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ABBREVIATED RD&D PROGRAM
PORTFOLIO SELECTION WORKBOOK

MASTER

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PREFACE

This workbook provides a "pencil and paper" implementation of an abbreviated version of the RD&D portfolio selection methodology described in A Resource Allocation Methodology for Establishing RD&D Budgetary Priorities *. The workbook is designed to be used in a fill-in-the-blanks fashion. By following the steps outlined, a person can perform a first-cut analysis of an RD&D program using nothing other than a pencil and paper and a hand calculator. Our purpose in designing an RD&D analysis process in a workbook format was two-fold. First, the workbook format guarantees that the analysis is of such a scope that it can be performed on a fast turnaround basis--an essential criterion for a preliminary program evaluation. Second, the workbook allows the analyst to become intimately familiar with the assumptions made in the analysis process and with the sensitivity of the results to these assumptions. It is our feeling that the workbook fulfills both of these purposes. However, we recognize that the tedious and repetitive calculations of the sort required in the workbook will neither be enjoyable or efficient once an understanding of the abbreviated methodology is obtained. Thus we have developed a system of interactive computer programs to perform the calculations outlined in the workbook. In addition, the flexibility and speed of the computer allow us to

* D. W. Boyd, D. W. North, and S. G. Regulinski. A Resource Allocation Methodology for Establishing RD&D Budgetary Priorities. Final Report prepared by Decision Focus, Incorporated for the U.S. Department of Energy under Contract DE-AC05-7BET05474, February 1979.

provide the facility for performing a wider variety of sensitivity analyses than we outlined in the workbook. Once the reader understands the abbreviated methodology presented in the workbook, we strongly urge him or her to use the interactive programs that are available on the DOE time-sharing system. A brief guide is available that outlines the functions of the programs and describes how to access them *.

* D. W. Boyd, D. Cohan, and S. G. Regulinski, "A Users' Guide to the Abbreviated RD&D Portfolio Selection Programs". Report prepared by Decision Focus, Incorporated for the U.S. Department of Energy under Contract DE-AC05-7BET05474, September 1979.

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Chapter 1

INTRODUCTION

This is a workbook for implementing an abbreviated version of the RD&D portfolio selection methodology described in A Resource Allocation Methodology for Establishing RD&D Budgetary Priorities.^{*} The purpose of the abbreviated methodology is to allow a fast, first-cut analysis of a set of programs and to provide a means of discovering important issues that deserve more detailed analysis. The flowchart in Figure 1-1 outlines the use of the abbreviated methodology in the overall process of evaluating RD&D programs.

The abbreviated methodology is identical in approach to the comprehensive portfolio selection methodology. The underlying concept is the coordination of the individual program analyses iteratively, a process that requires compatible methods of performing and coordinating the analyses. This is precisely the purpose of this workbook: to describe in a detailed, step-by-step fashion an abbreviated method of analyzing and coordinating individual programs.

^{*}D. W. Boyd, D. W. North, and S. G. Regulinski. A Resource Allocation Methodology for Establishing RD&D Budgetary Priorities. Final Report prepared by Decision Focus Incorporated for the U.S. Department of Energy under Contract DE-AC05-7BET05474, February 1979.

Figure 1-1. Role of Abbreviated Portfolio Analysis

INDIVIDUAL ANALYSIS

The basic purpose of the individual analyses is to determine the value of proposed federal programs. Each individual evaluation takes the form of a decision analysis. The structure used to perform the analysis and to coordinate it with other analyses is outlined in Figure 1-2.

The decision to fund a program is shown at the bottom of Figure 1-2. The effect of the program on a process is represented by the process model. Here are described those process cost and performance characteristics that are important to the market for an energy product. The product cost model takes the cost and performance characteristics and the feedstock price and calculates the cost of producing a unit of energy using the technology in question. The market model takes this cost, the demand for the energy product, and the characteristics of alternative sources of the same product, and specifies the market share captured by the new technology. From this point it is relatively straightforward to infer the impacts of the new technology on the energy system. The benefit model evaluates the impacts in a consistent way, given the cost of the federal support.

The structure for analysis shown in Figure 1-2 does not account for uncertainty. Explicitly accounting for the uncertainty of the federal program's impact on the technology and for the uncertainty in the energy marketplace as a whole is done by repeating the analysis for sets of parameters that characterize the range of possible futures. The possible futures are efficiently represented by a decision tree, as in Figure 1-3.

Figure 1-2. Structure of the Individual Evaluations

Figure 1-3. Decision Tree for Two-Stage Representation of the RD&D Decision Process

The tree specifies a set of scenarios--paths through the tree--showing how the development of a technology depends on RD&D program decisions and uncertainties about both the energy market and the program impact. By analyzing the program for each scenario and weighing the value of the program for that scenario by the probability of its occurrence, the expected value of the program can be computed. This expected value of the program now explicitly accounts for uncertainty.

COORDINATING THE INDIVIDUAL ANALYSES

To achieve consistency among the individual analyses, they must be carefully coordinated. The coordination ensures that the portfolio that results from the individual analyses is consistent with the goals of the department, the complexity of the marketplace, and the limited availability of funds. This goal is accomplished by providing three distinct types of coordinating signals:

1. Policy guidance to insure consistency between policy goals and the program analyses
2. Program/project coordination to account for interaction among programs that take place in the marketplace
3. Budget coordination to insure that budget requests do not exceed the budget available

Figures 1-2 and 1-3 illustrate how this coordination is integrated into the individual program analyses. The benefit model is specified by policy guidance so that all programs are analyzed with respect to the same criteria. Feedstock prices, demands for energy products, and the characteristics of alternative sources of the same energy product are

supplied by the program/project coordination, which also consistently describes the uncertainty in these parameters through the use of global planning scenarios. Finally, the shadow price on budget dollars is the mechanism for coordinating the allocation of scarce budget dollars.

THE ABBREVIATED METHODOLOGY

While the abbreviated methodology mirrors the comprehensive methodology in its approach, it has been much simplified. Since the purpose of the abbreviated methodology is to determine where more extensive analysis is worthwhile, it is useful to look at the simplifications made and the alternatives available to those simplifications as embodied in the comprehensive methodology. Table 1-1 compares the two approaches, showing both the simplifications and the comprehensive alternative.

By referring to Figure 1-2, which illustrates the structure of the individual analyses, the impact of the simplifications of the analyses can be shown. In the abbreviated methodology the only federal roles considered are direct, supply-side incentives, which take the form of federally funded or cost-shared RD&D programs. The impact of the federal program is captured by assessing the process economics with and without the federal program. All other models, such as the market or benefit models, are simple, one-line equations. Finally, the treatment of uncertainty is limited to a few scenarios and sensitivity analysis.

The coordination has been simplified by not attempting to update all the coordinating information. Instead, most coordination cycles are run open-

Table 1-1

COMPARISON BETWEEN ASSUMPTIONS FOR ABBREVIATED AND
COMPREHENSIVE PORTFOLIO SELECTION METHODOLOGIES

		ABBREVIATED PORTFOLIO ANALYSIS METHODOLOGY	COMPREHENSIVE PORTFOLIO ANALYSIS METHODOLOGY
DECOMPOSITION		Ad Hoc, Using Existing Responsibilities	Careful Definition of Working Groups and Detailed Specifications of Responsibilities
COORDINATION	Budget	Simplified Closed-Loop	Complete Closed-Loop
	Program/ Project	Open-Loop Using Best Available Data	Closed-Loop Using Detailed Regionalized Data
	Policy	Open Loop Varying Trade-offs (Weighted Factors) Over Ranges	Closed-Loop with Detailed Modeling or High-Level Policy Involvement Necessary
ANALYSIS	Federal Impact	"With or Without" Data Assessment	Detailed Multi-Party Program Evaluation
	Federal Roles	Only Direct, Supply-Side Incentives Considered	Full Range of Federal Roles Considered
	Treatment of Uncertainty	Nominal Assessments or Sensitivity to Ranges	Thorough Multi-Expert Assessment or Detailed Modeling
	Modeling	Simplified "One Equation"	Complex Structural Model

loop. The reason is simple: The results of the abbreviated approach are both a first-cut portfolio and a list of issues that deserve more attention. Thus, after the first iteration of the abbreviated approach, it may well be that it is more important to focus on a few key programs than to update the analysis of all programs. Figure 1-4 outlines the abbreviated methodology in the form of a summary flowchart.

THE WORKBOOK

The workbook is organized to separate the tasks of describing the research programs, analyzing the programs, and coordinating the analyses. To this end, the remainder of the workbook is organized into three chapters: coordination, program description, and program value computation. Coordinating the analyses requires providing the ground rules, common data, and assumptions to the program managers. Many of these ground rules and common assumptions are actually embedded in the structure of the workbook, so the workbook itself is part of the coordination. What remains is to provide the common data, contained in the coordination part of the workbook.

The RD&D program description is developed in Chapter 3. Here the resources that are to be devoted to the program are specified and the possible impacts of that program on the energy process are encoded. The program analysis, which uses the program description and the coordinating information, is conducted in Chapter 4. The analysis produces a consistent first cut at the program value that provides a basis for a portfolio analysis.

Figure 1-4. Flowchart of the Abbreviated Allocation Coordination Process

The workbook focuses primarily on implementation, not explanation, although it does contain some discussion of the methodology and the appendices elaborate on some specific aspects of the methodology. The reader is strongly encouraged to read the report referenced at the beginning of this chapter for further explanation.

Chapter 2

COORDINATION OF THE INDIVIDUAL ANALYSES

INTRODUCTION

This chapter brings together the necessary elements for coordinating the individual program analyses. A structure is defined for coordinating these analyses, and the data necessary to implement that structure are specified. The organization of this chapter and the flow of information that it requires are depicted by the flowchart in Figure 2-1. This flowchart divides the coordination into two parts. The first part, which comprises the first two steps, focuses on ensuring the consistent implementation of the policy goals of the department. The second part, which comprises all remaining steps, addresses consistency in assumptions about market impacts. Both parts produce explicit coordinating signals that are used in all program analyses.

POLICY GUIDANCE

The first step in providing explicit policy guidance is to specify what outcomes are to be valued. These are the outcomes that are both important to the nation and are likely to be affected by RD&D decisions. Initially the net economic impact, the net impact on environmental emissions, and the impact on oil imports are specified as the outcomes to be considered. Other outcomes can be added as necessary in the future to capture the full value of a research program.

Figure 2-1. Flow Chart for Generation of Coordinating Information

Specifying the outcomes to be valued sets in place the structure for implementing departmental policies. To implement these policies consistently, a value must be placed on effecting changes in the outcomes. This trade-off value, which is most conveniently expressed in economic terms, can be interpreted as the economic value that the country is willing to forego to effect a change in another outcome. For example, a trade-off value of one dollar per pound of sulfur oxide emissions to the air means that the country is just indifferent between spending a dollar to eliminate the pound of emission and keeping the dollar and the emission.

To determine the trade-off values for the abbreviated approach, we will either use existing information or assess this trade-off directly, rather than attempt detailed modeling and assessment. The direct assessment approach is illustrated for the energy import trade-off by presenting the policy maker with the hypothetical decision outlined in Figure 2-2. Without a particular program, the price of crude oil will be \$14 per barrel, and 10 million barrels of crude oil will be imported per day. As an alternative, the decision maker could authorize a particular hypothetical program that would result in sufficient production to reduce imports to 9 million barrels a day. Presumably, if this program would produce crude oil at the same price, \$14 per barrel, it would definitely be preferred, since it reduces imports and costs no more. Similarly, if it resulted in costs of, say, \$50 per barrel, most people would consider it unworthy of support.

Figure 2-2. Direct Assessment of Value Trade-Offs for Imported Oil

Somewhere in the range from no increase in cost to a clearly exorbitant increase lies a point of indifference. This point represents the trade-off on imported crude oil. Notice that this trade-off represents only the strategic value of reducing dependence on oil imports. It does not in any way attempt to measure the economic value of the oil. The economic value is set by the energy market.

Direct assessment is an abbreviated approach to a process that could involve much more detailed study. For trade-offs for which there is little existing information, it may be more realistic to specify a range of values within which the trade-off value may reasonably lie. The individual programs would then conduct sensitivity analysis to determine whether

decisions about their program are sensitive to that range. This would postpone more detailed value assessment until it became apparent that narrowing the range or specifying a single value were worth the effort.

The trade-offs on outcomes or their ranges are entered in Table 2-1.* This table becomes the basis for program valuation, as the trade-offs are the weighting factors for the benefit function. It allows all program outcomes to be converted to the same units as the economic outcomes are; thus, the value of the program is measured by a single number.

PROGRAM/PROJECT COORDINATION

Although consistency in valuing outcomes is important, it needs to be complemented by consistency in arriving at those outcomes. This is the goal of program/project coordination. Program/project coordination provides the coordinating information that allows the program analyses to be performed semi-independently, yet fully account for the interactions that occur in the marketplace. This information is provided by defining and using a consistent energy accounting system, a task that is approached in several steps as shown in Figure 2-1. The first step is to define the energy market on which RD&D programs potentially have an impact. Next, global planning scenarios are used to describe the future of these markets. Finally, an energy model is used to represent the interactions among technologies that take place in the marketplace. These three parts--the market definitions, the global planning scenarios, and the energy

*All tables will be found at the end of their respective chapters.

model--define a consistent energy accounting system. This system is used to provide the coordinating information for consistent program analyses.

In the first implementation of the workbook it is unlikely that special energy model runs will be made; existing energy model runs may have to be used instead. In this event the ideal process for providing the coordinating information is reversed. Instead of using the market definitions and the global planning scenarios to structure the energy model and the model runs, the structure of the existing model and the available model runs determine the market definitions and the global planning scenarios. However, in subsequent uses of this methodology it would be appropriate to move toward an integrated energy model and program planning system. In this discussion of the energy accounting system we will discuss each element as it would be handled under ideal circumstances. Thus the definition of the energy markets is the first step, followed by the development of the global planning scenarios and, finally, the running of the energy model. As appropriate we will discuss the effect of being constrained to using existing energy model runs.

Definition of Energy Markets

A consistent definition of the energy market requires that the total energy market be divided into markets for specific energy products. Since the sum of the demand for energy products must equal the total demand for energy, the problem of consistency in energy accounting is now focused on the individual markets. Thus, all accounting of energy supplied or demanded will be done within the context of the energy product markets.

Such a system has two natural consequences. The first is that all technologies must be analyzed with respect to the energy products that they help produce. Technologies that constitute only a piece of an energy production process will need to be analyzed together with the other pieces. Thus, analyzing a research program requires estimating its impact on the entire process, and valuing the program requires calculating how the change in the process affects the market for the energy product. In this workbook the term "process" denotes the entire collection of technologies that produce an energy product.

The second consequence of this part of the energy accounting system is the need for clear, unambiguous definitions of the markets. These definitions form the basis for comparing competing processes, and thus they should include a complete description of the structure of the market, in particular:

- o The product, described in all its important dimensions (e.g., Btu per unit weight or volume, sulfur content, ash content, etc.)
- o Where the product is delivered (e.g., over the fence, plant gate, busbar, home meter, etc.)
- o Typical size of production processes (e.g., 1000-MW capacity for central station baseload generating plants)
- o Regulatory environment, that is, whether a market is subjected to utility or ceiling price regulations or is nonregulated
- o Pertinent weather and site parameters

Table 2-2 is used to compile this data, which is then passed on to the program analysts as shown in Figure 2-1. This step is part of the process of developing a common structure for program analysis.

Global Planning Scenarios

The program analyses are based upon assumptions about the values of many variables. Some of these variables are common to many analyses. Other variables, while used only in a few analyses, are strongly related to variables used in many other analyses. Consistency across these analyses requires consistency among the common or related variables. The global planning scenario helps assure that consistency.

A global planning scenario consistently represents those events or variables that have a major impact on the energy market. Thus, the scenario describes the market, not in terms of all the prices and quantities that exist, but rather in terms of the events or variables that tend to drive the market: world oil prices, resource supply, environmental regulation, or tax regulations, for example. These global planning variables are then either used directly by the program analysts or used indirectly by taking the variables as the basis for an energy model and then using the resulting price and quantity information. In either event, the global planning scenario plays an important role in assuring consistency in the assumptions used in program analysis.

Since many of the global planning variables are uncertain, there are many plausible scenarios. Fortunately, uncertainty in only relatively few of these variables will affect program analyses. For the current implementation of the workbook two variables, the price of world oil and restrictions on the use of nuclear energy, are represented as uncertain. The basis for this selection was the policy and fiscal guidance provided

for the FY1981 budget preparation (Memorandum for Secretarial Officers from Alvin L. Alm, March 21, 1979). The selection of these variables can be revised as required.

The uncertainty in the world oil price will be represented as uncertainty about the average cost of imported crude oil in the year 2000. The prices of imported crude oil in other years will be modeled as having a deterministic relationship to the price in the year 2000.

To implement this model of the world oil price, two pieces of information must be specified: the high, nominal, and low average price of crude oil in the year 2000 and the relationship between these prices and the prices in other years. The high price is the price such that there is only a 10% chance of the observed price being higher; the low price is the price such that there is only a 10% chance of the observed price being lower; and the "nominal" price is the price such that it is equally likely that the observed price is higher or lower. This information is entered in Table 2-3.

The uncertainty about restrictions on the use of nuclear energy is represented as uncertainty about the existence in the year 1990 of a moratorium on the construction of nuclear power plants. The restrictions on the use of nuclear energy in all other years is modeled as having a deterministic relationship to the restrictions in effect in the year 1990. All plants whose construction begins prior to 1990 are assumed to be unaffected regardless of the outcome of the uncertainty. However, no plants would be constructed after 1990 if there were a moratorium in the

year 1990. In other words, the moratorium would be de facto permanent. Implementing this model requires only the probability of a moratorium's occurring by the year 1990. This information is entered in Table 2-3.

Energy Model

Defining the energy market and describing the global planning scenarios are both important steps in establishing a consistent program evaluation methodology. However, together they do not provide all the information needed to analyze a program. Analyzing a program requires information about the appropriate energy market, not in terms of the events or parameters that drive the entire market, but in terms of the actual interaction of technologies in the marketplace. In particular, analysis of a program requires price and quantity information about the particular section of the market that the research program hopes to impact. Providing this information requires integrating the market description and the global planning scenarios with an energy model, as shown in Figure 2-1.

