | |
| Fuel supply/Source – | |
| Anticipated date on-line – | |
| – Other | |
| – | |
| – | |
| ***Operational Data:*** | |
| Anticipated annual generation | |
| Heat rate (Btu/kWh) | |
| Net efficiency | |
| Emission rates | |
| Duty cycle | |
| – | |
| – | |
| – | |
| Emission control technologies | |
| – | |
| – | |
| Water consumption | |
| Steam production | |
| – Other | |
| – | |
| – | |
| ***Cost Data:*** | |
| Capital costs (estimated) | |
| O&M costs (estimated) | |
| – Fixed | |
| – Variable | |
| – Other | |
| – | |
| – | |

# Demand-Side Technology Application

| *Overview:* | *Description* |
|---|---|
| Project/Site – | |
| Technology/Supplier – | |
| Size/Quantity – | |
| Anticipated installation date – | |
| Anticipated life-cycle | |
| – Other | |
| – | |
| – | |
| *Operational Data:* | |
| Anticipated annual energy consumption | |
| kW/therms avoided | |
| Net efficiency | |
| Emissions avoided | |
| Duty cycle | |
| – | |
| – | |
| – | |
| – Other | |
| – | |
| – | |
| *Cost Data:* | |
| Capital costs (estimated) | |
| O&M costs (estimated) | |
| – Fixed | |
| – Variable | |
| Rebates | |
| Internal rate of return | |
| – Other | |
| – | |
| – | |
| – | |

# SUMMARY WORKSHEET FOR SETTING FUEL CYCLE RESEARCH PARAMETERS

***The following worksheet is to be completed individually by IRP/FCA working group participants. Please place a check mark in the cell corresponding to the stage/impact categories that you believe should be included in the fuel cycle research process. Your results will be used with those of other members of the working group to develop a consensus on the parameters to bound the fuel cycle research process.***

# SUMMARY WORKSHEET FOR SETTING FUEL CYCLE RESEARCH PARAMETERS

| IMPACTS \ STAGES | Exploration & Extraction | Raw Materials Processing | Manufacturing & Construction | Transportation | Storage | Conversion | Transmission & Distribution | End-Use | Waste Recycling | Waste Disposal (unrecovered) | Decommissioning/Retirement |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Environmental Impacts** | | | | | | | | | | | |
| **1. Terrestrial Impacts** | | | | | | | | | | | |
| a. Land requirements | | | | | | | | | | | |
| b. Soil impacts | | | | | | | | | | | |
| i. Run-off, leaching | | | | | | | | | | | |
| ii. Soil erosion | | | | | | | | | | | |
| **2. Groundwater and Aquatic Impacts** | | | | | | | | | | | |
| a. Run-off to open streams, rivers | | | | | | | | | | | |
| b. Migration to groundwater | | | | | | | | | | | |
| c. Water requirements | | | | | | | | | | | |
| **3. Atmospheric Impacts** | | | | | | | | | | | |
| a. Emissions | | | | | | | | | | | |
| **4. Species and Vegetation impacts** | | | | | | | | | | | |
| a. Terrestrial vegetation | | | | | | | | | | | |
| b. Terrestrial wildlife | | | | | | | | | | | |
| c. Aquatic ecosystems | | | | | | | | | | | |
| **5. Aesthetics** | | | | | | | | | | | |

## SUMMARY WORKSHEET FOR SETTING FUEL CYCLE RESEARCH PARAMETERS

| STAGES / IMPACTS | Exploration & Extraction | Raw Materials Processing | Manufacturing & Construction | Transportation | Storage | Conversion | Transmission & Distribution | End-Use | Waste Recycling | Waste Disposal (unrecovered) | Decommissioning/Retirement |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Social Impacts** | | | | | | | | | | | |
| **1. Education/Technical** | | | | | | | | | | | |
| a. Impact on educational institutions | | | | | | | | | | | |
| b. Impact on technical advancement | | | | | | | | | | | |
| **2. Community Impacts/ Social Patterns** | | | | | | | | | | | |
| **3. Infrastructure** | | | | | | | | | | | |
| a. Service/supply impacts | | | | | | | | | | | |
| b. Structural damage/improvements | | | | | | | | | | | |
| **4. Social/ Cultural Issues** | | | | | | | | | | | |
| **5. Demographics** | | | | | | | | | | | |
| **6. Safety/ Health** | | | | | | | | | | | |
| a. Morbidity | | | | | | | | | | | |
| b. Mortality | | | | | | | | | | | |

