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PORTFOLIO SELECTIONS FOR FOSSIL DEMONSTRATION PLANT PROGRAMS. REPORT NO. 1-703

ECONERGY, INC., LOS ANGELES, CALIF

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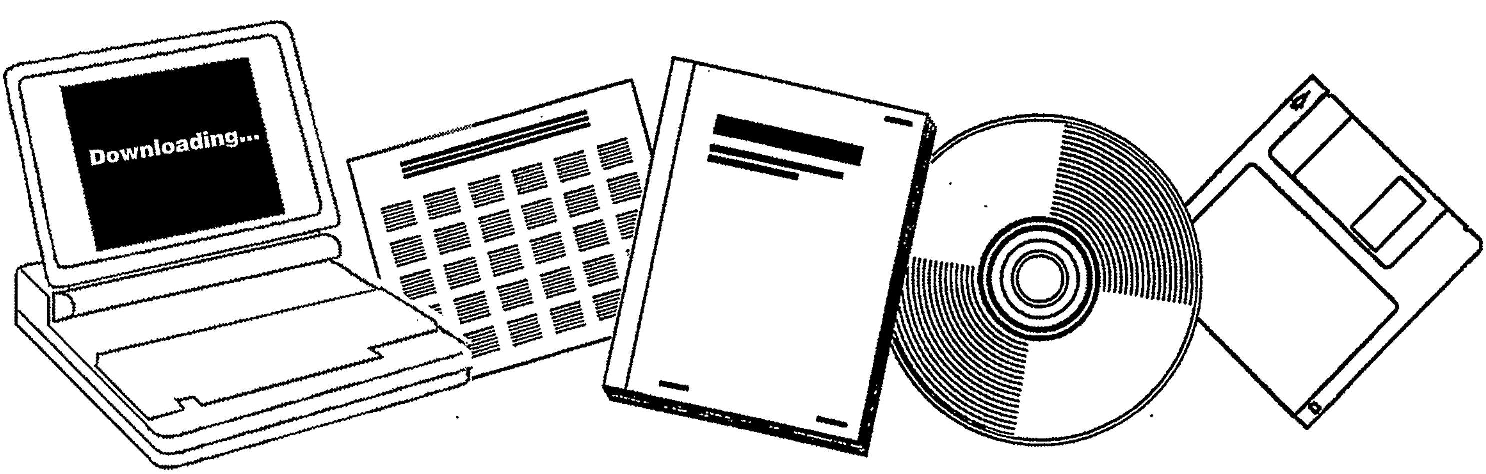

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PORTFOLIO SELECTIONS FOR FOSSIL DEMONSTRATION PLANT PROGRAMS

by

J. Morley English
Jeffrey L. Smith
Sharon G. Grant-Smith

prepared for
U. S. Energy Research and Development Administration
Washington, D.C.
Project Officer
Fred M. Glaser

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ECONERGY, INC.
11777 San Vicente Boulevard, Suite 907
Los Angeles, California 90049

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The preferential ranking of conversion technologies contained in this report should not be construed as indicating either ERDA preferences or those of the contractor. The conclusions reported were merely the result of applying the portfolio methodology developed in this study to a set of input data made available to Econergy, Inc. This input data has neither stood the test of close scrutiny nor does it reflect the most current information now available to ERDA. The only purpose of the results cited is to illustrate the portfolio methodology, which when refined can be a very useful analytical tool in assessing program plans.

PREFACE

In addition to the disclaimer on conclusions to be drawn from the model utilizing example data in conjunction with the model developed in this report, limitations and idealizations of the model also should be noted.

1.) Benefit measures have been predicated on a given revenue as determined by an arbitrary price of energy. Part of this revenue will accrue to overall societal benefit, not assignable specifically in any pro rata way to individual projects. Therefore, whatever the common component of price is, it will not affect portfolio selections. While a common energy price was taken, some consideration should be given in the future to how the various prices will change over time on a relative basis.

2.) The methodology developed provides for selection of a particular portfolio but provides no mechanism for arriving at that portfolio by budgeting the capital investment year by year to *build* the portfolio. An approach for doing this is under investigation.