The energy model generates a description of each market in the energy sector for each planning scenario. Each description has three dimensions. Demand is the first dimension; for some markets it is described in no more detail than the total quantity, while other markets, such as electric power markets, require such detail as load duration or load shape. The next dimension is the set of characteristics, including price, emissions, and imported energy requirements, that describe the alternative sources for meeting that demand. The final dimension describes the supply side of the market: the cost of feedstock for the processes that meet the demand.

The energy model captures the relationship among the markets and thus ensures that the quantities demanded and the characteristics of the competing processes are consistent with assumptions about supply, demand, regulation, and financial conditions. Thus, the coordinating information ensures that every individual analysis embodies a consistent view of the energy market.

To start the abbreviated analysis, the coordinating information should describe the markets as they would exist without new or incremental federal programs. Each analysis can thereby make an incremental comparison--the world with the new federal program compared to the world without. Describing markets in this way requires that each process be described as it would exist without new or incremental federal programs. Such descriptions are most easily and most efficiently made at the level of the individual programs. The data provided by the programs are then used by the energy model as shown in Figure 2-1.

If existing energy model runs are being used and they do not contain a representation of a particular process, the coordinating information for that program analysis will be incomplete. The program analysis is structured to complete the information by using the description of the process as it would exist without the federal program to create a description of the market as it would exist without the federal program. The coordinating information, therefore, must indicate whether the processes being analyzed are represented in the energy model or not.

Program/Project Coordinating Information for Program Analysis

The program/project coordinating information provides the information necessary to ensure consistent market impact assumptions within the program analyses. It is a compilation of the information generated in all steps of program/project coordination. This information includes the product market definitions, the global planning scenarios, and the market and feedstock descriptions for each scenario. The product market definitions, which are entered in Table 2-2, and the global planning scenarios, which are entered in Table 2-3, have been discussed above. The market and feedstock descriptions for each scenario, which result from integrating the market definitions, the scenarios, and the energy model, are discussed in detail here.

The market and feedstock descriptions that correspond to each global planning scenario are laid out in three tables. The first, Table 2-4, contains the demand for the energy product and the characteristics of the alternative supply sources that can meet that demand. The quantity demanded is defined as the demand that cannot be met or is not economically desirable to meet from existing capacity because of growth in demand or obsolescence of existing facilities: It is the demand that must be met by new capacity. The characteristics of the competing supply alternatives include not only the average levelized price but also the average emissions and imported fuel used. Notice that the average imported fuel used is measured on a per-unit-output basis and is the ratio of imported fuel used to product produced. This ratio is not constrained to be between zero and

one, since efficiency losses during production cause the energy of the product to be a fraction of the energy in the feedstock used.

The market description is continued on Table 2-5b where the market and financial parameters are presented. Since some of these parameters must be computed from more fundamental information, space for these calculations is provided in Table 2-5a. Finally, feedstock descriptions, which include the levelized price and the percentage imported, are entered in Table 2-6.

The timing conventions employed are designed to be compatible with both the energy model, which supplies much of the program/project coordination, and the budget planning practices within DOE. Thus, the timing convention for assessing benefits assumes five-year periods beginning at a round year, in this case 1980. However, for assessing costs, the timing convention begins with the year of the budget cycle being studied and continues in one-year increments in the near term and in five-year increments for the long term.

The timing conventions for assessing the benefits of a program assume a 35-year horizon divided into seven 5-year periods. The calculations done for each period reflect program impacts at the midpoint, or middle year, of the period. When aggregating impacts across time, it is assumed that the program impact is constant within a period and only changes between periods. Some adjustment is made for processes that become available in the middle of a period. Finally, periods are referred to by the first year of the five years. Thus, the 1985 period runs from 1985 to 1989.

The timing on the cost side is slightly different. Costs of the program will be assessed for each year of the first five years, since programs typically plan budget requests for five years into the future. Subsequent costs are assessed in terms of average yearly costs for six 5-year periods after the first five years. Thus, the cost planning horizon is 35 years.

All references to either the costs or benefits in the analyses are in "budget year" dollars. Thus, for the 1980 budget cycle all references to dollars will be in 1980 dollars. This version of the workbook will use 1980 dollars throughout.

SUMMARY

The coordination of the individual analyses takes place at two levels. The first level deals with consistent implementation of department policy, the second with consistent evaluation of program impacts. In both cases the actual coordination is provided in concrete, quantitative terms that have a definite place in all program analyses. Policy guidance specifies the impacts to be valued and the methods for valuing them. Program/project coordination defines the energy product markets, describes the global uncertainties facing those markets through the global planning scenarios, and describes in detail each product market for each scenario. The coordinating signals necessary to accomplish both policy guidance and program/project coordination are entered in the tables that follow. These tables form the basis for coordinating the program analyses and thereby make a significant contribution to arriving at a consistent, first-cut portfolio.

Table 2-1

TRADE-OFF VALUES FOR BENEFIT FUNCTION

VARIABLE ^a	TRADE-OFF VALUE	UNITS	SOURCE
Import Reduction		\$/10 ⁶ Btu	
SO ₂ Reduction		\$/1b	
NO _x Reduction		\$/1b	
Total Suspended Particu- lates (TSP) Reduction		\$/1b	
Carbon Monoxide Reduction		\$/1b	
Hydrocarbon Reduction		\$/1b	

^aVariable Definitions Can Be Found in Appendix A.

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Table 2-2
MARKET DEFINITIONS

PRODUCT	POINT OF DELIVERY	TYPICAL CAPACITY OF PROCESS	REGULATORY ENVIRONMENT	SITE FOR PROCESS INSTALLATION

Source: _____

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Table 2-3
GLOBAL PLANNING SCENARIOS

WORLD OIL PRICES IN YEAR 2000			
	Low	Nominal	High
Estimated Price (1980 \$/BBL)			
Probability that Observed Price Exceeds Estimate	.90	.50	.10

Source: _____

DETERMINISTIC MODEL OF WORLD OIL PRICES GIVEN THE PRICE IN THE YEAR 2000					
Price in Year 2000	Prices in Other Years				
	1985	1990	2000	2010	2020
Low					
Nominal					
High					

Source: _____

Probability of a Nuclear Moratorium by the Year 1990	_____
---	-------

Source: _____

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Table 2-4

MARKET DESCRIPTION: DEMAND AND ALTERNATIVE SUPPLY

Scenario _____ Product _____

Period	Demand ^a (10 ¹⁵ Btu/year)	Average Characteristics of Alternative Supply Sources						
		Levelized Price (\$/10 ⁶ Btu)	Emissions (lb/10 ⁶ Btu)					Imported Energy Used ^b
			SO ₂	NO _x	TSP	HC	CO	
1980								
1985								
1990								
1995								
2000								
2005								
2010								
2015								
2020								

Source: _____

^aDemand is defined as the quantity produced by incremental capacity additions.^bImported energy used is measured per unit output.

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Table 2-5a

INSTRUCTIONS FOR COMPUTING DEMAND AND FINANCIAL PARAMETERS

1. For the market being considered enter the appropriate values for:

- a) return to common equity $r_E = \underline{\hspace{2cm}};$
- b) return to preferred equity $r_P = \underline{\hspace{2cm}};$
- c) return to debt $r_D = \underline{\hspace{2cm}};$
- d) fraction financed by common equity $f_E = \underline{\hspace{2cm}};$
- e) fraction financed by preferred equity $f_P = \underline{\hspace{2cm}};$
- f) fraction financed by debt $f_D = \underline{\hspace{2cm}};$
- g) inflation rate $\text{inf} = \underline{\hspace{2cm}};$
- h) income tax rate $\text{TAX} = \underline{\hspace{2cm}};$

2. Compute

a) Current Dollar After Tax Cost of Capital (r)

$$r = r_E f_E + r_P f_P + r_D f_D (1 - \text{TAX}) = \underline{\hspace{2cm}};$$

b) Constant Dollar After Tax Cost of Capital (r_o)

$$r_o = \frac{r - \text{inf}}{1 + \text{inf}} = \underline{\hspace{2cm}}.$$

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Table 2-5a (cont.)

3. Enter the Current Dollar Social Discount Rate:

$$S = \underline{\hspace{2cm}}.$$

4. Compute the Constant Dollar Social Discount Rate

$$S_0 = \frac{S - \text{inf}}{1 + \text{inf}} = \underline{\hspace{2cm}}.$$

5. Compute the present value factor for each year from 1981-1985. Enter factors in Table 2-4b.

$$\text{Factor (year)} = \left(\frac{1}{1+S_0} \right)^{\text{YEAR}-1980}$$

6. Compute the present value factors for each 5-year period from 1986-2010 for the costs and for each 5-year period from 1980-2014 for the benefits. These factors assume that the costs and benefits occur at the end of the year, and that the numbers being discounted are the costs or benefits per year. The argument, YEAR, of the function used to compute these factors is the first year of the period. Enter factors in Table 2-8b.

$$\text{Factor (YEAR)} = \frac{1}{S_0} \left[1 - \left(\frac{1}{1+S_0} \right)^5 \right] \left(\frac{1}{1+S_0} \right)^{\text{YEAR}-1980}$$

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Table 2-5b

MARKET DESCRIPTION: DEMAND AND FINANCIAL PARAMETERS

SCENARIO: _____

PRODUCT: _____

1. Demand Parameters:

- a) Market Elasticity Parameter GAM = _____
- b) Load Factor LOADFC = _____
- c) Storage Capability Ratio (if storage process
can serve this market) SCAP = _____
- d) Data source _____
- _____

2. Financial Parameters

- a) Current Dollar After Tax Cost of Capital r = _____
- b) Constant Dollar After Tax Cost of Capital r_o = _____
- c) Income Tax Rate TAX = _____
- d) Investment Tax Credit Rate ITC = _____
- e) AFUDC Rate (if utility regulations apply to
this market) a = _____
- f) Inflation Rate inf = _____
- g) Constant Dollar Social Discount Rate S_o = _____
- h) Data Source _____
- _____

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Table 2-5b (cont.)

Present Value Factors			
Costs		Benefits	
Year/Period	Factor	Period	Factor
1981		1980	
1982		1985	
1983		1990	
1984		1995	
1985		2000	
1986-1990		2005	
1991-1995		2010	
1996-2000		2015	
2001-2005		2020	
2005-2010			

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Table 2-6

FEEDSTOCK PRICES

Scenario: _____

Market: Product Produced from Feedstock _____

Point of Feedstock Delivery _____

Period	FEEDSTOCK					
	Price (\$/10 ⁶ Btu)	Percent Imported	Price (\$/10 ⁶ Btu)	Percent Imported	Price (\$/10 ⁶ Btu)	Percent Imported
1980						
1985						
1990						
1995						
2000						
2005						
2010						
2015						
2020						

Source: _____

Chapter 3

PROGRAM ANALYSIS: RESEARCH PROGRAM DESCRIPTION

INTRODUCTION

This chapter steps through the first part of an actual analysis of an RD&D program: the development of the research program description. This description is composed of both a description of the resources to be devoted to the research and the potential results of the research. Since both of these pieces need to be described explicitly, this chapter provides a detailed, step-by-step set of instructions.

The organization of this chapter and the flow of information that it requires is shown by the flowchart in Figure 3-1. The first step is to specify the program budget and compute the discounted present value of program expenditures. Then, so the program analysis is compatible with other analyses, the markets where the technology, or process, under consideration will compete must be identified. Finally, the potential effect of the federal program is assessed by describing the process as it would exist in those markets both with and without the federal program. The last step shown in the figure is actually the second part of the program analysis, the computation of the program value. This step, which uses the program description, is described in detail in Chapter 4.

Figure 3-1. Flow Chart for Program Analysis

The flowchart contains a single loop. To demonstrate more clearly the cases represented by this loop, a simplified decision tree is shown in Figure 3-2. The program funding decision is followed by the resolution of several uncertain global variables, each combination of which is represented as a global planning scenario. For each combination of RD&D decision and global planning scenario the program may be a technical success or failure. If successful, the program is assumed to produce a technology that is commercialized. Finally, because the technology cost and performance is not yet commercially proven, this uncertainty is resolved last. The potential effect of the research program on either the probability of technical success or the technology cost and performance is captured by the program description. Thus, if the effect of the program on the technology or the technology itself differs from one global planning scenario to another, the process is described for each scenario. These alternative descriptions are represented by the loop in the flowchart.

PROGRAM BUDGET

The research program budget comes from the program plan. This plan must describe expenditures up to the point at which the process is commercially available. Since typically, the program plan is contingent upon intermediate RD&D results, the eventual budget allocations cannot be specified at the outset. In a detailed study of a research program, such a contingent allocation plan can be fully represented. For the abbreviated approach, the RD&D budget allocation is simplified by considering only a fixed research plan; contingent funding decisions are not considered. This

Figure 3-2. Decision Tree for RD&D Decision

fixed funding plan is then represented by the discounted present value of planned expenditures for the duration of the program.

Workspace for computing the discounted present value of program expenditures is provided in Table 3-1. Notice that the costs of the program are assessed for each year of the first five years, the typical planning horizon. Expenditures beyond this horizon have probably not been given as much thought as those within the horizon, so they are estimated in terms of average yearly expense for five-year periods. Later in the analysis the sensitivity of the program value to the assumptions about both the level of expenditures and the contingent nature of the funding decisions can be checked.

THE ENERGY PRODUCT MARKET

Since the value of the federal research program, which is computed in Chapter 4, is a function of how the program affects markets for energy products, it is necessary to establish what markets may be affected by the program. A market can only be affected by a program if that program develops or improves a technology that is a component of or forms a complete process for producing an energy product for that market. For example, the atmospheric fluidized bed (AFB) combustion program can impact the baseload electricity market because an AFB boiler, together with a steam turbine, a plant site, and support equipment, can generate baseload electricity. The important point is that the results of the RD&D programs are measured on the entire process for producing the energy product,

regardless of how much or how little of that process is affected by the program.

Definitions of the energy product markets are part of the coordinating information. Collectively this set of energy product markets describes the entire energy sector. Individually each market describes the product, the point of delivery, the typical quantity delivered, the regulatory environment, and the weather and site parameters where relevant. This set of energy product markets determine the markets that the RD&D program can affect.

THE IMPACT OF THE FEDERAL RESEARCH

With the markets identified, it is possible to move into the next several steps where the impact of the federal program is assessed by describing the process as it would exist both with and without the federal program. The procedure for describing a technology is called encoding. It is a structured procedure designed to produce a description of the technology that best reflects an expert's state of information. This procedure is laid out in great detail for the no-federal-RD&D case. The structurally analogous case in which there is a federal program is sketched briefly. The following discussion addresses the reader directly, providing a step-by-step "script" for the encoding procedure.

The No-Federal-RD&D Case

As the flowchart of Figure 3-1 implies, the procedure begins by focusing on a particular global planning scenario. Select one and review it carefully

to determine how it might impact the process that you are considering. This scenario defines the ground rules for the process description both with and without the federal program.

The fundamental purpose of the encoding task you are beginning is to represent explicitly the uncertainty about how a process with which you are familiar will look when it becomes technically feasible. It is not possible to determine a "right" single-point or deterministic estimate because such an estimate cannot represent the range of possible outcomes. Yet it is this range, the possibility of good outcomes as well as bad ones, that makes RD&D decisions difficult. Ignoring the range by using a single-point estimate does not make the decision easier, since one will be left wondering whether a different decision would have been made if a different single-point estimate had been used. However, the probability distribution that best represents your state of information can be used to insure that the decision reflects this uncertainty.

In the encoding procedure you are not setting up a goal for yourself. Indeed, it is best while working on the encoding task to imagine that you have no further involvement with the RD&D program. Imagine that you will inherit a large sum of money tomorrow and will live the rest of your life in the Bahamas or some other place that is attractive to you. This will help you avoid thinking of your process characterization as a goal for you and your program to meet.

Before actually beginning the encoding process, it is helpful to consider an issue that can impede the best representation of your state of information: the incentive system that you face. To explore the effect your incentive system may have on you, think about your answers to the following questions:

- o Are there any rewards for being involved with a program that "looks like a winner"? Would it enhance your chances for advancement? Improve your professional image? Make you happier?
- o Are there any penalties for working on a program that "looks like a loser"? Would it increase your chances of being transferred to some other program? Be less fulfilling professionally? Make you less happy?
- o Are there any rewards or penalties for characterizing a process in a certain way? Is there a general feeling among your colleagues that this process is a winner or a loser? Would they respond negatively if your characterization contradicted their general impression?

If you answered yes to any of the above questions, you might very well be motivated to distort your answers to the questions you will be asked about your technological process. Our ideal, of course, is to eliminate such distortions. However, since not everyone can be interviewed extensively, we must rely in large measure on your conscious awareness of the pressures and on a professional commitment not to let them influence you.

The variables that are used to describe the cost and performance of a process are listed in Table 3-2. These variables are defined in Appendix A for reference, and we will elaborate upon them further here. Our purpose is to structure the problem so that the variables describe the process as it would exist if it were implemented. As you know, we want to describe

the program under a variety of assumptions about the nature of the RD&D results. For the moment, let's focus on clearly defining the variables about which you will be providing information. The cost and performance characteristics of a process are defined as the characteristics actually experienced in an implementation of the process. There is no assumption that the process is implemented because it is economical. To see this more clearly, imagine the following scenario:

- o The process is implemented somewhere (perhaps because it is the most cost-effective process, perhaps for demonstration purposes, perhaps as a political gesture of support for that process).
- o The process is operated commercially.
- o When the useful life of the process is over, the records are inspected to determine the cost and performance characteristics.

The question is simply: What do those records show?

You can gain some insight about what the records would reveal if you inspect the current design of the process. Typically, this is represented by the process flowchart, which defines the process in terms of the technologies used and the relations between them. Please provide the process flowchart that you are using for the current technology description.

Although this process diagram provides much information and specifies many of the factors we want you to think about, it is only a point of departure. The cost and performance characteristics revealed by actual experience are not the same as those based on current design. Many things may happen to the current design before it is actually implemented. We can represent the

many things, including current design, that influence the cost and performance of an actual implementation of a process by using a diagram such as that in Figure 3-3. This diagram, called an influence diagram, is a way of describing all the factors that have an influence on the actual cost and performance.