# SUMMARY WORKSHEET FOR SETTING FUEL CYCLE RESEARCH PARAMETERS

| STAGES / IMPACTS | Exploration & Extraction | Raw Materials Processing | Manufacturing & Construction | Transportation | Storage | Conversion | Transmission & Distribution | End-Use | Waste Recycling | Waste Disposal (unrecovered) | Decommissioning/Retirement |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Economic Impacts** | | | | | | | | | | | |
| **1. Economic Development** | | | | | | | | | | | |
| a. Direct | | | | | | | | | | | |
| b. Indirect | | | | | | | | | | | |
| **2. Economic Competitiveness** | | | | | | | | | | | |
| **3. Employment** | | | | | | | | | | | |
| a. Direct | | | | | | | | | | | |
| b. Indirect | | | | | | | | | | | |
| **4. Public Sector** | | | | | | | | | | | |
| a. Facility and service requirements | | | | | | | | | | | |
| b. Public sector costs/revenues | | | | | | | | | | | |
| **Other** | | | | | | | | | | | |
| | | | | | | | | | | | |

# DETAILED WORKSHEETS TO THE GUIDE

*The following are the worksheets to the guide. They are provided for each of the eleven stages of the fuel cycle and list the full range of environmental, social, and economic impact categories and subcategories. In completing the worksheets, the results of the negotiated summary worksheet should be used in establishing parameters -- only including those stages/impacts agreed upon by the group.*

*The first column lists the categories and subcategories of impacts. Examples of specific elements within these impact categories are provided. Users can fill in the specific impact elements that occur in the fuel cycle of the specific technology and application being evaluated.*

*The "Include (Y/N)" column is provided for users to indicate whether or not impact categories/subcategories in each stage are being included.*

*To the right of the "Include (Y/N)" column, a "Quantitative Measure" column and a "Qualitative Measure" column have been provided. Quantitative or qualitative measures of the impact are to be inserted.*

| **STAGE 1: EXPLORATION & EXTRACTION** - The identification and development of primary energy resources. This includes impacts associated with extracting raw materials such as coal, natural gas, and mercury, or harvesting timber or bio-crops. Impacts directly associated with the extraction of primary resources are considered relevant. The analysis does not include impacts associated with co-product development. | | | |
|---|---|---|---|
| **A. ENVIRONMENTAL IMPACTS** | **Include (Y/N)** | **Qualitative Measure** | **Quantitative Measure** |
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| i. Mining | | | |
| - coal | | | |
| - mercury | | | |
| - | | | |
| - | | | |
| ii. Drilling: | | | |
| - oil | | | |
| - gas | | | |
| - | | | |
| - | | | |
| iii. Rehabilitation of existing sites | | | |
| - reforestation | | | |
| - land reclamation | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - metals | | | |
| - tailings | | | |
| - | | | |
| - | | | |
| ii. Soil erosion (i.e. logging, mining) | | | |
| - dissolved solids | | | |
| - turbidity | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - tailings | | | |
| - brine production | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - oil spills | | | |
| - phosphates | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - flooding for reservoirs | | | |
| - cooling water | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - sulfur dioxide | | | |
| - NOx | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |
| - | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - black lung | | | |
| - asthma | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - cancer | | | |
| - heart disease | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