3.) The method for establishing discounted cash flows is conventional. However, there are a number of unresolved issues that may have significant influence on the indicated portfolio selection. In particular, the question of differential inflation rates and an inflation adjusted discount rate are important but not considered in the illustrative example outlined in this report.

4.) The model developed was without regard to any provision for government/industry financial participation. In effect, the conclusions to be drawn represent an overall societal view. In practice there is a need to establish a base for such government/industry sharing.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. METHODOLOGY FOR SELECTION OF FOSSIL ENERGY PROCESSES

A unique methodology has been developed by Econergy for evaluation and selection of a set of proposed coal conversion processes. By incorporating the fundamental principles of portfolio theory, both the risks and economic benefits -- revenues less costs of capital, operation, and time -- can be determined for a set of processes. The trade-off between benefits and risks for each possible set of coal conversion processes is illustrated by examining their relative positions on a benefit-risk map in relation to a decisionmaker's risk attitude function.

The complexity and variety of risks possible in large capital investment decisions make the use of analytical techniques like those developed in portfolio theory a necessity. The overwhelming number of factors which must be considered in order to make a rational decision cannot possibly be assimilated by one person. Fortunately, by using mathematical programming techniques, many aspects of the possible investment can be viewed individually and the resulting information integrated in a logical manner to aid the decisionmaker with his ultimate choice of which coal conversion processes warrant investment. The decision with respect to a specific process depends not only on that individual process but on the entire set of alternative processes as well. This means that one of the primary effects of using the Econergy method of portfolio selection would be a reduction in the overall risk of the entire Fossil Energy program by means of proper diversification in the choice of funding coal conversion facilities.

1.1 Basic Portfolio Theory

Portfolio theory was originally developed for selection of securities to form a portfolio having minimum risk for a given level of expected return (Markowitz, 1959). Although basic portfolio theory was developed for a portfolio of securities, it is also directly applicable to different types of portfolios comprising investments in real facilities. Such a portfolio is the group of coal conversion facilities that have been (or will be) chosen by ERDA for funding in the Fossil Energy program.

The primary effect of this method of portfolio selection is the reduction of overall risk in the investment portfolio by means of diversification. Because the ultimate success of any particular coal conversion process is uncertain, investment in several processes for each product type (e.g. high BTU gas) significantly enhances the probability that at least one of the processes will turn out to be successful. Success of the ERDA Fossil Energy program hinges on development of a few successful processes which will lead to a commercial coal conversion industry. The goal of diversification is not to develop many successful processes, but rather to increase the probability of success for a few.

Risk measures in portfolio theory account for the uncertainty associated with future rates of return (a random variable) and can only be described probabilistically. Explicitly included is the risk in individual investment opportunities (measured by variance in the rate of return of a particular investment) and the interrelated risk among a group of investments (measured by covariance or correlation between the time rates of return for any two investments).

One significance of portfolio theory, aside from that of demonstrating the risk-reducing effects of diversification, is the means afforded for representing trade-off between risk and reward. This is accomplished graphically by representing risk on one axis and expected return on the other. It does not matter what measures, or surrogates, are used for risk or return. Thus, standard deviation of the outcome may be just as satisfactory as using the variance for a risk measure.