Notice that while current design does influence the cost and performance characteristics contained in the first construction bid, so do design changes, items left out of the current design, and changes in prices or productivity between now and the first bid. These other items may cause a significant difference between estimates based on the current design and estimates of the actual performance. Since it is the latter item that we want, you can see why the process chart of the current design serves only as a starting point. One of the important objectives of the characterization process is to obtain your judgment on the likelihood and effect of the other items that influence the cost and performance characteristics.

As you can see in Figure 3-3, some of the uncertainty in the cost and performance characteristics can be attributed to uncertain events that may also affect many other processes. These are the variables that are cross-hatched in the figure. An example of such an event is the passage of stricter environmental emission standards. Uncertainties such as these are called global uncertainties because of their pervasive impact on the energy market. Global uncertainties are included explicitly in global planning scenarios. Since you have already selected a global planning scenario as the basis for this assessment, you do not have to consider the impact of

Figure 3-3. Influence Diagram for Assessing Cost and Performance

uncertainty in global variables. You need only assess the uncertainty in technology cost and performance for the chosen global planning scenario.

We have now set the structure of your problem. We want you to describe the cost and performance characteristics of a process. These characteristics have been defined as what would be observed in an actual implementation of the process. These characteristics are uncertain in part because of exogenous events, such as environmental regulations, which we have called global uncertainties, and in part because of endogenous events such as research outcomes, which you can think of as local uncertainties. The global uncertainties are structured and quantified by the chosen global planning scenario. The remaining uncertainty is captured in the estimates that you will be asked to make.

We are now going to ask you to do some thought experiments. Although they may seem frivolous, we assure you that they have a very serious purpose, and we encourage you to work through them carefully.

Imagine the following scenario: On your very next vacation or business trip, your plane is hijacked. On the way to some distant country the plane runs out of fuel and comes down in the water. Happily, you survive the landing and swim to a nearby island paradise where you are able to live comfortably but without any communication with the outside world. Years later you are rescued, and in the process of getting back into your work life, you are given a report that lists the actual cost experience with several hundred processes that were the subject of RD&D while you were

first at DOE. Interested in how accurate the old DOE estimates were, you go back to some old reports listing these estimates and compare them to the actual experience of the industry.

The original estimates were given in terms of a high, nominal, and low.

Please give your answers to the following questions in the blanks provided:

- o What fraction of the processes had experience showing cost and performance to be better than the nominal estimate? _____
- o What fraction of the processes had experience showing cost and performance to be worse than the nominal estimate? _____
- o What fraction of the processes had experience showing cost and performance to be worse than the high estimate? _____
- o What fraction of the processes had experience showing cost and performance to be better than the low estimate? _____

It is quite possible that you think that the old DOE estimates are biased consistently, either underestimating or overestimating cost and performance characteristics. This kind of bias can be reduced by keeping in mind the cost and performance characteristics that you expect of energy technologies in general. The particular process about which you are knowledgeable is a member of that general set. We now turn to that specific process.

Consider the original disaster/rescue scenario. In this case, shortly after your rescue an old friend and colleague informs you that the process about which you were once quite knowledgeable, the process we are now

considering, was actually implemented. Your friend adds that substantial changes were made in the process design since you were involved.

o What do those changes look like? _____

o What cost or performance characteristics were most affected?

Imagine the disaster/rescue scenario again. In this case, your friend and colleague supplies you with the following information:

1. The federal government decided not to continue funding research on this particular process.
2. Private industry, however, picked up the idea and developed it to the point at which the old federal program goals were met.
3. The process was implemented, although not necessarily for economic reasons.
4. The global planning scenario that you selected has been realized.

In addition, your friend assures you that you will be truly amazed at how good the process looks.

o How could this happen? _____

o List the events that must have occurred for this to happen.

o Describe qualitatively the process as you imagine it to exist.

Now imagine the same scenario except that rather than telling you that you will be amazed at how good the process looks, your friend assures you that you will be amazed at how bad the process looks.

o How could this happen? _____

- o List the events that must have occurred for this to happen.

- o Describe qualitatively the process as you imagine it to exist.

Now that you have brought to mind many of the relevant pieces of information, we want to encode that information quantitatively. We will do this by focussing on each of the variables listed in Table 3-2. During this process you will be asked to compare the likelihood of a specific outcome of each of those variables, such as capital cost exceeding some number, to the likelihood of some reference event, such as the toss of a coin coming up heads. In this manner your state of information about the process can be made explicit and can be clearly understood by others.

Capital Cost. We start with the capital cost, often the most important variable in determining the economic viability of a process. We will devote considerable attention to this variable, so it can serve as an example for the other variables that constitute the process description.

To begin, review the assumptions under which you were working:

1. The federal government decided not to continue funding research on this particular process.
2. Private industry, however, picked up the idea and developed it to the point at which the old federal program goals were met.
3. The process was implemented, although not necessarily for economic reasons.
4. The global planning scenario that you selected has been realized.

Now think of a value for the capital cost that you think is very high under these assumptions. Write down this number, in whatever units you are comfortable using, for your initial estimate of the high value. _____

Next, adjust the initial estimate by considering this chance to gamble with someone else's money. You will be given a large sum of money--several hundred dollars--on the condition that you bet that entire sum on one of the two bets outlined in Figure 3-4 and described in detail as follows:

Bet #1: Wait until the research objectives are met and the process is implemented, then observe the capital cost of that implementation. If the costs are lower than your high estimate, you win and can keep the money. If the costs are higher than your high estimate, you lose and get nothing.

Bet #2: Wait until the research objectives are met and the process is implemented, then spin the roulette wheel pictured in Figure 3-5. If the shaded section comes up, you win and keep the money. If the shaded section does not come up, you lose and get nothing.

Clearly both of these bets are attractive in the sense that you have a good chance of winning a large sum of money on either bet. However, one of the two bets may be more attractive to you than the other. Do you think you are more likely to win by betting on the wheel or on the capital cost?

Figure 3-4. Two Alternative Bets

Figure 3-5. The Roulette Wheel

After you have decided which bet is more attractive, adjust your initial estimate. If you chose the wheel, increase your estimate; if you chose the capital cost, decrease your estimate. The objective is to set the high estimate of the capital cost at the point where you are just indifferent between betting on the wheel and betting on the capital cost. At this point, the likelihood that the actual capital cost of the process is higher than your high estimate is standardized. It can be understood by looking at the roulette wheel. What is the number at which you are indifferent?

Now think of an estimate for the capital cost that you think is very low. Express this number in the same units as before and write down this number as your initial estimate of the low value. _____

Once again this number should be adjusted by considering two bets. In this case the two bets that you are required to choose between are:

Bet #1: Wait until the research objectives are met. At this point the process is implemented without regard to cost. If the costs are higher than your low estimate, you win and can keep the money. If the costs are lower than your low estimates, you lose and get nothing.

Bet #2: This alternative is the same as before.

Once again adjust your initial estimate until you are indifferent between betting on the wheel and betting on the capital costs. What is the value at which you are indifferent? _____

Now think of a value for the capital cost that you think is a reasonable value to expect. What number corresponds to being a reasonable value to expect? _____ This is your initial estimate of the nominal

value. To adjust this estimate we offer a different set of bets:

Bet #1: Bet that the observed value is higher than your nominal value.

Bet #2: Bet that the observed value is lower than your nominal value.

In this case the objective is to adjust your estimate of the nominal value until you are indifferent between these two bets. What is the value at which you are indifferent? _____

Once you have adjusted your high, nominal, and low estimates of the capital costs, they should be converted from the units in which you expressed them to 1980 dollars per million British thermal units (1980 $\$/10^6$ Btu per year). Enter these values in Table 3-2.

The Remaining Cost and Performance Characteristics. The preceding discussion on encoding your information about capital cost was extremely detailed to serve as an example of how the encoding process works. We will not repeat that level of detail with the remaining variables. Instead, we will present the general procedure for encoding your uncertainty and then discuss only the important aspects of each variable.

The procedure starts with structuring the problem: the variable is defined and units are chosen. This first step is followed by the conditioning step in which all important information is brought up and kept in mind. The final step is to encode the values for low, nominal, and high outcomes by

comparing the likelihood of those outcomes to the likelihood of a spin of a roulette wheel or a toss of a coin.

All the variables are defined for reference in Appendix A. Operationally each variable is defined in terms of what would be observed once the process is actually implemented. The units used to express values of the variable should be whatever ones you find most comfortable. After the assessment is completed, the values can be converted to the units specified in Table 3-2.

The purpose of the conditioning step is to bring to your conscious mind all relevant information that you have about likely values of the cost and performance characteristics. Begin with the most general information that you have about cost and performance estimates of processes researched by DOE. From here go to more specific information about the process, its current design, possible changes in design, experimental results, and so forth. Next, examine the global planning scenario for information, the impact of pollution control regulation, for example. Finally, focus on the specific variable, considering in particular any information that explains why the variable would take an extreme value. It is this information that is most likely overlooked, since by nature we tend to focus on the expected value of a variable rather than the extreme value.

For focusing on extreme values it is helpful to pose a scenario in which the extreme value has obtained and then explain the occurrence of the value. Generating explanations of the occurrence of extreme values is the

single most important step in assessing your uncertainty. It must not be overlooked.

Once all the relevant information is brought to mind, it is possible to ask for high and low values. These values are then adjusted, using the roulette wheel, so that they meet the standard definition of likelihood. Assessment of the nominal value is always done last to avoid anchoring or ignoring relevant information about the extremes.

This general procedure--structure, condition, encode--should be followed for the remaining cost and performance characteristics. Although some of the remaining variables may be thought of as dependent or conditional upon the capital cost, we will not assess them that way here. All assessments are done as if the variables are independent until sensitivity analysis has selected the important variables. At that point, conditionality, or dependence, among the important variables may be explored. Conditionality upon the global planning scenario is considered, however. This means that the uncertainty about each variable is assessed assuming that the world is described by the planning scenario. With this structure, you can encode the uncertainty in all remaining variables with only slight variations. We will discuss each of the remaining variables only to point out important points for you to keep in mind while conditioning.

- o Operating and Maintenance Cost. The cost may be estimated upon the current process flowchart, and consequently attention should be given to what changes in the process design will mean to operating and maintenance costs.
- o Efficiency. The efficiency is the ratio of the product to the primary feedstock. For some processes this ratio is called the

thermal efficiency, while for heat pumps it is called the coefficient of performance. In any event, the number should be the average operating efficiency, not the peak load efficiency. The uncertainty of this number is related to the uncertainty both in final process design and in the performance of individual components in the design.

- o Year of Availability. This is defined as the year that the objectives of the program are achieved. There is no assumption that the process is economically viable. This date should not be confused with the date of commercial availability, which is usually taken to mean that the process is commercially viable, that is, economically attractive. By contrast, the year of availability is defined as the year when it is technically possible to implement the process upon a commercial scale.
- o Environmental Emission. It is entirely possible that the environmental emissions of the process are constrained by pollution regulations as defined in the global planning scenario. Since we assume that the process is technically feasible this means that at a minimum the applicable regulation can be met. Thus the only uncertainty that remains is whether the emissions are lower than required.

Please go through each of these variables and assign high, nominal, and low values just as you did for capital cost.

The Probability of Technical Success. The probability of technical success is the probability that the program objectives are met, which at a minimum means that the process is technically feasible. This variable, unlike the other performance parameters, represents a discrete event; either the program is technically successful or it is not. Hence, the encoding procedure for this variable is different.

The procedure starts with an initial estimate of the probability of technical success. Write down your initial estimate. _____

This initial estimate is then adjusted by constructing a new roulette wheel and then considering two bets. The new roulette wheel has x percent of its area shaded where x is your initial estimate. Sketch a picture of the new wheel and then consider these two bets:

Bet #1: You bet that the program is technically successful.

Bet #2: You bet that the shaded part of a new roulette wheel comes up.

In this case the objective is to adjust your initial estimate and the shaded area of the new roulette wheel until you are indifferent between the two bets. What is the probability at which you are indifferent? _____

Federal RD&D Case

The technology characterization encoding procedure has been illustrated in the context of assessing the cost and performance for the case of "No Federal RD&D" and "Technical Success." Similar scenarios can be developed for the other cases outlined in Figure 3-2.

The major difference between the federal RD&D cases and other cases lies in the assessment of the impact of a federal program. In a number of ways the federal RD&D program may produce results that would not have happened without the program. Federal support may improve the cost or performance characteristics of the process, or it may increase the probability of technical success. Even if the same cost and performance characteristics would have eventually been achieved without the federal program and even if the probability of a technical success is independent of the source of

research funding, the existence of a federal program may advance the year in which technical success is achieved.

The assessment of the federal RD&D case proceeds in much the same fashion as the encoding procedure just described. However, the conditioning step needs to be expanded to include the following questions designed to explore the potential impacts of the program:

- o What is the program's objective? _____

- o If the program is successful, what variables would be affected?

- o How is this different from what would have happened had there been no federal program? _____

With this additional structure, encode your uncertainty about each variable by going through the structuring, conditioning, encoding sequence as in the no-federal-RD&D case. Record your estimates in Table 2-3.

The Remaining Global Planning Scenarios

Thus far you have encoded your uncertainty about the characteristics of a process given that a particular global planning scenario has been realized. Now it is time to consider the impact of the remaining global planning scenarios. Study each of the remaining scenarios carefully to determine whether they affect any of the variables characterizing the process differently than the first scenario did. It is quite possible that they will not. However, if there is a differential impact among scenarios, repeat the encoding procedure for both the federal RD&D case and the no-federal-RD&D case for each such scenario.

The process descriptions that result from this encoding procedure are fundamental to the analysis. The no-federal-RD&D case descriptions are necessary for the coordinating group to generate the appropriate coordinating signals. The federal RD&D case descriptions are the basis for computing the program value. The computation of the program value is the next step.

SUMMARY

Decision making in the RD&D area relies heavily on expert judgment, and encoding this judgment allows it to be explicitly incorporated in the decision process. Encoding is not an easy task. However, it is far

superior to ignoring the critical uncertainties that confront RD&D decisions. Indeed, as we will see in the next chapter, the encoding process forms the basis for guiding all further analytic efforts to the most productive areas.

Table 3-1a

INSTRUCTIONS FOR CALCULATING THE PRESENT VALUE OF
PLANNED PROGRAM EXPENDITURES

1. Enter the planned program expenditures (in 1981 dollars) in column one in Table 3-1b. For the six 5-year periods from 1986-2015, enter the average yearly expenditure.
2. Enter the present value factors in column two. These numbers come from the coordinating information (Table 2-5b, cost column). They take into account the fact that expenditures for the period from 1986-2015 are yearly averages.
3. Multiply the expenditures by the present value factors and enter in column three.
4. Sum the numbers in column three and enter the total at the bottom of the column.

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Table 3-1b

COMPUTATION OF THE PRESENT VALUE OF
PLANNED PROGRAM EXPENDITURES

Column	1	2	3
Year	Program Expenditures ^a F_i	Present Value Factor P_i	$P_i \times F_i$
1981			
1982			
1983			
1984			
1985			
1986-1990 ^b			
1991-1995 ^b			
1996-2000 ^b			
2001-2005 ^b			
2006-2010 ^b			
2011-2015 ^b			

^aExpenditures in millions of dollars per year.

^bProgram Expenditures during these periods should be the average yearly expenditures.

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Table 3-2a

CONVERSION PROCESS DESCRIPTION - NO FEDERAL PROGRAM

Scenario: _____

	Low	Nominal	High
1. Capital cost* ($\$/10^6$ Btu per year)	_____	_____	_____
2. Availability (dimensionless)	_____	_____	_____
3. Operating and maintenance ($\$/10^6$ Btu)	_____	_____	_____
4. Efficiency (dimensionless)	_____	_____	_____
5. Construction lead time (years)	_____	_____	_____
6. Year available (year)	_____	_____	_____
7. Property tax and insurance rate (dimensionless)	_____	_____	_____
8. Tax life (years)	_____	_____	_____
9. Book life (years)	_____	_____	_____
10. Sulfur oxides ($1b/10^6$ Btu)	_____	_____	_____
11. Nitrogen oxides ($1b/10^6$ Btu)	_____	_____	_____
12. Particulates ($1b/10^6$ Btu)	_____	_____	_____
13. Carbon monoxide ($1b/10^6$ Btu)	_____	_____	_____
14. Hydrocarbons ($1b/10^6$ Btu)	_____	_____	_____
15. Probability of technical success _____			

*For definitions of variables see Appendix A.

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Table 3-2b

STORAGE PROCESS DESCRIPTION - NO FEDERAL PROGRAM

Scenario: _____

	Low	Nominal	High
1. Capital cost* of process except for storage device (\$/10 ⁶ Btu per year)	_____	_____	_____
2. Capital cost of storage device (\$/10 ⁶ Btu)	_____	_____	_____
3. Availability (dimensionless)	_____	_____	_____
4. Operating and maintenance (\$/10 ⁶ Btu)	_____	_____	_____
5. Efficiency (dimensionless)	_____	_____	_____
6. Construction lead time (years)	_____	_____	_____
7. Year available (year)	_____	_____	_____
8. Property tax and insurance rate (dimensionless)	_____	_____	_____
9. Tax life (years)	_____	_____	_____
10. Book life (years)	_____	_____	_____
11. Sulfur oxides (lb/10 ⁶ Btu)	_____	_____	_____
12. Nitrogen oxides (lb/10 ⁶ Btu)	_____	_____	_____
13. Particulates (lb/10 ⁶ Btu)	_____	_____	_____
14. Carbon monoxide (lb/10 ⁶ Btu)	_____	_____	_____
15. Hydrocarbons (lb/10 ⁶ Btu)	_____	_____	_____
16. Transmission and distribution credit (\$/10 ⁶ Btu per yr)	_____	_____	_____
17. Spinning reserve credit (\$/10 ⁶ Btu)	_____	_____	_____
18. Probability of technical successs _____			

*For definitions of variables see Appendix A.