| STAGE 2: RAW MATERIALS PROCESSING - Impacts associated with the processing of raw materials for use in manufacturing and construction, conversion to electricity, DSM technologies, etc. Examples include oil refining, coal beneficiation, the preparation of synthetic materials to be used in insulation, and the processing of noble metals or electrochromic materials to be used in advanced coatings for energy-efficient windows. | | | |
|---|---|---|---|
| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - processing facilities | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - metals | | | |
| - tailings | | | |
| - ash | | | |
| - | | | |
| - | | | |
| ii. Soil erosion | | | |
| - dissolved solids | | | |
| - turbidity | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - phosphates | | | |
| - lead | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - oil spills | | | |
| - inorganic carbons | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - processing requirements | | | |
| - cooling water | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - sulfur dioxide | | | |
| - NOx | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - asthma | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - cancer | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 3: MANUFACTURING & CONSTRUCTION - Final parts, products, equipment, and facilities that will facilitate energy production, consumption, or conservation. This includes power plant construction and the manufacture of photovoltaic panels, lamps, and ballasts.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - manufacturing facilities | | | |
| - plant site | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - toxics | | | |
| - ash | | | |
| - | | | |
| - | | | |
| - | | | |
| ii. Soil erosion | | | |
| - dissolved solids | | | |
| - turbidity | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - nitrates | | | |
| - lead | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - toxicls | | | |
| - pH | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - processing requirements | | | |
| - cooling water | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - sulfur dioxide | | | |
| - NOx | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - asthma | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - cancer | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| **1. Employment** | | | |
| - **direct job additions/losses** | | | |
| - **indirect job additions/losses** | | | |
| - | | | |
| - | | | |
| - | | | |
| **2. Economic development** | | | |
| - **direct business additions/losses** | | | |
| - **indirect business addtns./losses** | | | |
| - | | | |
| - | | | |
| - | | | |
| **3. Economic competitiveness** | | | |
| - **Industrial competitiveness** | | | |
| - **Regional competitiveness** | | | |
| - | | | |
| - | | | |
| **4. Public Sector** | | | |
| **a. Facility and service requirements** | | | |
| - **roads/transportation** | | | |
| - **utilities** | | | |
| - | | | |
| - | | | |
| **b. Public Sector costs/revenues** | | | |
| - **tax revenues** | | | |
| - **government expenditures** | | | |
| - | | | |
| - | | | |
| **5. Other** | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 4: TRANSPORTATION - Transportation activities occur throughout the fuel cycle. Examples include: transporting raw materials to be processed or manufactured; moving manufactured goods to the point of use; moving oil or gas via a pipeline; and moving waste to be disposed of or recycled.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - railways | | | |
| - pipeline right-of-ways | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - spills | | | |
| - ash | | | |
| - | | | |
| - | | | |
| - | | | |
| ii. Soil erosion | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - nitrates | | | |
| - oil spills | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - toxicls | | | |
| - pH | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - methane | | | |
| - carbon monoxide | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 5: STORAGE - Storage requirements and related impacts occur throughout the fuel cycle. Examples include the storage of raw materials, parts, equipment, refined fuel oil, or consumer products. It is important not to duplicate storage-related impacts in this stage with impacts associated with permanent waste disposal or similar impacts that would be accounted for in other stages.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - tank farms | | | |
| - temporary waste storage | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - oil | | | |
| - lead | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Rehabilitation of existing sites | | | |
| - reforestation | | | |
| - land reclamation | | | |
| - | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - dissolved iron | | | |
| - toxics | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - lead | | | |
| - phosphates | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - containment ponds | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - limestone dust | | | |
| - coal dust | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