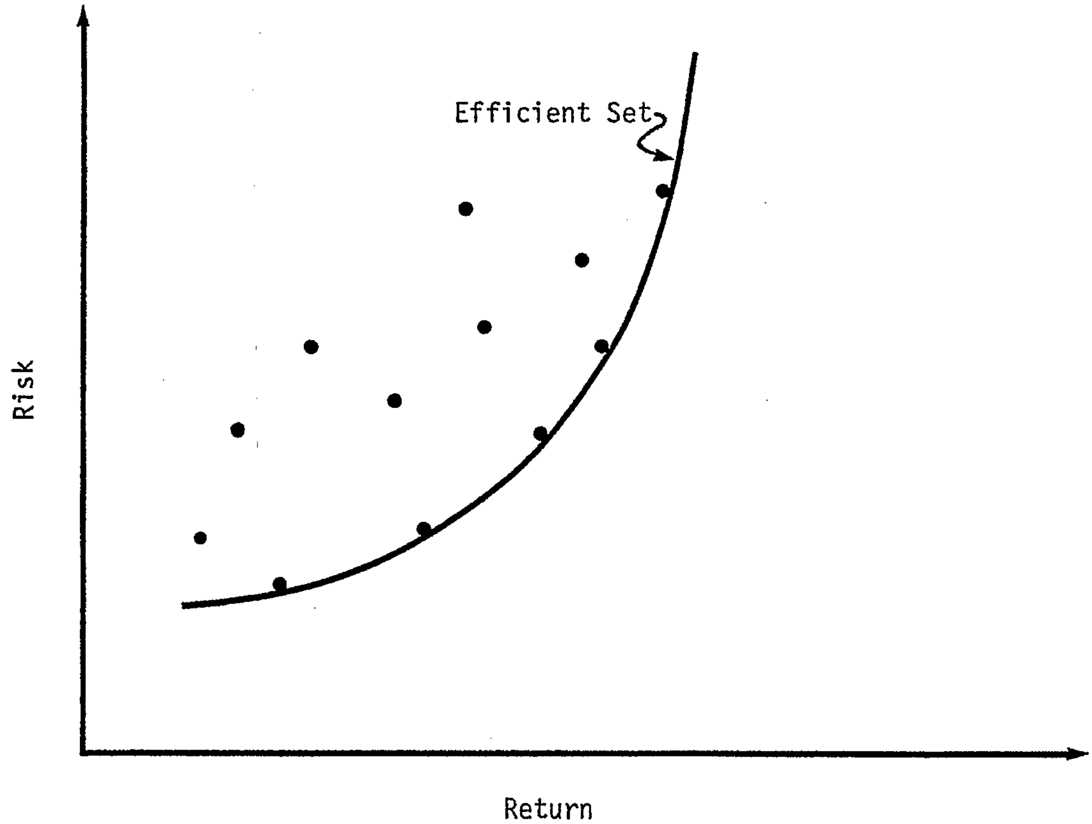
The expected return of a portfolio, E(r), can be expressed mathematically by

$$E(r) = \sum_{i=1}^{n} x_i r_i \qquad \text{for } i = 1, 2, \ldots, n \tag{1-1}$$

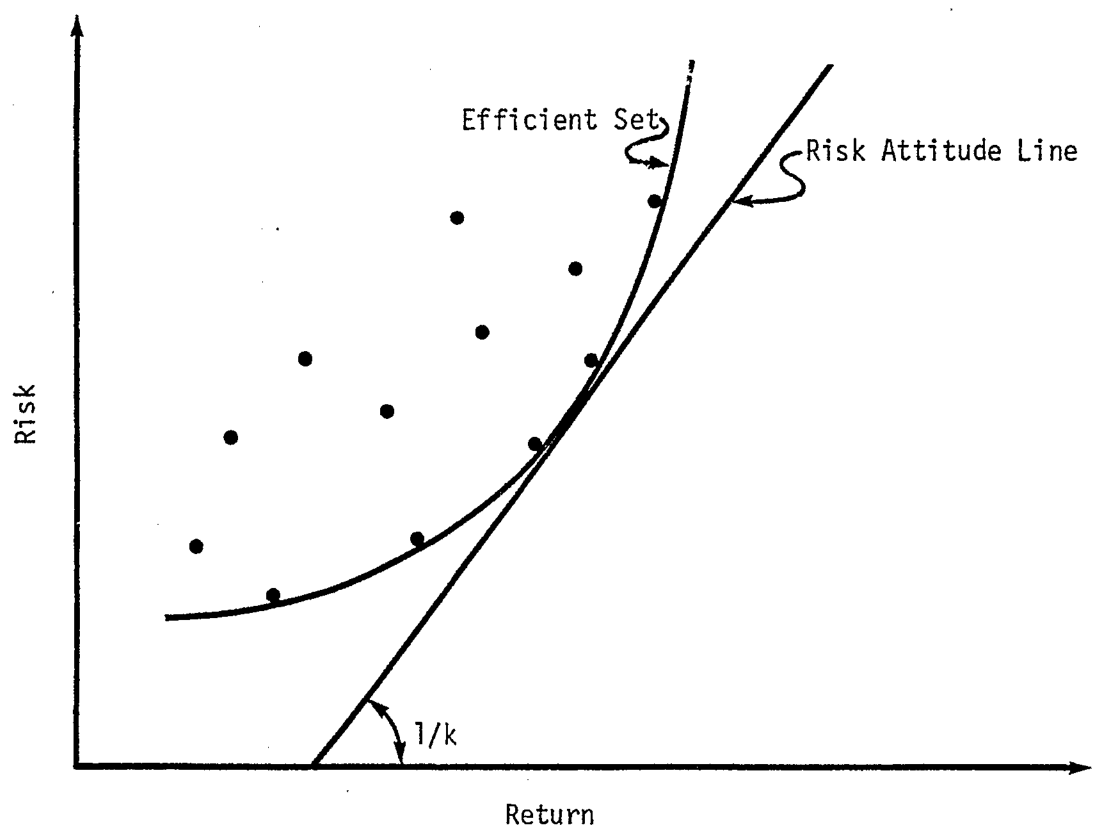
where r_i symbolizes expected return for the i^{th} investment, and x_i is the proportion of capital invested in the i^{th} opportunity. To maximize E(r), all capital could be invested in the one opportunity that offers the highest return. However, a more rational approach is to diversify investments and lower overall risk.