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Table 3-3a

CONVERSION PROCESS DESCRIPTION WITH IMPACT OF FEDERAL PROGRAM

Scenario: _____

	Low	Nominal	High
1. Capital cost* (\$/10 ⁶ Btu per year)	_____	_____	_____
2. Availability (dimensionless)	_____	_____	_____
3. Operating and maintenance (\$/10 ⁶ Btu)	_____	_____	_____
4. Efficiency (dimensionless)	_____	_____	_____
5. Construction lead time (years)	_____	_____	_____
6. Year available (year)	_____	_____	_____
7. Property tax and insurance rate (dimensionless)	_____	_____	_____
8. Tax life (years)	_____	_____	_____
9. Book life (years)	_____	_____	_____
10. Sulfur oxides (lb/10 ⁶ Btu)	_____	_____	_____
11. Nitrogen oxides (lb/10 ⁶ Btu)	_____	_____	_____
12. Particulates (lb/10 ⁶ Btu)	_____	_____	_____
13. Carbon monoxide (lb/10 ⁶ Btu)	_____	_____	_____
14. Hydrocarbons (lb/10 ⁶ Btu)	_____	_____	_____
15. Probability of technical success _____			

*For definitions of variables see Appendix A.

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Table 3-3b

STORAGE PROCESS DESCRIPTION WITH IMPACT OF FEDERAL PROGRAM

Scenario: _____

	Low	Nominal	High
1. Capital cost* of process except for storage device (\$/10 ⁶ Btu per year)	_____	_____	_____
2. Capital cost of storage device (\$/10 ⁶ Btu)	_____	_____	_____
3. Availability (dimensionless)	_____	_____	_____
4. Operating and maintenance (\$/10 ⁶ Btu)	_____	_____	_____
5. Efficiency (dimensionless)	_____	_____	_____
6. Construction lead time (years)	_____	_____	_____
7. Year available (year)	_____	_____	_____
8. Property tax and insurance rate (dimensionless)	_____	_____	_____
9. Tax life (years)	_____	_____	_____
10. Book life (years)	_____	_____	_____
11. Sulfur oxides (lb/10 ⁶ Btu)	_____	_____	_____
12. Nitrogen oxides (lb/10 ⁶ Btu)	_____	_____	_____
13. Particulates (lb/10 ⁶ Btu)	_____	_____	_____
14. Carbon monoxide (lb/10 ⁶ Btu)	_____	_____	_____
15. Hydrocarbons (lb/10 ⁶ Btu)	_____	_____	_____
16. Transmission and distribution credit (\$/10 ⁶ Btu per yr)	_____	_____	_____
17. Spinning reserve credit (\$/10 ⁶ Btu)	_____	_____	_____
18. Probability of technical successs _____			

*For definitions of variables see Appendix A.

Chapter 4

PROGRAM ANALYSIS: COMPUTATION OF PROGRAM VALUE

INTRODUCTION

The computation of the value of the program is at the heart of the abbreviated approach. Here the program-specific data developed in Chapter 3 are integrated with the coordinating information, resulting in a consistent first cut at the program value that provides a basis for a portfolio analysis.

The value of the program is computed by comparing the world with the new federal program to the world without. The nature of the coordinating information determines how this comparison is made. If the coordinating information describes the world without the federal program (i.e., the information comes from an energy model that contains a description of the process as it would exist without the new federal R&D program), then the value of that program is easy to assess. The world described by the coordinating information is compared to the world with the process as it would exist with a federal program.

If the coordinating information does not describe the world without the new federal program (i.e., the information comes from an energy model that does not contain a description of the process as it would exist without the new federal program), then a different approach must be taken. The market

description provided by the coordinating information is taken as the base case. The value of moving from the base case to the case with the process that results from no new federal program is computed. Similarly, the value of moving from the base case to the case with the process as it would exist with the new federal program is computed. The value of the new federal R&D program is simply the difference between these two values.

Both of these approaches to computing the value of the new federal program are similar. In both approaches, the value of having the process that results from the new federal program is computed. In the first approach, the value of having the process as it would exist without the federal program is known. This is the base case and thus has value zero. In the second approach, the value of having the process as it would exist without the federal program is not known. This case is not the base case; its value is not known and must be computed. Thus, in either approach the program value computation begins by computing the value of the process under a variety of scenarios and then using these values to determine the value of the new federal R&D program.

The interactive computer program makes the computation of the program value quite easy. However, the logic and the details of the computation are obscured. To illuminate the logic of calculating the program value, this chapter explains that computation in great detail. Doing the calculations by hand is a valuable experience in that it exposes the analyst to all aspects of the problem of valuing an RD&D program.

Workspace and instructions are provided so that all computations can be made with the aid of a hand-held calculator. You will find the computations easier if you pull the tables from the book since arranging them side-by-side makes intermediate results more accessible. In addition, a programmable pocket calculator makes the calculations particularly easy since many of the calculations are repetitive.

THE VALUE OF THE ENERGY PROCESS

Computing the value of the federal R&D program begins with computing the value of the energy process. The organization of these computations and the flow of information that they require is shown in Figure 4-1. The coordinating information, shown on the left, is used in all steps of the calculation. Intermediate results are shown on the right except when used immediately in the following step. The steps of the computation result in a single value of the process, which becomes an endpoint on the decision tree shown in Figure 3-2. The computation must be repeated for each combination of decision alternative (fund or do not fund), global planning scenario, and program outcome.

The timing conventions used throughout these calculations assume a 35-year horizon divided into nine 5-year periods. Each period is referred to by its first year; thus the 1985 period refers to the period from 1985 to 1989. The calculation done for this period reflects program impacts at the midpoint, or middle year, of the period. When aggregating impacts across time, assume that the program impact is constant within a period and only changes between periods (an adjustment is made for processes that become

Figure 4-1. Flowchart for Process Value Computation

available during a period). As before, all benefits are assessed in "budget year" dollars, which in this version of the workbook are 1980 dollars.

To begin the calculation of the value of the process, select a path through the tree. This means that a decision alternative (fund or do not fund), a global planning scenario, and a technical outcome must be selected. Of course, if the do-not-fund alternative is described in the coordinating information, then this alternative does not have to be explored here. The tables used for each step of the calculation are set up to allow considering several paths at once. Because of the nature of the calculations, it is particularly easy to pick a decision alternative and a global planning scenario and then consider the low, nominal, and high technical outcomes simultaneously. The path chosen determines the data that are to be used.

Begin the computation by calculating the capital charge rate. This computation isolates the differences between industry and utility financing. Tables 4-1 and 4-2 are used for the capital charge rate calculation. Appendix B presents a discussion of the assumptions behind these calculations.

The next two steps of the calculation determine the values of changes in emissions and imported fuel usage. These values are based on the difference in emissions produced or imported fuel consumed between the average competing process and the new process. The computation of these

values is structured by tables 4-3 and 4-4. In particular, Table 4-3 computes the value of the change in emissions per unit output as:

$$\Delta E = \sum_{\text{Emission Type}} (EA_i - E_i) T_i$$

where:

- ΔE = Value of the change in emissions per unit output
- EA_i = Emissions of type i from alternative processes
- E_i = Emissions of type i from new process
- T_i = Trade-off value for emissions of type i

Similarly, Table 4-4 computes the value of the change in imported fuel used as:

$$\Delta I = (IA - \%I/EFF) T_I$$

where:

- ΔI = Value of the change in imported fuel used per unit output
- IA = Average imported fuel used by alternative processes per unit output
- $\%I$ = Percent of feedstock used that is imported
- EFF = Efficiency
- T_I = Trade-off value for reducing imports

The fourth step of the process value calculation is the sensitivity analysis. The purpose of the sensitivity analysis is to determine which of the uncertain variables in the process description should be represented as uncertain in the program analysis. Representing all variables as uncertain would require a decision tree of several hundred thousand branches.

Fortunately not all of the uncertainty in the process description variables is important in determining the uncertainty in the cost of the process. The sensitivity analysis determines which variables are important to represent as uncertain and thereby reduces the magnitude of the decision tree.

The sensitivity analysis is done by first computing the total social cost per unit output using all nominal values for the variables and then varying each variable across its range one at a time. Since some of the variables change over time, the year 2000 is chosen as the year for which values for these variables are taken. Only those variables whose range significantly impacts the social cost are chosen to be represented as uncertain. The equations used for the sensitivity analysis and space for making the computations are provided in Table 4-5.

If the hand computation is being done for a single branch of the tree to illustrate the methodology, it is not necessary to do the sensitivity analysis. The computation can be done by using the nominal values of all variables since this combination of values will be a branch on the tree regardless which variables are selected to be represented as uncertain. However, the sensitivity analysis does provide insight into the process value, and for this reason alone it is useful to do.

The fifth step of the process value calculation computes the levelized cost of the process. The levelized cost equation and workspace for making this calculation is provided in Table 4-6. The result of the calculation is

used both to determine the market penetration, which is the next step, and to determine the economic benefit in a later step.

The next two steps compute the quantity produced by the new process. The first of these steps computes the penetration of the new process into the market for new capacity, or more exactly, the product demand which cannot be met by existing capacity. The penetration into this market is measured as a percentage, and workspace and instructions for its computation is provided in Table 4-7. To determine the quantity produced from the percentage market share, it is necessary to know how much of the product demand is met by new capacity and how much is produced over the life of each unit of capacity added. The size of the demand that is met by new capacity is part of the coordinating information. Workspace and instructions for using this information to calculate the quantity produced by the new process is provided in Table 4-8.

The economic benefit of the new process depends on the probability distribution of prices existing in the market place and on the probability distribution of prices of the product from the new process. Table 4-9 provides instructions and workspace for calculating the expected economic benefit of the new process for that part of the market that adopts it. A discussion of the assumptions used in the calculation of expected economic benefit is presented in Appendix C.

The final step of the process value computation is the calculation of the gross process value. This value is composed of the value of the changes in

emission production and imported fuel usage and the economic value of the process. This step integrates all of the previous calculations. Workspace for doing this calculation is provided in Table 4-10.

At the end of the process value computation the gross process value has been computed for one decision alternative, one scenario, and one technology outcome. There are, of course, several decision alternatives, many scenarios, and several technology outcomes for each scenario. Thus, this computation is repeated for each combination of scenario and technology outcomes, as shown in Figure 3-2. In addition, if the alternative of not funding is not described by the coordinating information, then the process value computations must be repeated for this alternative also. The values from these computations are used to compute the expected value of the federal R&D program.

THE VALUE OF THE FEDERAL R&D PROGRAM

While the interactive computer program simplifies the computation of the expected value of the federal R&D program, the computation can also be done by hand. A decision tree that explicitly represents each decision alternative, scenario, and technology outcome is used to organize the values of the process computed above. Notice that if the coordinating information describes the alternative of not funding, this alternative has value zero, since it is the base case. Otherwise this alternative has different values for each combination of scenario and technology outcome. The tree that arranges these values is then "solved" to determine the value of each decision alternative and consequently the value of the federal R&D program.

Solving the decision tree, also called rolling back the tree, requires two simple operations corresponding to the two types of nodes in the tree. A circular, or chance, node represents an uncertain event. The possible outcomes of that event are represented by branches emanating from the node. Associated with each branch is the probability of its occurrence and the value of the process given its occurrence. The object at this node is to compute the expected value by multiplying the probability times the value and summing across all branches. This expected value now becomes the value of the branch leading to that uncertainty node.

A square, or decision, node represents the selection of one of several alternatives. Each alternative is represented by a branch emanating from the node. Associated with each branch is the value (or expected value) of selecting that alternative. The object at this node is to select the branch that yields the highest value. This value now becomes associated with the branch leading to the decision node.

By starting with the right-most nodes and performing the above two operations, the tree is solved. At the end there are two expected values associated with the two alternative decisions, fund and do not fund. The value associated with the fund alternative, however, is the gross value, so the cost of the federal program, computed in Table 3-1b, must be subtracted from it. Now the two values can be compared. The difference between them is the value of the federal R&D program.

SUMMARY

The computation of the program value synthesizes information about the R&D program, the energy market, and the goals of the department. The purpose is to provide a first cut at the value of the program, and together with other program analyses to provide a first cut at an RD&D portfolio. Just as important, however, is the goal of identifying the important issues, and sensitive variables. Once this abbreviated analysis is completed, the question is: Where do we go from here? The results of this analysis should be the guide to what is examined in greater detail, whether it is the project, the portfolio, or even the policy guidance that influenced their selection.

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Table 4-1

DATA FOR CALCULATING THE CAPITAL CHARGE FACTOR

1. From the coordinating data (Table 2-5b) enter the appropriate values for:

a) current dollar after-tax cost of capital	$r =$ _____;
b) constant dollar after-tax cost of capital	$r_0 =$ _____;
c) inflation rate	$inf =$ _____;
d) income tax rate	$TAX =$ _____;
e) investment tax credit rate	$ITC =$ _____;
f) AFUDC rate (if needed)	$a =$ _____.

2. From the process description (Table 3-2 or 3-3) enter the appropriate value for:

a) construction lead time	$CL =$ _____;
b) property tax and insurance rate	$PTI =$ _____;
c) tax life	$TL =$ _____;
d) book life	$BL =$ _____.

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Table 4-2

CALCULATION OF THE CAPITAL CHARGE RATE

1. Compute the present value factors:

$$a) \quad PV(r_o, BL) = \frac{1}{r_o} \left[1 - \left(\frac{1}{1+r_o} \right)^{BL} \right] = \underline{\hspace{2cm}};$$

$$b) \quad PV(r, BL) = \frac{1}{r} \left[1 - \left(\frac{1}{1+r} \right)^{BL} \right] = \underline{\hspace{2cm}};$$

$$c) \quad PV(r, TL) = \frac{1}{r} \left[1 - \left(\frac{1}{1+r} \right)^{TL} \right] = \underline{\hspace{2cm}};$$

$$d) \quad D(\text{inf}, CL) = \left(\frac{1}{1+\text{inf}} \right)^{CL/3} = \underline{\hspace{2cm}}.$$

2. Compute appropriate construction cost financing and tax factors:

Regulated Utility

Unregulated Industry

$$a) \quad \left(\frac{1+a}{1+\text{inf}} \right)^{CL/3} \quad \left(\frac{1+r}{1+\text{inf}} \right)^{CL/3} = \underline{\hspace{2cm}};$$

$$b) \quad \frac{\text{TAX} \times D(\text{inf}, CL)}{TL} \quad PV(r, TL) \quad \text{same as utility} = \underline{\hspace{2cm}};$$

$$c) \quad \frac{\text{ITC} \times D(\text{inf}, CL)}{1+r} \quad \text{ITC} \left(\frac{1+r}{1+\text{inf}} \right)^{CL/3} = \underline{\hspace{2cm}}.$$

$$d) \quad \text{PTI}(1-\text{TAX})PV(r, BL)D(\text{inf}, CL) \quad \text{same as utility} = \underline{\hspace{2cm}}.$$

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Table 4-2 (continued)

CALCULATION OF THE CAPITAL CHARGE RATE

3. Compute Effective Capital Cost Factor:

$$(\text{line 2a}) - (\text{line 2b}) - (\text{line 2c}) + (\text{Line 2d}) = \text{ECCF} = \underline{\hspace{2cm}}.$$

4. Compute Capital Charge Rate:

$$\text{CCR} = \frac{1}{1-\text{TAX}} \frac{1}{\text{PV}(r_0, \text{BL})} \text{ECCF} = \underline{\hspace{2cm}}.$$

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Table 4-3a

INSTRUCTIONS FOR COMPUTING THE VALUE OF THE CHANGE IN
ENVIRONMENTAL EMISSIONS

Note: The value of environmental emissions may be both scenario- and program outcome-dependent.

1. Enter the values of the average environmental emissions from competing sources in Table 4-3b. These data come from the coordinating information (Table 2-4).
2. Enter the values for the environmental emissions by the process in Table 4-3b. These data come from the process description (Table 3-2 or 3-3).
3. Compute the difference in emissions by subtracting the emissions by the new process from those from the average competing process. The difference may be positive, indicating an emission decrease, or negative, indicating an emission increase.
4. Enter the trade-off values for the environmental emissions in Table 4-3b. These data come from the coordinating information (Table 2-1).
5. Multiply the difference in the emissions by the trade-off value and enter in the final column of Table 4-3b. These values may be positive, indicating an improvement in the environment, or negative, indicating increased emissions.

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Table 4-3a (cont.)

6. Compute the value of the change in environmental emissions, ΔE , by summing the values in the last column of Table 4-3b.
7. This computation is for one period only. If the levels of emissions per unit output are not changing, then the value of the change in emissions can be used for all years. If the levels of emissions are changing, then the value of the change in emissions must be adjusted or computed for each year.

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Table 4-3b

COMPUTATION OF THE VALUE OF THE CHANGE IN
ENVIRONMENTAL EMISSIONS

Scenario: _____

Program Outcome: _____

Process: _____ Period: _____

Emission	Emission by Competing Process (lb/10 ⁶ Btu)	Emissions by Process (lb/10 ⁶ Btu)	Difference ^a (lb/10 ⁶ Btu)	Trade-off (\$/lb)	Value of Difference (\$/10 ⁶ Btu)
SO ₂					
NO _x					
TSP					
CO					
HC					
TOTAL ΔE					

^aDifference can be negative.

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Table 4-4a

INSTRUCTIONS FOR CALCULATING THE VALUE OF THE CHANGE IN IMPORTS

Note: The value of reducing imports may be both scenario- and program outcome-dependent.

1. From the process description enter the appropriate value for:

efficiency

EFF = _____.

2. From the coordinating data (Table 2-1) enter the appropriate value for:

premium for reducing imports

T_I = _____.

3. Enter the percent of imported feedstock used in Table 4-4b. These data come from the coordinating information (Table 2-6).
4. Divide the percent of imported feedstock used by the thermal efficiency and enter in column two.
5. Enter the average imported energy used per unit output by the competing processes in Table 4-4b. These data come from the coordinating information (Table 2-4).
6. Compute the value of the change in imported fuel usage, ΔI , by subtracting the imported fuel used per unit output of the new process from that of the average competing process and multiplying the difference by the premium for reducing imports.