| STAGE 6: CONVERSION - This stage accounts for those impacts associated with transforming energy resources into useful electricity. Examples include: power plant operation, the operation of photovoltaic systems, and the operation of hydroelectric facilities. It would also include the use of natural gas by non-utility generators for the production of electricity. | | | |
|---|---|---|---|
| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - generating stations | | | |
| - hydroelectric dams | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - radionuclides | | | |
| - ash | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Rehabilitation of existing sites | | | |
| - reforestation | | | |
| - land reclamation | | | |
| - | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - PCBs | | | |
| - other toxics | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - lead | | | |
| - chlorine | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - cooling water | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - sulfur dioxide | | | |
| - carbon dioxide | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| • school capacity | | | |
| • | | | |
| • | | | |
| b. Impact on technical advancement | | | |
| • R&D advancement | | | |
| • potential product development | | | |
| • | | | |
| c. Other | | | |
| • | | | |
| • | | | |
| 2. Community Impacts/Social Patterns | | | |
| • displacement | | | |
| • | | | |
| • | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| • housing supply | | | |
| • | | | |
| • | | | |
| b. Structural damage/improvements | | | |
| • private property damage | | | |
| • property values | | | |
| • | | | |
| 4. Social/Cultural Issues | | | |
| • change in quality of life | | | |
| • | | | |
| • | | | |
| 5. Demographics | | | |
| • | | | |
| • | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| • | | | |
| • | | | |
| • | | | |
| b. Mortality (occupational deaths) | | | |
| • | | | |
| • | | | |
| • | | | |
| c. Other | | | |
| • | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| **1. Employment** | | | |
| **- direct job additions/losses** | | | |
| **- indirect job additions/losses** | | | |
| - | | | |
| - | | | |
| - | | | |
| **2. Economic development** | | | |
| **- direct business additions/losses** | | | |
| **- indirect business addtns./losses** | | | |
| - | | | |
| - | | | |
| - | | | |
| **3. Economic competitiveness** | | | |
| **- Industrial competitiveness** | | | |
| **- Regional competitiveness** | | | |
| - | | | |
| - | | | |
| **4. Public Sector** | | | |
| **a. Facility and service requirements** | | | |
| **- roads/transportation** | | | |
| **- utilities** | | | |
| - | | | |
| - | | | |
| **b. Public Sector costs/revenues** | | | |
| **- tax revenues** | | | |
| **- government expenditures** | | | |
| - | | | |
| - | | | |
| **5. Other** | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 7: TRANSMISSION & DISTRIBUTION - This stage accounts for those impacts associated with the construction and operation of tranmission and distribution equipment. This includes transmission lines, step-up and step-down substations, and switching stations.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - right-of-ways | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - PCBs | | | |
| - corrosion | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Rehabilitation of existing sites | | | |
| - reforestation | | | |
| - land reclamation | | | |
| - | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - lead | | | |
| - other toxics | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - associated toxics/pollutants | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - accessibility | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - total harmonic distortion | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - non-occupational accidents | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
| --- | --- | --- | --- |
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 8: END-USE - This stage includes those impacts associated with the use of energy consuming products such as light bulbs, heating/cooling equipment, and gas ranges. It also includes the end-use of energy conservation products such as insulation or devices that may be installed as part of a DSM program.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - HVAC equipment | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - leaks and corrosion | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - PCBs | | | |
| - lead | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - cooling tower aerosols | | | |
| - CFCs | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - cooling water | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - methane | | | |
| - NOx | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - housing supply | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - private property damage | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - Industrial competitiveness | | | |
| - Regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 9: WASTE RECYCLING - This stage includes those activities associated with the recycling of wastes generated throughout the fuel cycle. This includes the recycling or reprocessing of raw materials for re-use and the recycling of parts or equipment. Examples include recycling of packaging materials for use in shipping lamps, mercury and glass recycling and the recycling of wastewater.**

| A. ENVIRONMENTAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - treatment/reprocessing facilities | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - uncaptured mercury | | | |
| - ash | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Rehabilitation of existing sites | | | |
| - land reclamation | | | |
| - | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - phosphates | | | |
| - wastewater toxics | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - associated toxics/pollutants | | | |
| - lead | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - processing | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - sulfur dioxide | | | |
| - NOx | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - accessibility | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - damage to private property | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - non-occupational accidents | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - industrial competitiveness | | | |
| - regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

| STAGE 10: WASTE DISPOSAL (UNRECOVERED) - This stage includes those impacts and activities associated with the permanent disposal of wastes generated throughout the fuel cycle. This includes managed landfilling and incineration, unmanaged disposal to the environment, and the storage of toxic chemicals. | | | |
|---|---|---|---|
| **A. ENVIRONMENTAL IMPACTS** | **Include (Y/N)** | **Qualitative Measure** | **Quantitative Measure** |
| | | | |
| 1. Terrestrial Impacts | | | |
| a. Land requirements | | | |
| - landfills | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Soil impacts | | | |
| i. Runoff, solute migration | | | |
| - PCBs | | | |
| - metals | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Rehabilitation of existing sites | | | |
| - land reclamation | | | |
| - reforestation | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Groundwater impacts | | | |
| a. Leaching, runoff, migration of constituents to the aquifer | | | |
| - ash | | | |
| - radioactive wastes | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - phosphates | | | |
| - dissolved iron | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - processing | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - CFCs | | | |
| - particulates | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - damage to private property | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - non-occupational accidents | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - industrial competitiveness | | | |
| - regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