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Table 4-4b

COMPUTATION OF THE VALUE OF THE CHANGE IN IMPORTS

Scenario: _____ Program Outcome: _____

Process: _____ Feedstock: _____

Period ^a	Percent Imports %I	Imported Energy Used per Unit Output %I/EFF	Average Imported Energy Used per Unit Output by Competing Processes	ΔI (\$/10 ⁶ Btu)
1980				
1985				
1990				
1995				
2000				
2005				
2010				
2015				
2020				

^aValues need be entered only for periods in which the process is available.

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Table 4-5a

SENSITIVITY ANALYSIS INSTRUCTIONS

1. From Table 2-5b enter the appropriate values for:
 - a) load factor LOADFC = _____;
 - b) storage capability ratio SCAP = _____.
2. From Table 2-6 enter the feedstock cost in the year 2000 for the nominal global planning scenario: FEED = _____.
3. From Table 4-2 enter the value for:
capital charge rate CCR = _____.
4. From Table 4-3b enter the value of the change in environmental emissions: ΔE = _____.
5. From Table 4-4b enter the value of the change in imported feedstock used: ΔI = _____.
6. Using the nominal values of all process description variables and the appropriate equation, compute the social cost
 - a) Conversion Process:

$$\text{SOCIAL COST} = \frac{\text{CCR} \times \text{CC}}{\text{AVAIL} \times \text{LOADFC}} + \text{O\&M} + \text{FEED/EFF} + \Delta E + \Delta I$$
$$= \underline{\hspace{2cm}}$$

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Table 4-5a (cont.)

b) Storage Process:

$$\begin{aligned} \text{SOCIAL COST} &= \frac{CC_S \times \text{SCAP} + CC_r - \text{T\&D}}{\text{AVAIL} \times \text{LOADFC}} \quad (\text{CCR}) \\ &\quad - \text{SR} + \text{O\&M} + \text{FEED/EFF} + \Delta E + \Delta I \\ &= \underline{\hspace{2cm}} \end{aligned}$$

where:

CC = capital cost
 CC_S = capital cost of storage device
 CC_r = capital cost of process except for storage device
 SCAP = storage capability ratio
 T&D = transmission and distribution credit
 SR = spinning reserve credit
 AVAIL = availability
 O&M = operating and maintenance cost
 EFF = efficiency

7. For each process description variable compute the social cost for both the high and low values of the variable. The social cost for each value and the difference in social cost induced by the range of the variable are entered in Table 4-5b.

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Table 4-5b
Sensitivity Analysis

Variable	Social Cost		Change in Social Cost Due to Change in Variable
	Low	High	

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Table 4-6a

INSTRUCTIONS FOR COMPUTING LEVELIZED COST

Note: The levelized cost may be both scenario- and program outcome-dependent.

Scenario: _____ Program Outcome: _____

Enter values for each period in which the process is available. For example, if it becomes available in 1992, values should be entered in the row for 1990, but not for 1980 or 1985.

1. From Table 2-5b enter the appropriate values for:

a) load factor LOADFC = _____.

b) storage capability ratio SCAP = _____.

2. From Table 4-2 enter the value for:

capital charge rate CCR = _____.

3. Enter the appropriate values for the feedstock price FEED(i) in Table 4-6b. These data come from the coordinating information (Table 2-6).

4. All other data necessary for computing the levelized cost are contained in the process description.

5. Compute the levelized cost for each time period, P(i) using the appropriate equation:

- a) Conversion Process:

$$P(i) = \frac{CC \times CCR}{AVAIL \times LOADFC} + O\&M + \frac{FEED(i)}{EFF}$$

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Table 4-6a (continued)

b) Storage Process:

$$P(i) = \frac{CC_s + SCAP \times CC_r - T\&D}{AVAIL \times LOADFC} (CCR) - SR$$

$$+ O\&M + \frac{FEED(i)}{EFF}$$

where:

CC = capital cost

CC_s = capital cost of storage device

CC_r = capital cost of process except for storage device

T&D = transmission and distribution credit

AVAIL = availability

SR = spinning reserve credit

O&M = operating and maintenance cost

EFF = efficiency

Space is provided in Table 4-6b to make these computations for several scenarios or several program outcomes.

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Table 4-6b

COMPUTATION OF LEVELIZED COST

Scenario: _____ Program Outcome: _____

Process: _____ Feedstock: _____

Period ^a	Feedstock Price ^b	Levelized Cost		
1980				
1985				
1990				
1995				
2000				
2005				
2010				
2015				
2020				

^aValues should only be entered for periods in which the process is available.^bAll units are $\$/10^6$ Btu.

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Table 4-7a

INSTRUCTIONS FOR CALCULATING THE MARKET SHARES

Note: The market shares are both scenario- and program outcome-dependent.

1. From the coordinating data (Table 2-5b) enter the appropriate value for:

market elasticity parameter

GAM = _____.

2. In column two of Table 4-7b enter the appropriate values for the levelized price of competing supply, P_c . These data come from the coordinating information (Table 2-4).
3. The levelized price of the process, P , comes from Table 4-6b.
4. Compute the market share, MS , for each period in which the process is available.

$$MS(i) = \left[1 + \left(\frac{P(i)}{P_c(i)} \right)^{GAM} \right]^{-1}$$

Space is provided in Table 4-7b to make these calculations for several scenarios or several program outcomes.

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Table 4-7b

CALCULATION OF THE MARKET SHARE

Scenario: _____ Program Outcome: _____

Process: _____ Market: _____

Period ^a	Competition Price (P _c) (\$/10 ⁶ Btu)	Market Share		
1980				
1985				
1990				
1995				
2000				
2005				
2010				
2015				
2020				

^aValues need be entered only for periods in which the process is available.

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Table 4-8a

INSTRUCTIONS FOR COMPUTING THE QUANTITY PRODUCED

Note: The quantity produced by the process is both scenario- and program outcome-dependent. Note also that the quantity produced is in 10^{15} Btu (quads) because the coordinating information is in 10^{15} Btu/year.

1. From the coordinating data (Tables 2-5b) enter the appropriate value for:

social discount rate (constant dollar) $S_0 = \underline{\hspace{2cm}}$

2. From the process description enter the appropriate value for:

book life $BL = \underline{\hspace{2cm}}.$

3. Compute the discounted present value factor for the quantity produced across the life of the process:

$$PV(S_0, BL) = \frac{1}{S_0} \left[1 - \left(\frac{1}{1+S_0} \right)^{BL} \right] = \underline{\hspace{2cm}}.$$

4. In the first column of Table 4-8b enter the quantity produced by the incremental capacity additions. These data come from the coordinating information (Table 2-4).

5. Using the market shares in Table 4-7b, compute the quantity produced over the life of the process, $QP(i)$, for each period that the process is available:

$$QP(i) = Q(i) \times MS(i) \times PV(S_0, BL)$$

Space is provided in Table 4-8b to make these calculations for several scenarios or several program outcomes .

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Table 4-8b

COMPUTATION OF QUANTITY PRODUCED BY THE PROCESS

Scenario: _____ Program Outcome: _____

Process: _____ Market: _____

Period ^a	Quantity Produced by Incremental Capacity Added ^b	Quantity Produced During Life of Process		
1980				
1985				
1990				
1995				
2000				
2005				
2010				
2015				
2020				

^aValues need only be entered for periods in which the process is available.^bValues in 10¹⁵ Btu (Quads).

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Table 4-9a

INSTRUCTIONS FOR COMPUTING THE ECONOMIC BENEFITS

Note: The economic benefits are scenario- and program-outcome dependent.

1. From the coordinating data (Table 2-5b) enter the appropriate value for:

market elasticity parameter

GAM = _____.

2. The levelized price of the process, P, comes from Table 4-6b.
3. The levelized price of competing supply, P_c , and the market share captured by the new process, MS, comes from Table 4-7b.
4. Compute the expected price savings of those using the new process for each year in which the new process is available:

$$EPS(i) = \left\{ P_c(i) \left[1 - (1-MS(i))^{(GAM+1)/GAM} \right] - P(i) [MS(i)]^{(GAM+1)/GAM} \right\} 1/MS(i)$$

Space is provided in Table 4-9b to make this computation for several scenarios or several program outcomes.

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Table 4-9b

COMPUTATION OF THE ECONOMIC BENEFITS

Scenario: _____ Program Outcome: _____

Process: _____ Market: _____

Period ^a	Economic Benefits ^b		
1980			
1985			
1990			
1995			
2000			
2005			
2010			
2015			
2020			

^aValues need only be entered for periods in which the process is available.^bValues in $\$/10^6$ Btu.

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Table 4-10a

INSTRUCTIONS FOR COMPUTING THE GROSS PROCESS VALUE

Note: The gross process value is both scenario- and program outcome-dependent.

1. Enter the present value factor, $PV(i)$, for each period in Table 4-10b. These data come from the coordinating information (Table 2-5b benefit column). For cases in which a process becomes available in the middle of a period (e.g., in a year ending with a digit other than 0 or 5), the present value factor for that period is adjusted by multiplying it by the fraction of the period that the process is available.
2. The value of the change in environmental emission, ΔE , comes from Table 4-3b; the value of the change in imported energy consumed, ΔI , comes from Table 4-4b; the economic value, EPS , comes from Table 3-9b; and the quantity produced comes from Table 3-8b.
3. Compute the gross value, $GV(i)$, for each year that the process is available:

$$GV(i) = QP(i) [EPS(i) + \Delta I(i) + \Delta E(i)] PV(i)$$

Space is provided in Table 4-10b to make these calculations for several scenarios or several program outcomes.

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Table 4-10b

COMPUTATION OF THE GROSS PROCESS VALUE

Scenario: _____ Program Outcome: _____

Process: _____ Market: _____

Period ^a	Present Value Factor	Present Gross Benefits		
1980				
1985				
1990				
1995				
2000				
2005				
2010				
2015				
2020				

^aValues should only be entered for periods in which the process is available.^bValues in \$ x 10⁹.

Appendix A
GLOSSARY OF TERMS

Variable	Abbreviation	Page
Allowed Escalation Rate	a	A-3
Availability	AVAIL	A-4
Book Life	BL	A-5
Capital Cost	CC	A-6
Carbon Monoxide Emissions	CO	A-7
Construction Lead Time	CL	A-8
Constant Dollar After-Tax Cost of Capital	r_o	A-9
Constant Dollar Social Discount Rate	S_o	A-10
Current Dollar After-Tax Cost of Capital	r	A-9
Current Dollar Social Discount Rate	S	A-10
Efficiency	EFF	A-11
Fraction Financed by Common Equity	f_E	A-12
Fraction Financed by Debt	f_D	A-12
Fraction Financed by Preferred Equity	f_P	A-12
Hydrocarbons Emissions	HC	A-7
Income Tax Rate	TAX	A-13
Inflation Rate	inf	A-14
Investment Tax Credit Rate	ITC	A-13
Load Factor	LOADFC	A-4
Market Share Elasticity	GAM	A-15
Nitrogen Oxides Emissions	NO_x	A-7

Variable	Abbreviation	Page
Operating and Maintenance Cost	O&M	A-16
Premium on Imports	T_I	A-17
Property Tax and Insurance Rate	PTI	A-13
Return to Common Equity	r_E	A-18
Return to Debt	r_D	A-19
Return to Preferred Equity	r_P	A-18
Storage Capability Ratio	SCAP	A-20
Sulfur Dioxide Emissions	SO_2	A-7
Tax Depreciation Life	TL	A-21
Total Suspended Particulates Emissions	TSP	A-22
Trade-Off on Environmental Emissions	T_i	A-23
Year Available	YRAVL	A-24

Variable: Allowed Escalation Rate (a)

Definition: The allowed escalation rate for funds used during construction is set by the regulatory agency. This is more formally called the AFUDC rate (Allowance for Funds Used During Construction).

Units: Dimensionless

Interpretation: The rate base, upon which regulated utilities earn a prescribed return, is determined by specifying the value of each plant. The value of a new plant is not its capital cost. The cost of servicing financial obligations during construction, including return to equity holders and interest on debt, increases the cost of the plant. This increase in the costs is reflected in the value of the plant by escalating construction costs forward to the first year of operation at the allowed escalation rate.

Usage: The allowed escalation rate is used to compute the capital charge per unit product from a utility owned process.

Range $0 \leq a \leq 1$

Variables: Availability (AVAIL)
Load Factor (LOADFC)

Definition: Nonelectric power:
 Load Factor = 1
 Availability = stream factor

Electric power:
 Load Factor = fraction of time that a demand is
 placed upon the process

 Availability = fraction of the time when a demand
 is placed upon a process that the
 process is available to meet the
 demand

Units: Availability: dimensionless
Load Factor: dimensionless

Interpretation: For nonelectric power processes, the availability--or
stream factor--is the percent of the time that the
process is actually in operation. This accounts for
both scheduled and unscheduled down time. For electric
power processes, the load factor is a demand-driven
parameter. It is a function of the load duration curve
and is provided by the coordinating information. The
availability is a process-driven parameter that
accounts for scheduled and unscheduled maintenance.

Usage: AVAIL and LOADFC are both used to compute the capital
charge per unit output of a process.

Range: $0 < \text{AVAIL} \leq 1$
 $0 < \text{LOADFC} \leq 1$

Variable: Book Life (BL)

Definition: For existing processes, the book life is defined by the appropriate regulatory agency or by standard accounting practice. For new processes it should be estimated based on similar existing processes.

Units: Years

Interpretation: The book life, which is generally representative of the useful life of the process, is best interpreted as the useful economic life of the process--that time during which the process can be reasonably expected to be economically competitive. It is the period over which the capital cost is amortized.

Usage: The book life is used to determine the capital charge for a unit of output from a process.

Range: $BL \geq 0$

Variable: Capital Cost (CC)

Definition: CC = capital cost of representative process

Units: $\$/10^6$ BTU per yr

Interpretation: The capital cost is based upon a plant of the size indicated by the coordinating information and the following assumptions:

- Capital cost includes land, plant facilities, auxiliary devices, off-site equipment, start-up costs, paid up royalties, working capital and contingencies as appropriate.
- Capital cost excludes interest during construction, investment tax credit, depreciation, inflation, and operating and maintenance cost.
- For storage processes the capital cost of the storage device is separated from the capital cost of the rest of the process.

Usage: The capital cost is used along with the capital charge rate, the operating and maintenance cost, the fuel price, and the efficiency, to determine the levelized cost of the output of a process.

Range: $SCC \geq 0$

Variables: Carbon Monoxide Emissions (CO)
Hydrocarbons Emissions (HC)
Nitrogen Oxides Emissions (NO_x)
Sulfur Dioxide Emissions (SO₂)

Definitions: The emissions are those gaseous compounds generated by the process and emitted into the ambient air.

Units: lb/10⁶ Btu output

Interpretation: The emissions are interpreted as those governed by Environmental Protection Agency regulations, in particular the new source performance standards, the prevention of significant deterioration regulations, and the nonattainment area regulations.

Usage: The emissions are part of the process description and are used to compare emissions among competing processes.

Range: CO ≥ 0
HC ≥ 0
NO_x ≥ 0
SO₂ ≥ 0

Variable: Construction Lead Time (CL)

Definition: The construction lead time is the length of time between the beginning of the plant construction and the time of its operation.

Units: Years

Interpretation: The time to construct includes the actual construction time as well as start-up.

Usage: The time to construct is used in the equation to determine the capital charge for a unit of output from a process.

Range: $CL \geq 0$

Variables: Current Dollar After-Tax Cost of Capital (r)
Constant Dollar After-Tax Cost of Capital (r_0)

Definition: $r = r_E f_E + r_P f_P + r_D f_D (1 - \text{Tax})$

$$r_0 = \frac{r - \text{inf}}{1 + \text{inf}}$$

r_E = Return to Common Equity

r_P = Return to Preferred Equity

r_D = Return to Debt

f_E = Fraction Financed by Common Equity

f_P = Fraction Financed by Preferred Equity

f_D = Fraction Financed by Debt

TAX = Tax Rate

inf = Inflation rate

Units: Dimensionless

Interpretation: The cost of capital, both current and constant, is the weighted average cost of capital, accounting for the fact that interest on debt is tax deductible. Notice that the constant dollar cost of capital is computed from the current dollar cost of capital; not from the weighted sum of constant dollar return to debt and equity. Computing the constant dollar cost of capital from the weighted sum of constant dollar return to debt and equity will seriously overstate the cost of capital.

Usage: The cost of capital is used to compute the capital charge for a unit of output from a process.

Range: $r \geq 0$

$$r_0 \geq 0$$

Variables: Current Dollar Social Discount Rate (S)

Constant Dollar Social Discount Rate (S_0)

Definition: The current dollar social discount rate is the slope of the nation's aggregate indifference curve between consumption now and consumption later.

$$S_0 = \frac{S - \text{inf}}{1 + \text{inf}},$$

where inf = inflation rate.

Units: Dimensionless

Interpretation: The social discount rate is the time preference rate used for making social decisions. Theoretically, it could change over time and over consumption patterns, but as a practical matter one rate is specified and used for all time periods and consumption patterns.

Usage: The constant dollar social discount rate is used to discount values to present value constant dollar measures of social benefits or costs.

Range: $S > 0$

Variable: Efficiency (EFF)

Definition:
$$EFF = \frac{\text{total energy content of product}}{\text{total energy content of primary input}}$$

Units: $\frac{10^6 \text{Btu}}{10^6 \text{Btu}}$ (dimensionless)

Intepretation: The efficiency is the ratio of the product to primary input under average operating conditions. For some processes, this ratio is called the thermal efficiency; for others, it is simply the efficiency; and with heat pumps, it is the coefficient of performance.

Usage: See usage under capital cost.

Range: $0 < EFF \leq 1$. (The coefficient of performance can be greater than one.)

Variables:	Fraction Financed by Debt (f_D)
	Fraction Financed by Common Equity (f_E)
	Fraction Financed by Preferred Equity (f_P)
Definition:	$f_D = \frac{\text{capital investment financed by debt}}{\text{total capital investment}}$
	$f_E = \frac{\text{capital investment financed by common equity}}{\text{total capital investment}}$
	$f_P = 1 - \text{fraction financed by debt}$ - fraction financed by common equity
Units:	\$/\$(dimensionless)
Interpretation:	For nonregulated industries, the common equity fraction is that fraction financed with equity capital--by selling stock or retaining corporate earnings. The debt fraction is the remaining financing that comes from the debt markets. For regulated industries, both common and preferred stock are generally issued to raise the capital that is not raised in the debt market.
Usage:	These variables are used to determine the cost of capital for the process.
Range:	$0 \leq f_D \leq 1$ $0 \leq f_E \leq 1$ $0 \leq f_P \leq 1$

Variables: Income Tax Rate (TAX)

Investment Tax Credit Rate (ITC)

Property Tax and Insurance Rate (PTI)

Definition:
$$\text{TAX} = \text{state tax rate} + (1 - \text{state tax rate})$$
$$\times \text{federal tax rate}$$

The investment tax credit rate is defined by IRS guidelines, and the property tax and insurance rate is defined by convention.

Units: Dimensionless

Interpretation: The income tax rate is the effective state plus federal income tax. It accounts for the fact that state tax is federal tax deductible. The investment tax credit is the IRS-allowed tax credit on new investment. The property tax and insurance rate is the percentage per year of the capital cost that accrues to local governments in the form of property taxes plus the percentage that is spent on insurance.

Usage: All of these parameters are used to determine the capital charge for a unit of output from a process.

Range: $0 \leq \text{TAX} \leq 1$
 $0 \leq \text{ITC} \leq 1$
 $0 \leq \text{PTI} \leq 1$

Variable: Inflation Rate (inf)

Definition: The yearly percentage change in the consumer price index.

Units: Dimensionless

Interpretation: The inflation rate does not influence the relative prices of goods from one year to the next. However, if absolute prices are compared across time, inflation plays an important role.

Usage: The inflation rate is used to compute the capital charge for a unit of output from a process.

Range: Usually between 0 and 1.

Variable: Market Share Elasticity (GAM)

Definition:
$$GAM = \frac{N}{N-1} E$$

where:

N is the number of alternative sources of supply for the market; and E is the percentage decrease in market share resulting from a one percent increase in price when the market shares of all inputs are equal.

Units: Dimensionless

Interpretation: The market share elasticity parameter is a measure of the competitiveness of the market. The larger the parameter value, the more competitive the market. Notice that this parameter is a measure of the market share elasticity, not of the elasticity of demand.

Usage: This parameter is used to compute the market share.

Range: $GAM > 0$

Variable: Operating and Maintenance Cost (Nonfuel) (O&M)

Definition:
$$O\&M = \frac{\text{annual nonfuel operating \& maintenance cost of a representative process}}{\text{annual output of a representative process}}$$

Units: $\$/10^6$ Btu

Interpretation: As with capital cost, the operating and maintenance cost for the particular process assumes the plant size, as specified in the coordinating information, and the following conditions:

- Annual operating and maintenance cost includes total annual production expense less cost of primary fuels (plus any adjustment for by-products or other fuel inputs). Labor, overhead, royalties, utilities, excise taxes, fixed production expense, scheduled and unscheduled maintenance, and auxiliary device operating cost are included.
- Primary fuel, depreciation, interest, income taxes, property taxes, and insurance are excluded.

Usage: See usage under capital cost.

Range: $O\&M \geq 0$

Variable: Premium on Imports (T_I)

Definition: The difference between the slope of the nation's aggregate indifference curve between imported crude oil and income and the indifference curve between domestic crude oil and income, both evaluated at the current values for crude oil consumption and income.

Units: \$/bbl

Interpretation: The premium on imports is the amount the country would be willing to pay above the basic price for a barrel of crude oil to replace imported with domestic crude oil. It includes the value of reducing the country's trade deficit, its dependence on foreign supply, and the consequent threat of an embargo.

Usage: The premium on imports is used to value changes in the level of imports caused by the implementation of a program.

Range: $T_I \geq 0$

Variables: Return to Common Equity (r_E)
Return to Preferred Equity (r_P)

Definition: The return to common (preferred) equity is the amount paid to common (preferred) equity holders in order to secure their investment. It is measured in percent of the investment per year in current dollars. The rate is determined by the common (preferred) equity market.

Units: Dimensionless

Interpretation: The return to common (preferred) equity is the cost of capital in the common (preferred) equity market--the common (preferred) stock market.

Usage: Both the return to common equity and the return to preferred equity are used to compute the cost of capital.

Range: $r_E > 0$
 $r_P > 0$

Variable: Return to Debt (r_D)

Definition: The return to debt is the interest paid on debt. It is determined by the debt market and measured in current dollars.

Units: Dimensionless

Interpretation: The return to debt is the cost of capital in the debt market.

Usage: The return to debt is used to compute the total cost of capital for a process.

Range: $r_D \geq 0$

Variable: Storage Capability Ratio (SCAP)

Definition: $SCAP = \frac{\text{energy stored}}{\text{capacity replaced}}$

Units: $\frac{10^6 \text{ Btu}}{10^6 \text{ Btu/yr}}$

Interpretation: The storage capability ratio is a ratio of the energy storage capability necessary for the storage device to replace a unit of capacity. The ratio is load-dependent since the amount of energy consumed during peak demand determines the necessary storage capability.

Usage: The storage capability ratio is used with the capital cost of the storage device and the capital cost of the converter device to determine the total capital cost of the storage process.

Range: $0 \leq SCAP \leq 1$

Variable: Tax Depreciation Life (TL)

Definition: The tax depreciation life is defined by IRS guidelines.

Units: Years

Interpretation: The tax depreciation life of a process is the time over which the original capital investment is depreciated for tax purposes. In effect, a tax "credit" arises as a result of treating depreciation as an expense for tax purposes. This has the effect of lowering the present value of capital investment.

Usage: Tax depreciation life is used to determine the capital charge for a unit of output from a process.

Range: $TL > 0$

Variable: Total Suspended Particulates Emissions (TSP)

Definition: The total suspended particulates emissions is the total mass of suspended particulate matter generated by a process and emitted into the ambient air.

Units: $1\text{b}/10^6$ Btu output

Interpretation: The total suspended particulates emissions are interpreted as those TSP emissions governed by Environmental Protection Agency regulations, in particular the new source performance standards, the prevention of significant deterioration regulations, and the nonattainment area regulations. Typically TSP emissions include sulfates, nitrates, organic materials, trace metals, and other matter.

Usage: The TSP emissions are part of the process description and are used to compare emissions among competing processes.

Range: $\text{TSP} \geq 0$

Variable: Trade-Off on Environmental Emissions
(T_i , $i = \text{SO}_x, \text{NO}_x, \text{TSP}, \text{HC}, \text{CO}$)

Definition: A trade-off on an environmental emission is the slope of the nation's aggregate indifference curve between the emission and income evaluated at the current values for the emission and income.

Units: \$/lb

Interpretation: A trade-off on an environmental emission is the country's willingness to pay for a reduction in the level of that emission.

Usage: The trade-off on environmental emissions is used to value changes in the level of emissions caused by the implementation of a program.

Variable: Year Available (YRAVL)

Definition: Year available is the first year a process can begin commercial operation.

Units: Years

Interpretation: The year available is the year that the process could begin production, assuming that the R&D program is successful. The year available must allow for the construction period. However, no assumption is made that the process is economically attractive simply because it is available.

For processes existing at the beginning of 1980, the year of commercial availability is defined to be 1980.

Usage: The year of commercial availability is used to determine when a process begins to compete for a share of the market.

Range: $YRAVL \geq 1980$ and integer

Appendix B

LEVELIZED COST OF ENERGY PRODUCTS
FROM A REGULATED UTILITY

INTRODUCTION

This discussion develops a method of computing the levelized cost to a regulated utility of producing energy using a particular energy technology. This levelized cost is used to make a simple comparison from the utility's viewpoint of production processes that have different cash requirements across their lives. Using levelized costs to compare the costs of alternative energy technologies assumes that the utility's preferences for cash flows that extend over time can be measured by the discounted present value of those flows. Often this is a reasonable assumption since the utility's cash requirements are generally financed in large capital markets whose assessment of the utility's financial health is relatively stable. In this case, the value of the marginal dollar invested, usually called the cost of capital, is insensitive to the magnitude and timing of the investment. However, the same may not be true of a company whose financial structure would be greatly affected by financing the construction of a large plant. Before using levelized costs, one must be sure that the discounted cash flow is a reasonable measure of preference for cash flows that extend over time. If the discounted cash flow is a reasonable measure of preference, then the levelized cost is also a reasonable measure. One measure is simply a direct transformation of the other.

The computation of the levelized cost of an energy product begins by estimating all costs incurred in making that product. These estimates are represented in terms of current dollars, that is, actual dollars spent in the years in which the costs are incurred. The first step ends with an estimate of the current dollar cash flow associated with the energy product. This estimate is shown in Figure B-1a, where construction, operating and maintenance, and feedstock costs are highlighted.

The next step is to take account of the utility regulations that specify whether and how the current dollar costs specified in the first step can be charged to ratepayers. Thus, we apply a representative set of utility regulations to the current dollar costs and compute the current dollar regulated cost of service. This current dollar cost-of-service price is shown in Figure B-1b. In this figure no revenues are assumed to be collected prior to the operation of the facility, an assumption about the particular utility regulations that will be discussed in detail later.

The final step in computing the levelized cost of an energy product is to discount the current dollar revenues to present value using the discount rate appropriate for application to current dollars. This present value, which is a measure of total revenue requirements, is then converted to an equivalent levelized cost, which is a measure of cost per unit. The resulting levelized cost is shown in Figure B-1c. The vertical axis in this figure, unlike that in figures B-1a and B-1b, is marked off in constant dollars, not current dollars. The unit cost shown in Figure B-1c

a) Actual Utility Spending

b) Regulated Cost of Service

c) Levelized Cost of Service

Figure B-1. The computation of the level cost of an energy product produced by a regulated utility.

^aCL = Construction Length
BL = Book Life

gives a convenient single number that can be used to compare the cost of producing energy using different technologies.

Our objective in performing the steps outlined above is to produce a simple formula--one that could be solved on a hand-held calculator--for computing the levelized constant dollar cost. Achieving this simplicity requires a number of assumptions. However, we will always start with a general representation then clearly state any simplifying assumptions. Thus, the discussion will serve as both a general description of levelized costs and a detailed description of a simplified method of computing them.

In the following discussion, the timing convention will be to count time from the point when the plant begins operating: This is time zero. Costs and revenues are counted at the end of the year. For example, the feedstock cost during the first year would be $\text{Feed}(1)$. Construction costs, since they occur before the plant begins operating, are counted backward from time zero. Thus, the construction cost in the i^{th} year before operation would be $\text{cc}(i)$. Estimates of all costs are assumed to be in base or reference year dollars. In the calculations, these base year dollars will be converted to current dollars.

UTILITY SPENDING PATTERN--Step One

The first step in calculating the levelized cost of an energy product produced using a particular technology is to determine the actual spending pattern that the utility would incur to produce the product. This pattern

describes the payments and timing of the payments for construction costs, operating and maintenance costs, feedstock costs, taxes, and insurance. In general, it is generated from estimates of each of these costs, their escalation rates, and their spending pattern. We will discuss each cost separately and then aggregate to produce the total current dollar spending pattern.

Construction Cost

The capital or construction cost of the plant is estimated on a "build today, operate today" basis. This estimate is in a particular year's dollars, called the base year or t_b . In addition there is an estimate of the construction cost spending pattern, given in terms of the fraction of the total cost spent in each year before operation. Thus, f_i is the fraction of the total cost in t_b dollars spent in the i^{th} year before operation. Given the construction cost escalation rate, e_c , we compute the current dollar spending pattern:

Construction Cost in the i^{th} Year before Operation

$$\begin{aligned}
 &= cc \times f_i \times (1+e_c)^{t_o-t_b-i+1} \\
 &= cc (1+e_c)^{t_o-t_b} \times \frac{f_i}{(1+e_c)^{i-1}} \quad i = CL, \dots, 1 \quad (B-1)
 \end{aligned}$$

where

cc = Total construction cost in base year dollars

f_i = Fraction of the total cost, cc , spent in the i^{th} year before operation

e_c = Current dollar escalation rate of construction costs

t_o = Time when process begins operation

t_b = Base year in which cost estimates are made

CL = Construction period length

Notice that since the time during construction is counted backwards from the point of operation, the escalation factor is based on the base year, the date of operation, and the particular year of construction under consideration.

Equation B-1 is the estimate of the actual spending during the construction period. Although the equation may appear more complicated than necessary, its advantage is that the individual terms are easier to estimate than is the entire equation. One can estimate capital or construction costs without having to keep track simultaneously of cost escalation and spending patterns. The cost escalation rate, which influences estimates of construction costs for all processes, can be specified independently, thereby insuring consistency when making comparisons. Finally, assumptions about the construction profile are explicit, making it easy to review and test for sensitivity.

Operating and Maintenance Cost

The operating and maintenance (O&M) cost does not include tax or fuel costs. Occasionally the levelized O&M cost is estimated directly, a process that works well if the O&M cost escalates at the general rate of inflation. If it does not, as assumed here, then it should be treated like

other costs in this section by computing the actual costs incurred each year. To do this the following terms are defined:

$O\&M(0)$ = Operating and maintenance cost for the first year, t_0 , estimated in base year, or t_b , dollars

e_0 = Current dollar O&M cost escalation rate

The current dollar O&M cost for the i^{th} year of operation is:

$$\begin{aligned} O\&M(i) &= O\&M(0) \times (1+e_0)^{t_0-t_b+i} \\ &= O\&M(0) \times (1+e_0)^{t_0-t_b} \times (1+e_0)^i \end{aligned} \quad (B-2)$$

In some cases the O&M costs exhibit a profile not well approximated by an escalation rate. Generally, however the O&M costs are a small enough part of the total costs that it is not worthwhile to use calculations more elaborate than Eq. B-2.

Feedstock Cost

The feedstock cost is generally an important component of the total cost of an energy product. Consequently, considerable effort has been expended in modeling the factors that influence the feedstock cost. This discussion assumes that such a model is available to compute the current dollar feedstock cost, $Feed(i)$. There are other methods of estimating this cost; for example, it could be estimated like the O&M cost by using an initial cost and an escalation rate. However, this discussion will pursue no other methods and simply assumes that $Feed(i)$ is provided.

Taxes

Three tax items are considered explicitly: income tax, the investment tax credit, and property tax.

Income Tax. The income tax is considered due at the end of each year in which revenues are collected. For each such year the current dollar income tax liability is computed as the tax rate times the current dollar taxable income. Hence, for year i the income tax is:

$$\begin{aligned} \text{Income Tax}(i) = & \text{TAX} \times [\text{Rev}(i) - \text{O\&M}(i) - \text{Feed}(i) \\ & - \text{Interest on Debt}(i) - \text{Tax Depreciation}(i) \\ & - \text{Property Taxes and Insurance}(i)] \end{aligned} \quad (\text{B-3})$$

where

TAX = income tax rate
REV = revenue
O&M = operating and maintenance cost
Feed = feedstock cost

The tax rate, TAX, should be computed so as to reflect both state and federal income taxes. If one defines:

FTAX = federal income tax rate

STAX = state income tax rate

then the appropriate total tax rate is:

$$\text{TAX} = \text{FTAX} (1 - \text{STAX}) + \text{STAX} .$$

This formula accounts for the fact that state income tax is deductible for federal income tax purposes.

Investment Tax Credit. The investment tax credit reduces the tax liability by an amount equal to some fraction of the total capital investment. Since the total capital investment does not include the cost of financing construction, it can be computed by simply summing the capital investment during each year of construction as given in Eq. B-1.

$$\begin{aligned} \text{Total Capital Investment} &= \sum_{i=1}^{CL} cc \times (1+e_c)^{t_0-t_b} \frac{f_i}{(1+e_c)^{i-1}} \\ &= cc \times (1+e_c)^{t_0-t_b} \sum_{i=1}^{CL} \frac{f_i}{(1+e_c)^{i-1}} \end{aligned}$$

The investment tax credit then, is the total capital investment times the investment tax credit rate, ITC, which is specified by the IRS:

$$\text{Investment Tax Credit} = \text{ITC} \times cc \times (1+e_c)^{t_0-t_b} \sum_{i=1}^{CL} \frac{f_i}{(1+e_c)^{i-1}} \quad (\text{B-4})$$

This credit can be applied against any tax liability from three years before the investment to seven years after the investment. The credit applies to the incremental investment for each year. Hence, if \$100 is spent in the first year of construction and there is a 10% investment tax credit rate, the \$10 credit can be applied to any tax liability from three years before to seven years after the first year of construction. The only other restriction is that the credit cannot reduce the total tax liability in any one year more than 50%.

No incentive exists for the utility to wait to take the investment tax credit. However, it is possible that the utility does not have sufficient tax liability to take the credit when it is first possible to do so.

Recognizing this problem, the PUCs does not require the utilities to pass the benefit of the credit to the consumers if it has not yet accrued to the utility. Thus, the effect of the investment tax credit on the regulated cost of service depends on when the benefit accrues to the utility and when the utility must pass it through to the consumers.

Property Tax. Property tax is less well specified than either the income tax or the investment tax credit rate, since there are as many property tax rates as there are districts with the authority to impose a property tax. Conventions for estimating the property tax also vary. A common practice is to estimate both the property tax and insurance together as a fraction of the total capital investment. An alternative is to estimate the cost directly and include it in the O&M cost. This discussion assumes that both property tax and insurance are estimated as a fraction of the total capital investment.

The Total Spending Pattern

The total current dollar spending pattern for the utility can now be constructed by adding the construction, O&M, feedstock, tax, and insurance costs. This spending pattern does not affect the consumer directly. The cost that the consumer sees is determined by the appropriate public utility regulations. The next section will show how typical utility regulations

convert the actual utility spending pattern into the cost of service paid by consumers.

REGULATED COST OF SERVICE--Step Two

Public regulation of utilities is based on two premises. The first is that utilities operate more efficiently in a noncompetitive atmosphere than in a competitive one and that consumers can gain from that increased efficiency. The second is that the prices of goods produced by industries in noncompetitive or monopolistic markets must be regulated so that the industries do not extract monopolistic rents from consumers. Once these two premises are accepted, the only thing left to do is to set the regulated price.

Establishing a formula for the regulated price is the responsibility of the local public utility commission (PUC), and the regulations that have resulted are as varied as the commissions themselves. Fortunately, all of the price regulations are based on the same basic idea: The price set should just compensate the utility for the cost of providing service. This cost includes a return on the capital investment, depreciation of that investment, and the variable cost of providing service.