**STAGE 11: DECOMMISSIONING/RETIREMENT - This stage includes those impacts and activities associated with the permanent removal of an electric generating plant from service. This includes dismantling the plant and restoring the site. It may also include retooling the facility for continued use as an electric generating plant.**

| **A. ENVIRONMENTAL IMPACTS** | **Include (Y/N)** | **Qualitative Measure** | **Quantitative Measure** |
|---|---|---|---|
| | | | |
| **1. Terrestrial Impacts** | | | |
| **a. Land requirements** | | | |
| - net impact on land requirements | | | |
| - | | | |
| - | | | |
| - | | | |
| **b. Soil impacts** | | | |
| i. Runoff, solute migration | | | |
| - leaching of toxics (e.g. PCBs) | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| **c. Rehabilitation of existing sites** | | | |
| - land reclamation | | | |
| - reforestation | | | |
| - | | | |
| - | | | |
| **d. Other** | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| - | | | |
| **2. Groundwater impacts** | | | |
| **a. Leaching, runoff, migration of constituents to the aquifer** | | | |
| - lead | | | |
| - radioactive wastes | | | |
| - | | | |
| - | | | |
| - | | | |

| A. ENVIRONMENTAL (CONT'D) | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| b. Aquatic | | | |
| - pH | | | |
| - unmanaged wastewater | | | |
| - | | | |
| - | | | |
| c. Water requirements | | | |
| - processing | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Atmospheric | | | |
| a. Emissions | | | |
| - CFCs | | | |
| - carbon monoxide | | | |
| - | | | |
| - | | | |
| b. Other | | | |
| - | | | |
| - | | | |
| 4. Species/Vegetation | | | |
| a. Terrestrial vegetation | | | |
| - woodlands | | | |
| - flora/fauna | | | |
| - | | | |
| - | | | |
| b. Terrestrial wildlife | | | |
| - endangered species | | | |
| - migratory species | | | |
| - | | | |
| - | | | |
| c. Aquatic | | | |
| - wetlands | | | |
| - ecosystems | | | |
| - | | | |
| - | | | |
| d. Other | | | |
| - | | | |
| - | | | |
| 5. Aesthetics | | | |
| - noise | | | |
| - visual (air/water) | | | |

| B. SOCIAL IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Educational/Technical | | | |
| a. Impact on local educational institutions | | | |
| - school capacity | | | |
| - | | | |
| - | | | |
| b. Impact on technical advancement | | | |
| - R&D advancement | | | |
| - potential product development | | | |
| - | | | |
| c. Other | | | |
| - | | | |
| - | | | |
| 2. Community Impacts/Social Patterns | | | |
| - displacement | | | |
| - | | | |
| - | | | |
| 3. Infrastructure | | | |
| a. Service/Supply Impacts | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Structural damage/improvements | | | |
| - damage to private property | | | |
| - property values | | | |
| - | | | |
| 4. Social/Cultural Issues | | | |
| - change in quality of life | | | |
| - | | | |
| - | | | |
| 5. Demographics | | | |
| - | | | |
| - | | | |
| 6. Safety/Health | | | |
| a. Morbidity (occupational injuries) | | | |
| - | | | |
| - | | | |
| - | | | |
| b. Mortality (occupational deaths) | | | |
| - | | | |
| - | | | |
| - | | | |
| c. Other | | | |
| - non-occupational accidents | | | |

| C. ECONOMIC IMPACTS | Include (Y/N) | Qualitative Measure | Quantitative Measure |
|---|---|---|---|
| | | | |
| 1. Employment | | | |
| - direct job additions/losses | | | |
| - indirect job additions/losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 2. Economic development | | | |
| - direct business additions/losses | | | |
| - indirect business addtns./losses | | | |
| - | | | |
| - | | | |
| - | | | |
| 3. Economic competitiveness | | | |
| - industrial competitiveness | | | |
| - regional competitiveness | | | |
| - | | | |
| - | | | |
| 4. Public Sector | | | |
| a. Facility and service requirements | | | |
| - roads/transportation | | | |
| - utilities | | | |
| - | | | |
| - | | | |
| b. Public Sector costs/revenues | | | |
| - tax revenues | | | |
| - government expenditures | | | |
| - | | | |
| - | | | |
| 5. Other | | | |
| - | | | |
| - | | | |
| - | | | |

# APPENDIX A
# POTENTIAL DATA RESOURCES AND TOOLS FOR FUEL CYCLE RESEARCH

## A. DATA RESOURCES

Exhibits A-1 through A-3 provide examples of data and information resources that can be utilized in performing a fuel cycle analysis of environmental, social, and economic impacts for energy technologies.