This section will take this fundamental concept and derive two formulas. The first, a basic cost-of-service expression, will not be specific enough to allow us to compute a price, but it will show all the important elements of the price without making many assumptions about utility regulations. The second formula is a specific cost-of-service formula, from which we can compute the current dollar cost of service for each year of a plant's

operation. This equation is representative of current PUC practice. Those areas where practice varies widely will be discussed.

The Basic Cost-of-Service Formula

In general, the cost of service is composed of three parts: the return on the money invested to provide service, the depreciation of that investment, and the variable cost of providing service. The undepreciated part of the investment is called the rate base, a legally defined quantity upon which the utility is allowed to earn a return. The variable cost of service includes the O&M, feedstock, tax, and insurance. Thus, for each year, j :

$$\begin{aligned}\text{Cost of Service}(j) &= \text{Return on Rate Base}(j) \\ &\quad + \text{Depreciation of the Rate Base}(j) \\ &\quad + \text{Operating Costs}(j) \qquad \qquad \qquad (B-5)\end{aligned}$$

where

$$\begin{aligned}\text{Operating Costs}(j) &= \text{Operating and Maintenance Cost}(j) \\ &\quad + \text{Feedstock Cost}(j) \\ &\quad + \text{Income Tax}(j) \\ &\quad + \text{Property Tax and Insurance}(j) \ .\end{aligned}$$

This equation is misleadingly simply. Recall from Eq. B-3 that the income tax is a function of the revenue, which is collected from consumers and therefore is just the cost of service. If we substitute this relation into Eq. B-5, we have the more complicated but more fundamental expression for the current dollar cost of service in year j :

$$\begin{aligned}
\text{Cost of Service}(j) &= R \times \text{Rate Base}(j) \\
&+ \text{Book Depreciation}(j) \\
&+ \text{O\&M}(j) + \text{Feed}(j) \\
&+ \text{Property Tax and Insurance}(j) \\
&+ \text{TAX} \times [\text{Cost of Service}(j) - \text{O\&M}(j) \\
&\quad - \text{Feed}(j) - \text{Interest on Debt}(j) \\
&\quad - \text{Tax Depreciation}(j) \\
&\quad - \text{Property Tax and Insurance}(j)] \\
&- \text{Investment Tax Credit}(j) \qquad \qquad \qquad (\text{B-6})
\end{aligned}$$

where

R = Regulated current dollar rate of return on the rate base.

Book Depreciation = Allowed depreciation of the rate base

O&M = Current dollar operating and maintenance cost

Feed = Current dollar feedstock cost

TAX = Income tax rate

Collecting the cost-of-service terms in Eq. B-6 and rearranging yields:

$$\begin{aligned}
\text{Cost of Service}(j) &= \frac{R}{1-\text{TAX}} \text{Rate Base}(j) \\
&+ \frac{\text{Book Depreciation}(j) - \text{TAX} \times \text{Tax Deprec.}(j)}{1-\text{TAX}} \\
&+ \text{O\&M}(j) + \text{Feed}(j) \\
&+ \text{Property Tax and Insurance}(j) \\
&- \frac{\text{TAX}}{1-\text{TAX}} \text{Interest on Debt}(j) \\
&- \frac{1}{1-\text{TAX}} \text{Investment Tax Credit}(j) \qquad \qquad \qquad (\text{B-7})
\end{aligned}$$

We can simplify further by noting that the return on the rate base, R , is regulated at the cost of capital. The cost of capital is computed as a weighted average cost of capital from available sources. If we consider three sources of capital--debt, equity, and preferred equity--the weighted cost of capital is:

$$R = f_D r_D + f_E r_E + f_P r_P \quad (B-8)$$

where

f_i = the fraction of the investment financed from source i

r_i = the current dollar cost of capital from source i

i = the source: debt(D), equity(E), or preferred equity(P).

If debt is retired at the same rate as the plant depreciates, the interest on debt is the cost of debt times the fraction of the rate base financed by debt or:

$$\text{Interest on Debt}(t) = r_D f_D \text{ Rate Base}(t) \quad (B-9)$$

Substituting equations B-8 and B-9 into B-7 yields the basic cost-of-service expression:

$$\begin{aligned} \text{Cost of Service}(j) = & \frac{r}{1-\text{TAX}} \text{ Rate Base}(j) \\ & + \frac{\text{Book Depreciation}(j) - \text{TAX} \times \text{Tax Deprec.}(j)}{1-\text{TAX}} \\ & + \text{O\&M}(j) + \text{Feed}(j) \\ & + \text{Property Tax and Insurance}(j) \\ & - \frac{1}{1-\text{TAX}} \text{ Investment Tax Credit}(j) \end{aligned} \quad (B-10)$$

where

$$r = f_D r_D (1-TAX) + f_E r_E + f_P r_P$$

= the current dollar after-tax weighted cost of capital.

Now that the basic cost-of-service equation has been derived, it is useful to review all the important assumptions made in getting to this point.

The first assumption is that the PUC sets the regulated rate of return at the average cost of capital. This is almost always the case since any lower rate would make it difficult, or even impossible, to raise the capital, while any higher rate would result in higher prices than necessary. It could easily be that the actual rate of return is different from the regulated rate of return because of the lag between the time the rates are set and the time the utility goes into the market for capital. However, the important point is that the rate of return is the average cost of capital from the PUC's point of view. Thus, the cost of service in Eq. B-10 is the cost of service from the point of view of the regulatory agency.

The next assumption concerns who benefits from the various incentives for capital investment, in this case the investment tax credit and the difference between book and tax depreciation. Investors argue that Congress intended the investment tax credit and the favorable tax depreciation schedules to encourage investment. The benefits should accrue to investors, and therefore the associated terms should not be included in the cost-of-service calculation. Consumers, on the other hand, maintain that the return on investment in the utility industry is attractive enough

to attract investors without added incentives; any additional incentive simply takes advantage of the monopolistic market condition. The benefits of the investment tax credit and the favorable tax depreciation schedules should be passed on to consumers, and therefore the associated terms should appear in the calculation.

The responses of the PUCs to these arguments vary, although less so about the benefits of depreciation than about the benefits of the investment tax credit. By and large, the PUCs require that the benefits of favorable tax depreciation schedules be passed through to consumers, as we have assumed in Eq. B-10. Requirements on handling the investment tax credit, however, range from passing it on to consumers in the year that it is taken to passing it on linearly over the book life of the plant. Eq. B-10 includes only the assumption that the credit is passed on to the consumers; it does not specify how. The next subsection will introduce a more specific assumption.

The final assumption is that debt is retired at the same rate as the plant depreciates. This assumption is made because it simplifies the equation and is a relatively good approximation to standard practice.

A Specific Cost-of-Service Formula

The above expression for the cost-of-service price illustrates the important components of that price without making many simplifications or assumptions. However, it is not specific enough to actually calculate a price. In this subsection the expression in Eq. B-10 will be used to develop a specific cost-of-service equation by specifying the rate base,

book depreciation, tax depreciation, investment tax credit, and property tax and insurance for each year. Necessarily we will make some assumptions. However, as before, we will point out all the assumptions made and some possible alternatives.

The Rate Base. The rate base in any given year is defined as the initial rate base minus the accumulated book depreciation. If we assume straight line book depreciation, the rate base and the depreciation can be written:

$$\text{Rate Base}(j) = \text{Rate Base}(0) \left[1 - \frac{(j-1)}{BL} \right] \quad (B-11)$$

$$\text{Book Depreciation} = \frac{\text{Rate Base}(0)}{BL} \quad (B-12)$$

where BL is the book life. This leaves only the rate base at time zero unspecified.

The rate base at time zero--the initial book value of the plant--is typically determined using the allowance for funds used during construction (AFUDC) method. Under this method consumers do not pay construction costs until after construction is completed. The cost of financing construction during the construction period is added to the capital cost of the plant to determine its initial book value. This financing cost, which includes return to equity holders and interest on debt that must be paid during construction, is regulated just like the rate of return on the rate base. The allowed rate is called the "AFUDC rate."

To compute the initial rate base, the construction costs for each year are escalated forward to the first year of operation at the AFUDC rate, a . If

cc(i) is the construction cost incurred i years before operation, the initial rate base can be expressed as:

$$\text{Rate Base}(0) = \sum_{i=1}^{CL} cc(i) (1+a)^{i-1} \quad (B-13)$$

The construction costs for each year, cc(i), were defined in Eq. B-1, and substituting Eq. B-1 into Eq. B-13 yields:

$$\begin{aligned} \text{Rate Base}(0) &= \sum_{i=1}^{CL} cc (1+e_c)^{t_o-t_b} \frac{f_i}{(1+e_c)^{i-1}} (1+a)^{i-1} \\ &= cc (1+e_c)^{t_o-t_b} \sum_{i=1}^{CL} f_i \left(\frac{1+a}{1+e_c} \right)^{i-1} \end{aligned} \quad (B-14)$$

where

cc = the total construction cost in t_b dollars estimated on a build today, operate today basis

e_c = the current dollar escalation rate of construction costs

f_i = fraction of the total construction cost, cc, spent in the i th year before operation

t_o = time when process begins operation

t_b = base year in which cost estimates are made

This expression is based on the assumptions that the AFUDC method is used to compute the rate base and that compounding of the AFUDC is permitted. Although these assumptions are representative of a large number of PUCs, they are by no means the only approaches to dealing with construction costs. A less common approach, for example, is to allow some or all

construction costs into the rate base before construction is completed. Another approach, used by the California PUC as late as 1978, did not allow the AFUDC to be compounded. For large capital cost projects the method chosen has important implications for the cost-of-service price.

Eq. B-14 requires that the construction spending pattern, f_i , be specified in terms of the fraction of the cost spent in each year. For many energy technologies, the construction pattern is approximated fairly well by assuming that the entire cost is incurred two-thirds of the way through the construction period. This assumption is made because it will greatly simplify the computation of the levelized cost. More ambitious persons or those with computers can retain the detail of Eq. B-14. However, if the simplifying assumption is made, the initial rate base would be:

$$\text{Rate Base}(0) = cc(1+e_c)^{t_o-t_b} \left(\frac{1+a}{1+e_c} \right)^{CL/3} \quad (\text{B-15})$$

Under this simplifying assumption we compute the construction cost part of the rate base--the initial rate base minus the AFUDC--which we label

" R_o ,"

where

$$R_o = cc(1+e_c)^{t_o-t_b} \left(\frac{1}{1+e_c} \right)^{CL/3} \quad (\text{B-16})$$

Tax Depreciation. The important question about tax depreciation, as discussed earlier, is who receives the benefits of a tax depreciation schedule that is different from a book depreciation schedule. If both

schedules are identical, the utility is repaid for the depreciation in the same year that it takes the depreciation as an expense. The effect is that the repayment for depreciation is not considered taxable income. If, however, the asset is depreciated faster for tax purposes than for book purposes, in the early years the tax deduction is larger than the repayment, while in later years the reverse is true. The effect is to push taxable income into the future and to move nontaxable income towards the present. In a net present value sense, the total taxes are reduced and after-tax income is increased. Who receives the extra income: the utilities in the form of greater profits or the consumers in the form of lower rates? Typically, PUCs require the utilities to pass the income through to consumers. This assumption is made here.

The IRS determines the tax depreciation schedules that are permissible. This discussion will assume straight-line depreciation over a tax life of TL years. It would also be possible to assume double declining balance, or sum of the year's digits methods, since they also have closed form expressions and thus lend themselves to hand calculations. However, the popular method of using double declining balance with a switchover to straight line (at the year such that the net present value of tax depreciation is at a maximum) is somewhat cumbersome for our purposes.

In computing the tax depreciation for each year it must be noted that only the capital spending part of the rate base is depreciable for tax purposes; the AFUDC part is not. To compute the tax depreciable part of the rate

base, R_0 , the construction costs given in Eq. B-1 are summed across the construction period, yielding:

$$\begin{aligned}
 R_0 &= \sum_{i=1}^{CL} cc \times (1+e_c)^{t_0-t_b} \times \frac{f_i}{(1+e_c)^{i-1}} \\
 &= cc \times (1+e_c)^{t_0-t_b} \sum_{i=1}^{CL} \frac{f_i}{(1+e_c)^{i-1}} \quad (B-17)
 \end{aligned}$$

Therefore, the annual tax depreciation using the straight-line method is:

$$\text{Tax Depreciation}(j) = \frac{R_0}{TL} \quad (B-18)$$

Investment Tax Credit. As discussed earlier, the requirements for passing the benefits of the investment tax credit through to the consumer are diverse. It is rare not to pass the credit through at all; popular methods range from passing it through as it is accrued to passing it through linearly over the book life of the plant. For capital-intensive facilities the difference is substantial.

This discussion assumes that the investment tax credit is passed through the first year of operation. Under this condition and with a tax credit rate of ITC, the investment tax credit as shown in Eq. B-4 becomes:

$$\text{Investment Tax Credit}(j) = \text{ITC} \times R_0 \delta(1,j) \quad (B-19)$$

where

$\delta(1,j)$ = the Kronecker delta function, which takes the value one when j is equal to one and zero otherwise.

Notice that the investment tax credit applies only to the construction cost part of the rate base; it does not apply to the AFUDC part.

Property Tax and Insurance. The yearly cost of property tax and insurance is estimated as a fraction of the total capital investment. Thus, for year j , these costs are:

$$\text{Property Tax and Insurance}(j) = \text{PTI} \times R_0 \quad (\text{B-20})$$

where

PTI = percentage of the capital investment spent on property taxes and insurance

R_0 = sum of the construction costs

We have now made enough assumptions about the nature of the public utility regulations to transform the basic cost-of-service equation, Eq. B-10, to one whereby we can calculate the yearly cost-of-service price.

Substituting eqs. B-11, B-12, B-18, B-19, and B-20 into B-10 and rearranging yields:

$$\begin{aligned} \text{Cost of Service}(j) = & \frac{r}{1-\text{TAX}} \text{Rate Base}(0) \left[1 - \frac{j-1}{\text{BL}} \right] \\ & + \frac{\text{Rate Base}(0)/\text{BL} - \text{TAX} \times R_0/\text{TL}}{1 - \text{TAX}} \\ & + \text{O\&M}(j) + \text{Feed}(j) \\ & + \text{PTI} \times R_0 \\ & - \frac{\text{ITC}}{1 - \text{TAX}} R_0 \delta(1,j) \quad (\text{B-21}) \end{aligned}$$

Substituting Eq. B-15, the approximate formula for the initial rate base, and Eq. B-16, the approximate formula for the construction cost part of the rate base, into Eq. B-21 yields:

$$\begin{aligned}
 \text{Cost of Service (j)} = & \frac{r \times CC}{1-TAX} (1+e_c)^{t_o-t_b-CL/3} \\
 & \times (1+a)^{CL/3} \left[1 - \frac{j-1}{BL} + \frac{(1+a)^{CL/3}}{BL} - \frac{TAX}{TL} \right] \\
 & + PTI(1-TAX) - ITC (1,j) \\
 & + O\&M(j) + \text{Feed}(j) \quad . \quad (B-22)
 \end{aligned}$$

This is the specific cost-of-service equation. There were many alternative assumptions that could have been made that would have resulted in a different equation. However, the important point is that this equation is representative of cost-of-service pricing regulation and is simple enough to be computed on a hand-held calculator.

LEVELIZED COST OF SERVICE--Step Three

The final step in computing the levelized cost of an energy product is to levelize the current dollar regulated cost of service. This section will levelize the cost of service by starting with the definition of a levelized cost. This leads to a general formulation of the levelized cost of an energy product. This general equation is solvable, but to make the solution convenient a constant production profile is assumed. A discussion of this assumption and the resulting levelized cost-of-service equation concludes this section.

The Levelized Cost

The levelized cost-of-service price is defined as that constant dollar price that produces a stream of revenues the discounted present value of which is equal to the discounted present value of the stream of revenues produced by the regulated cost-of-service price. Using algebraic notation the definition becomes:

$$\sum_{j=1}^{BL} \bar{p} (1+inf)^j q(j) \frac{1}{1+x}^j = \sum_{j=1}^{BL} p(j)q(j)\left(\frac{1}{1+x}\right)^j \quad (B-23)$$

where

$\bar{p}$ = levelized of constant dollar price

$q(j)$ = quantity produced at time j

$p(j)$ = current dollar cost-of-service price at time j

x = current dollar discount rate

Notice that $\bar{p}$ has been inflated at the inflation rate, inf , because $\bar{p}$ is a constant dollar price, but x , the discount rate, is a current dollar discount rate. Inflating $\bar{p}$ at the inflation rate gives the current dollar equivalent of the constant dollar price, which then can be discounted at the current dollar discount rate.

We solve Eq. B-23 for $\bar{p}$, producing:

$$\bar{p} = \frac{\sum_{j=1}^{BL} p(j)q(j)\left(\frac{1}{1+x}\right)^j}{\sum_{j=1}^{BL} q(j)\left(\frac{1+inf}{1+x}\right)^j} \quad (B-24)$$

This is the general representation of the levelized constant dollar price.

An Approximate Formula for Computing Level Cost-of-Service Price

Eq. B-24 computes the levelized cost exactly. However, it is extremely cumbersome for computing on a hand-held calculator because there are two summations to compute and the production profile, $q(t)$, to deal with. The complexity of this equation can be substantially reduced by assuming that the production profile is constant over the book life. This is a reasonable approximation if the profile is constant over the majority of the early years, since the production in the later years is discounted heavily. Assuming a uniform production profile yields:

$$\bar{p} = \text{Ann}(x_0, \text{BL}) \sum_{j=1}^{\text{BL}} p(t) \left(\frac{1}{1+x} \right)^j \quad (\text{B-25})$$

where:

$$\text{Ann}(x_0, \text{BL}) = \left[\sum_{j=1}^{\text{BL}} \left(\frac{1}{1+x_0} \right)^j \right]^{-1} = \frac{x_0(1+x_0)^{\text{BL}}}{(1+x_0)^{\text{BL}} - 1}$$

$$x_0 = \frac{1+x}{1+\text{inf}} - 1 = \frac{x-\text{inf}}{1+\text{inf}}$$

$\text{Ann}(x_0, \text{BL})$ is often called the annuity factor, and x_0 is the constant dollar discount rate equivalent to the current dollar rate, x , given the inflation rate, inf .

Recall that $p(j)$ is the cost of service at time j , which is defined in the specific cost of service, Eq. B-22. The appropriate discount rate is r ,

the current dollar after-tax weighted cost of capital. Using r and substituting Eq. B-22 into Eq. B-25 yields:

$$\begin{aligned} \bar{p} = & \text{Ann}(r_o, \text{BL}) \sum_{j=1}^{\text{BL}} \left(\frac{1}{1+r} \right)^j \left\{ \frac{\text{cc}}{1-\text{TAX}} (1+e_c)^{t_o-t_b-\text{CL}/3} \right. \\ & \times \left[(1+a)^{\text{CL}/3} \left[1 - \frac{j-1}{\text{BL}} \right] \right. \\ & \quad + \frac{(1+a)^{\text{CL}/3}}{\text{BL}} - \frac{\text{TAX}}{\text{TL}} \\ & \quad \left. \left. + \text{PTI}(1-\text{TAX}) - \text{ITC} (1,j) \right] \right. \\ & \left. + \text{O\&M}(j) + \text{Feed}(j) \right\}. \end{aligned} \quad (\text{B-26})$$

where

$$r_o = \frac{r-\text{inf}}{1+\text{inf}} = \text{the constant dollar weighted cost of capital.} \quad (\text{B-27})$$

The constant dollar after-tax weighted cost of capital must be computed from the current dollar weighted cost of capital. The current dollar weighted after-tax cost of capital is defined as:

$$r = f_D r_D (1-\text{TAX}) + f_E r_E + f_P r_P \quad (\text{B-28})$$

where

f_i = the fraction of the investment financed from source i

r_i = the current dollar cost of capital from source i

i = the source: debt (D), equity (E), or preferred equity (P).

Rearranging Eq. B-26 and solving the summations that have closed form expressions yields:

$$\begin{aligned}
 \bar{p} = & cc(1+e_c)^{t_o-t_b-CL/3} \frac{Ann(r_o, BL)}{1-TAX} \\
 & \times \left\{ (1+a)^{CL/3} - \frac{TAX}{TL} PV(r, TL) \right. \\
 & \left. + PTI(1-TAX)PV(r, BL) - \frac{ITC}{1+r} \right\} \\
 & + Ann(r_o, BL) \sum_{j=1}^{BL} O\&M \left(\frac{1}{1+r} \right)^j \\
 & + Ann(r_o, BL) \sum_{j=1}^{BL} Feed(j) \left(\frac{1}{1+r} \right)^j
 \end{aligned} \tag{B-29}$$

Although Eq. B-29 is a lengthy expression, each term has an intuitive explanation. The levelized feedstock cost $\overline{Feed}$ is:

$$\overline{Feed} = Ann(r_o, BL) \sum_{j=1}^{BL} Feed(j) \left(\frac{1}{1+r} \right)^j \tag{B-30}$$

The levelized operating and maintenance cost, $\overline{O\&M}$, is:

$$\overline{O\&M} = Ann(r_o, BL) \sum_{j=1}^{BL} O\&M \left(\frac{1}{1+r} \right)^j \tag{B-31}$$

The capital cost excluding the cost of financing construction is:

$$R_o = cc(1+e_c)^{t_o t_b - CL/3} \quad (B-32)$$

Finally, the capital charge rate, CCR, is:

$$CCR = \frac{Ann(r_o, BL)}{1-TAX} \left\{ (1+a)^{CL/3} - \frac{TAX}{TL} PV(r, TL) \right. \\ \left. + PTI(1-TAX) PV(r, BL) - \frac{ITC}{1+r} \right\} \quad (B-33)$$

Within this capital charge rate expression the first term in the brackets is the cost of financing construction, the second term is the benefit of tax depreciation, the third term is the cost of property tax and insurance, and the final term is the benefit of the investment tax credit.

In our earlier discussion of the operating and maintenance cost, we suggested that the levelized operating and maintenance cost be estimated directly. This approach works well if the operating and maintenance costs escalate at about the inflation rate for the majority of the life of the facility. An alternative approach is to estimate both the operating and maintenance cost from an initial cost and an escalation rate as shown in Eq. B-2. If this equation is substituted into the levelizing formula for the operating and maintenance cost, Eq. B-31, the following expression can be derived:

$$\begin{aligned}
& \text{Ann}(r_o, \text{BL}) \sum_{j=1}^{\text{BL}} \text{O\&M}(t) \left(\frac{1}{1+r} \right)^j \\
& = \text{Ann}(r_o, \text{BL}) \text{O\&M}(0) (1+e_o)^{t_o-t_b} \left(\frac{1+e_o}{r-e_o} \right) \left[1 - \left(\frac{1+e_o}{1+r} \right)^{\text{BL}} \right] \quad (\text{B-34})
\end{aligned}$$

where

e_o = the operating and maintenance cost escalation rate

$\text{O\&M}(0)$ = the initial operating and maintenance cost estimated in t_b dollars.

The feedstock cost is assumed to come from some model more sophisticated than the simple model, where feedstock costs are estimated from an initial cost and an escalation rate. If this is the case, the levelized feedstock cost can be computed from the estimates and Eq. B-30. All other parameters are estimated directly.

SUMMARY

Eq. B-29 is the approximate formula for calculating the levelized cost of energy products from a regulated utility. Together with eqs. B-27, B-28, and B-34 it meets our criteria for an equation that is solvable on a hand-held calculator. Of course, a number of simplifying assumptions were made to arrive at this equation. However, the constraints imposed by those assumptions are not large compared to the convenience of the results. If a more exact formulation is required, this discussion can still be of help since the basic cost-of-service equation, B-10, and the exact levelizing formula, B-24, form the basis for the more elaborate formulations of the levelized cost-of-service price.

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Appendix C
MARKET SHARE MODEL

The market share model determines the share of an energy market served by each technology of a set of competing technologies. It allows the computation of both the average, or mean, product price and the effect upon the market shares and average product price of a new technology. The model simplifies the complex interactions of the actual market place in two important ways. First, it assumes that all of the attributes important to technology selection are represented by the product price. Thus, the market share captured by each technology is a function only of the price of the energy product produced by that technology. Second, it aggregates both the producers* who use the technology and the technologies that they use. So, rather than attempting to represent the detailed decisions of each energy producer in the market, the model reflects only their aggregate behavior. Further, rather than investigating in detail the market share claimed by each specific technology, related technologies are grouped into generic technologies and only these generic technologies are considered. The following sections discuss this market model, derive the market share function and average market price that it implies, and, finally, demonstrate the effect of a new technology on the market.

*Notice that the energy producers would actually be called consumers in traditional market share discussions. They "consume" energy-producing technologies.

MARKET MODEL DESCRIPTION

To describe the technologies competing in a particular market, we will assume that each specific technology is a member of a set of related technologies, so that each specific technology has a price p_{ij} , the price of producing an energy output using the specific technology where

i = the group of related technologies, the generic technology (e.g., second-generation coal gasification)

j = the specific technology (e.g., a particular second-generation coal gasification technology such as the hy-gas process)

The product price associated with each specific technology is not known with certainty since this price is influenced by two types of parameters:

1. strictly technology-dependent parameters
2. user-specific parameters

Thus, while all producers face the same technology-dependent parameters, they face different user-specific parameters, such as site, feedstock availability, wage rates, operating and maintenance experience, and so on. The net result is that the product cost differs for different users of the same technology, and consequently a number of technologies will be adopted in the market rather than a single, "least-cost" technology.

For the moment, we assume that the technology-dependent parameters are known with certainty and are the same for all energy producers. What is the implication for a particular p_{ij} of the variability in user-specific parameters? From each individual producer's point of view the price of producing a product using the technology can be calculated deterministically, assuming no technological uncertainty and assuming the

user-specific characteristics are known. The difference in production costs resulting from user-specific characteristics can then be represented by a histogram such as that sketched in Figure C-1. Note that in this histogram the area of any region around a particular price, such as p_0 , represents the fraction of producers who would incur price p_0 if they employed the specific technology under consideration.

From the point of view of the market as a whole, the histogram constructed in Figure C-1 can be interpreted as a probability density function. It describes the uncertainty in product price caused by different producer characteristics. Notice that it does not reflect any other uncertainties;

Figure C-1. Histogram of Production Costs Using a Specific Technology

in particular, it does not reflect general technological uncertainties. We will assume that such a probability density function characterizes each specific technology in each generic class under consideration.

In general, the product prices for each member of a particular generic class will not be independently distributed. For example, the technologies that use the same feedstocks will have probabilistically dependent product prices. However, it is frequently possible to represent the events that influence product prices and lead to dependencies in such a way that it is reasonable to assume that product prices are conditionally independent. For example, it may be reasonable to assume product prices are independent if the feedstock price is known. The RD&D resource allocation methodology implemented in this workbook and described in detail in Boyd et. al [1] is an example of a highly developed structure aimed, in part, at producing such conditional independence. If we assume that such structuring is possible, then each specific technology j in a generic class i can be described by a probability density function $f_{ij}()$:

$f_{ij}() =$ probability density function describing uncertainty in p_{ij}

where all the $f_{ij}()$ are conditionally independent.

Now consider the generic technology. For a cost-minimizing producer, the generic or representative technology is the least-cost technology, so the product price from the generic technology* is

*The aggregation into generic technologies could take place at different levels depending on the particular decision being evaluated or the particular situation being studied. The best test operationally is whether or not the least-cost assumption is a reasonable approximation.

$$p_i = \min_j (p_{ij}) .$$

Thus, the probability distribution function on the generic technology price can be derived from distributions on the specific technology costs. It can be shown [2] that the distribution of the least cost from a sample of independently distributed costs approaches the Weibull distribution. For this reason, we assume that uncertainty in the price of a product produced by a generic technology has the distribution:

$$f_i(x) = \left(\frac{b_i}{a_i}\right) \left(\frac{x}{a_i}\right)^{b_i-1} \exp \left[- \left(\frac{x}{a_i}\right)^{b_i} \right] \quad (C-1)$$

where a_i , b_i , and x are all greater than zero. Figures C-2a and C-2b show sketches of $f_i(\cdot)$ for various parameter values. The mean and variance of the Weibull distribution are

$$\bar{x}_i = a_i \Gamma(1 + b_i^{-1}) \quad (C-2)$$

$$\check{x}_i = a_i^2 \left[\Gamma(1 + 2b_i^{-1}) - \Gamma^2(1 + b_i^{-1}) \right] . \quad (C-3)$$

Notice that a_i is a scale parameter and b_i determines the shape of the distribution.

Recall that the uncertainty represented in each of the generic product price probability density functions arises from the differing characteristics among users in the particular energy market under consideration. Since these potential users are the same for any generic technology serving the market, we assume that the shape of the probability density functions describing each generic technology product price is the same. Technically

Figure C-2a. Variation in Weibull probability density function as a function of shape parameter b , where scale parameter a has been set to 1.

Figure C-2b. Variation in Weibull probability density function as a function of scale parameter a , where shape parameter b has been set to 3.0.

this means that the shape parameter b_i is the same for all technologies. The differing characteristics of the various generic technologies are reflected in different values of the scale parameter a_i .

MARKET SHARE FUNCTION DERIVATION

Our problem now is to compute the shares of a particular energy market captured by competing generic technologies the product prices of which are uncertain and have Weibull distributions. We will do this by first developing the market share function for the case of arbitrary product price distributions and then applying that function to the case of product prices that have Weibull distributions.

Since a technology is only selected by a particular producer because its perceived price is less than that of all other technologies, the share of the market that a technology serves is equal to the probability that it has the least product cost. The market share to technology i can be found by computing for a particular product price, which the i^{th} technology can take, the probability that all other technologies will experience a greater product price. Figure C-3 illustrates in simplified form this calculation for two technologies. Next, this probability is weighted by the probability that technology i will have the particular price. This weighted probability is summed over all possible prices that the i^{th} technology can take. By structuring the problem so that the probability distributions for the generic technologies are conditionally independent as discussed in the previous section, the market share calculation can be expressed mathematically as

Figure C-3. Illustration of First Step in Calculating Market Share for the Case of Two Technologies

$$MS_i = \int_0^{\infty} f_i(x_i) \prod_{j \neq i} \int_{x_i}^{\infty} f_j(x_j) dx_j dx_i . \quad (C-4)$$

This same formula is used elsewhere in the market share literature [3].

Now this general formula can be applied to the case of product prices that have Weibull distributions by substituting Eq. C-1 into Eq. C-4:

$$MS_i = \int_0^{\infty} \left(\frac{b}{a_i} \right) \left(\frac{x_i}{a_i} \right)^{b-1} \exp \left[- \left(\frac{x_i}{a_i} \right)^b \right] \left[\prod_{j \neq i} \int_{x_i}^{\infty} \left(\frac{b_j}{a_j} \right) \left(\frac{x_j}{a_j} \right)^{b-1} \left[\exp - \left(\frac{x_j}{a_j} \right)^b \right] dx_j dx_i \right] .$$

These integrals can be solved to yield:

$$MS_i = \frac{a_i^{-b}}{\sum_{j=1}^n a_j^{-b}} .$$

Substituting the mean values of the distributions, $\bar{p}_i$, as determined by Eq. C-2, we have

$$MS_i = \frac{\bar{p}_i^{-b}}{\sum_{j=1}^n \bar{p}_j^{-b}} . \quad (C-5)$$

Thus, the market share depends only on the average price of the product produced using each generic technology. The market share for a market with two technologies has the familiar S-shaped behavior shown in Figure C-4. This market share model, or a derivative, has been used in a variety of energy modeling applications [4,5].

AVERAGE PRODUCT COST

Given the market shares specified in Eq. C-5, it is possible to calculate the average product cost by computing the distribution for the product cost after technology selection. The mean of this distribution is the average product cost.

The product cost in the energy marketplace after technology selection is an uncertain variable defined as the minimum over the uncertain generic technology costs:

$$p = \min_i (p_i)$$

Figure C-4. Market Share Curve for Two Technologies

where p is the uncertain cost in the energy marketplace. Since the generic technology prices are independently distributed, the cumulative probability density function for p can be written immediately as:

$$F(p) = 1 - \prod_{i=1}^n [1 - F_i(p)]$$

where

$F()$ = cumulative probability density function for the market price

$F_i()$ = cumulative probability density function for the price of the product produced by the i^{th} generic technology

Since each of the generic product prices have Weibull distributions, we have

$$F_i(p) = 1 - \exp \left[- \left(\frac{p}{a_i} \right)^b \right] \quad (C-6)$$

and

$$F(p) = 1 - \exp \left[- p^b \sum_{i=1}^n \left(\frac{1}{a_i} \right)^b \right]. \quad (C-7)$$

Comparing equations C-6 and C-7, we see that the market price has a Weibull distribution with parameters b and

$$a = \left[\sum_{i=1}^n \left(\frac{1}{a_i} \right)^b \right]^{-1/b}.$$

Substituting from Eq. C-2 for the a_i 's, we obtain the average market price immediately as

$$\bar{p} = \left[\sum_{i=1}^n \left(\bar{p}_i \right)^{-b} \right]^{-1/b}. \quad (C-8)$$

From Eq. C-8 we see that the average market price is less than the average product price for each generic technology.

INTRODUCTION OF A NEW TECHNOLOGY

The foregoing results provide us with the necessary background to answer the critical question from the standpoint of R&D assessment: What is the impact of the introduction of a new energy technology? To avoid dealing with behavioral considerations, the market with the new technology will be considered only in the long run; that is, modeling producers' reactions to a new, untested technology are avoided by looking at the market a long time after the new technology has been introduced. In this context the market with the new technology is compared to the market without it.

The percentage decrease in average product costs between the old market situation and the new one can be expressed in terms of the old and new average product prices:

$$\text{Percentage Decrease} = \frac{\bar{p}_0 - \bar{p}_N}{\bar{p}_0} = 1 - \frac{\bar{p}_N}{\bar{p}_0} \quad (\text{C-9})$$

where

$\bar{p}_0$ = old average product price

$\bar{p}_N$ = new average product price

Using the definition of the average price given in Eq. C-8, and assuming that there were n technologies in the old market and $n+1$ technologies in the new market, yields a simple expression for the fractional decrease in the average product price:

$$\frac{\bar{p}_0 - \bar{p}_N}{\bar{p}_0} = 1 - \frac{\bar{p}_{n+1}}{(\bar{p}_0^b + \bar{p}_{n+1}^b)^{1/b}} \quad (\text{C-10})$$

where $\bar{p}_{n+1}$ is the average product price from the $n+1$, or new, technology. It is clear from Eq. C-10 that this decrease is always positive.

Benefit of a New Technology

If we assume inelastic demand, the total benefit of having the new technology is simply the change in average product price times the quantity of product consumed. The total benefit B is written:

$$B = (\bar{p}_0 - \bar{p}_N) q \quad (\text{C-11})$$

The benefit can be expressed in terms of the old average product price $\bar{p}_0$ and the new technology's average product price $\bar{p}_{n+1}$ by using Eq. C-10 to expand Eq. C-11:

$$B = \left[1 - \frac{\bar{p}_{n+1}}{(\bar{p}_0^b + \bar{p}_{n+1}^b)^{1/b}} \right] \bar{p}_0^q \quad (C-12)$$

Market Share of a New Technology

Finally, the market share served by the new technology in the long run can be computed by expanding the market share function of Eq. C-5:

$$MS_{n+1} = \frac{\bar{p}_{n+1}^{-b}}{\sum_{i=1}^{n+1} \bar{p}_i^{-b}} = \frac{\bar{p}_{n+1}^{-b}}{\sum_{i=1}^n \bar{p}_i^{-b} + \bar{p}_{n+1}^{-b}} = \frac{\bar{p}_{n+1}^{-b}}{\bar{p}_0^{-b} + \bar{p}_{n+1}^{-b}} \quad (C-13)$$

Equations C-12 and C-13 are the relationships implemented in the workbook. They show that the change in average price, the total benefit of that change, and even the market share of a new technology can be computed by simply knowing the average price in the old market and the average new technology product price. It is not necessary to know the prices or the market shares of all other technologies.

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