As illustrated, there are a number of disparate sources of information that can be used to augment fuel cycle research. As the earlier report to this project (*Volume I: Evaluation of the Fuel Cycle Assessment Guide for Framing a Fuel Cycle Analysis*) illustrated, **there remain major gaps in the data and analytical techniques available to fully analyze fuel cycle impacts**. Many of the data resources listed below are specific to Maryland and/or the technology case examples evaluated for this project; however, they demonstrate the types of resources that could be utilized to assess impacts for other technologies and in other states.

To perform an effective fuel cycle research effort, data research must be as case specific as possible. Often, discussions with industry personnel can provide important insight into manufacturing, construction, storage, transportation, and operational processes that occur along the fuel cycle.

## EXHIBIT A-1
## FUEL CYCLE DATA RESOURCES: ENVIRONMENTAL IMPACTS

- **State Agency Environmental Impact Reports (i.e., Environmental Reviews by the Maryland Power Plant and Environmental Review Division)** - These provide significant case-specific information for the construction and conversion stages of power plants. They include:

  - Estimated air emissions
  - Estimated discharges to area rivers and streams
  - Impacts on local ecosystems (wetlands, plant and animal life)
  - Water supply.

  Operating utility environmental impact statements and CAAA/CWA compliance studies also provide estimates of impacts such as these.

- **U.S. Environmental Protection Agency (EPA), <u>Toxic Release Inventory (TRI)</u> database** - Data on annual releases of over 300 TRI chemicals from over 23,000 manufacturing facilities in the U.S. It can support fuel cycle research regarding raw materials processing and manufacturing. Also, EPA document AP-42 describes environmental impacts and provides estimated emission factors for criteria and non-criteria pollutants for approximately 200 industrial activities, including petroleum refining, coal cleaning, bagasse combustion, and many others.

- **Operator Information: Applications for permit(s)-to-construct/operate and EISs** - Augments site-specific environmental impact data for manufacturing facilities, mining/drilling operations, power plants, bulk terminals, landfills, and recycling facilities. Also, utility-specific emission rates can be used to estimate emissions offset from proposed DSM programs.

- **Mine Safety and Health Administration, <u>Mining Information System</u>** - Maintains data on dust samples for mines.

- **U.S. Department of Interior, Office of Surface Mining, Reclamation and Enforcement** - Maintains annual, state-level data on coal mining reclamation.

- **U.S. Department of Transportation, Office of Pipeline Safety, <u>Annual Report</u>** - Provides case-specific annual data on pipeline accidents, releases to the environment, and impacts.

- **U.S. EPA Star Program** - Provides aggregated historical data on releases/accidents for natural gas pipelines.

- **National Acid Precipitation Assessment Program, <u>Response of Vegetation to Atmospheric Deposition and Air Pollution</u>**

- **U.S. Fish & Wildlife Service, <u>Impacts of Coal-Fired Power Plants on Fish, Wildlife and Their Habitats</u>**

- **U.S. Department of Energy, Energy Efficiency and Renewable Energy, <u>Energy System Emissions and Material Requirements</u>** - Provide estimates of environmental impacts from the use of photovoltaics and other energy resources. **<u>Energy Technologies and the Environment: Environmental Information Handbook</u>**, October 1988, provided much of the information for the previously mentioned DOE report.

## EXHIBIT A-2
## FUEL CYCLE DATA RESOURCES: SOCIAL IMPACTS

- **State Agency Impact Reports** - These provide case-specific information for selected social impacts occurring during the construction and conversion stages of power plants. These include:

    - Noise associated with construction and operations
    - Visual impacts
    - Population impacts
    - School enrollment impacts
    - Marginal housing demand
    - Transportation-related impacts
    - Cultural impacts.

- **U.S. Department of Transportation, Office of Pipeline Safety, Annual Report** - Provides case-specific annual data on pipeline accidents, injuries and deaths.

- **Mine Safety and Health Administration, Mining Information System** - Maintains health and safety data for coal mines including: accidents, resultant illness, injury or cause of death, employee days lost, and the average number of employee hours of exposure.

- **Case/Operator-specific research**

## EXHIBIT A-3
## FUEL CYCLE DATA RESOURCES: ECONOMIC IMPACTS

- **Economic impact models/software tools (see Exhibit A-4)**

- **Company-specific employment data and projections**

- **Mine Safety and Health Administration, Mining Information System** - Maintains coal operator data on quarterly employment (number of employees per ton of clean coal produced).

- **State Agency Environmental Impact Reports** - In addition to estimating environmental and social impacts, some impact assessments performed by state agencies will evaluate impacts such as:

    - Public sector: expenditures on public safety and public works
    - Construction/Conversion-stage employment impacts
    - Direct, indirect, and induced income
    - Public sector revenues.

Again, these typically are just for the construction and conversion stages of supply-side technologies.

## B. MODELS AND TOOLS

To assess the impacts of fuel cycle processes, socio-economic impacts, and environmental releases, computer-based models or expert roundtables can be considered as tools for making an assessment. Exhibit A-4 lists selected models and software packages that can be used for performing an environmental and/or socioeconomic impact analysis of specific supply- and demand-side energy technology applications. These tools can be considered for transforming raw data into estimated environmental, social, and economic impacts. Many of the computer-based tools that are shown were profiled in *Fuel Cycle Assessment: A Compendium of Models, Methodologies and Approaches.*

**Exhibit A-4**
**COMPUTER-BASED ANALYTICAL TOOLS:**
**Environmental and Socioeconomic Impact Analysis Models and Software Packages**

**Models**

- Maryland Impact Modeling System
- IMPLAN
- DEGREES
- TEMIS
- Long-range Energy Alternatives Planning System (LEAP)
- GEMINI
- Electric and Gas Electric Utility Modeling System (EGUMS)
- Air Emissions Risk Assessment Model (AERAM)
- United Nations Environment Programme (UNEP) Environmental Data Base

**Software Packages**

- OPTIONS: Energy Options for Local Economic Development
- P/G% Decision Aiding Software

**Modeling/AnalyticalTechniques**

- Dynamic Programming
- Monte Carlo Simulations
- Source Release Assessment
- Exposure Assessment
- Dose-Response
- Chemical Mass Balance Models
- Trajectory Models
- Gaussian Models

Note: With the exception of IMPLAN and the Maryland Impact Modeling System, each of the above is profiled in *Fuel Cycle Assessment A Compendium of Models, Methodologies and Approaches* or is to be included in the final draft.

Exhibit A-4 also lists modeling and analytical techniques that can be considered for performing the analysis. These are in addition to some of the qualitative techniques described in Section 3. Descriptions of some modeling and analytical techniques are presented below.

**Dynamic Programming** - Dynamic programming is a multi-stage decision process where the outcome at one stage affects the 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 the 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 is dependent on the boundaries established by the user, as well as the user's 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 (where deemed necessary by the user) to assess impacts of latter stages on previous stages. The dynamic programming approach involves several different concepts, including the following:

- The process is broken up 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 the interconnectedness of the stages and the calculation of the system state variable from one stage to the next.

- The return in each stage (or through the total process) is that result of the decision that 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 the optimal solution in each stage 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 that 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 making 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.

**Monte Carlo Simulations** - Monte Carlo simulation is a means of project analysis that 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 forecast errors (or a range of probabilities) 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 can then 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 because, 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 -- the output is only as good as the logic and data inputs used.

**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 used to determine toxic release, run-off, and similar fuel cycle impacts in the 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 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 estimate releases.

**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/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 that focus on a single or specific set of risk agents are difficult and costly to perform because of 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 indicate and assess the transport and fate of the hazardous substances under analysis

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

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

**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, and 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 the 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 his/her 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 by using sensitivity analysis or tests of statistical significance. Uncertainty is typically expressed by using probability distributions, confidence intervals, or worst-case/best-case scenarios.

**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.

**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 that is bounded on the bottom by the ground and on the top by an inversion base and that varies 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 the 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, the neglect of wind shear effects can seriously impair the reliability of trajectory model results.

**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 is 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

- There is no wind sheer.
- Sources are continuous and non-varying.
- 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.

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