If all available combinations for coal conversion facility investments are examined, a set of points is determined which may be plotted on a risk/return diagram, Figure 1-1(a). The points that represent the best opportunities make up a boundary called the efficient set.

Any point on the efficient set boundary represents maximum return for a given level of risk. Therefore, the most desirable investment possibilities are down and to the right. All points in the interior region of the set are said to be dominated by points along the boundary.



(a)



(b)

Figure 1-1 Risk/Return Diagram

A rational decisionmaker would *never* choose any interior opportunity. In order to determine an appropriate point on the efficient set, the expected utility of the decisionmaker is determined.

Expected utility, E(u), for investment decisionmaking may be represented by

$$E(u) = E(r) - k \cdot V \tag{1-2}$$

where k represents a parameter of the investor's risk acceptance, and V represents variance in the rate of return of the portfolio. This expression may be depicted on a risk/return diagram, Figure 1-1(b), by the risk attitude line which has a slope 1/k. The risk attitude line can be thought of as sliding along the return axis (with slope 1/k) until it just touches the efficient set. The investment portfolio on the efficient set boundary closest to the point of intersection with the risk attitude line is the optimal investment alternative for the decisionmaker.

A higher sloping risk attitude line (larger value of 1/k) represents a decisionmaker willing to accept more risk for the prospect of higher payoff (return). On the other hand, a flatter line (smaller value of 1/k) represents a decisionmaker willing to give up certain prospective payoffs for reduced levels of risk.

In addition to understanding basic portfolio theory, it is important to have a clear understanding of what specifically is meant by risk. An investor, whether it be ERDA or an energy company, perceives risk in terms of a probability that a prospective investment in a coal conversion process will result in the return falling below expectations. Aside from this basic risk, there are numerous separable risks that may be treated when investments are considered for coal conversion systems. One of these is the financial risk associated with the probability that revenues will not exceed operating costs, i.e., net benefits will not materialize as expected. There is a technological risk that some unproven technology will not prove feasible. For example, it may turn out that the critical factor in the ultimate success of the conversion process is a particularly vital component which simply cannot be developed. Also, there is a risk that capital costs of the project will overrun estimates. Finally, coupled with the latter risk, the possibility exists that schedules for start-up of the project will slip. Each of these risks will have its own loss-function associated with failure to meet expectations.

1.2 The Econergy Portfolio Model

1.2.1 Revenues and Costs

The purpose of the Econergy portfolio model is to provide quantitative justification for the decision to include certain coal conversion processes in the ERDA demonstration plant portfolio. The model was developed and reported in "Benefits, Costs and Risks for Portfolios of Coal Demonstration Plants," (English, et al, 1976) using the concepts of basic portfolio theory described above.

The net benefits, B, of ERDA's investment portfolio in coal conversion facilities are defined in terms of the basic portfolio model variables: revenue, R, operating cost, O, investment cost, I, and time cost, T.

$$B = R - O - I - T \tag{1-3}$$

However, the benefits derived from specific processes may not be the only benefits. There are societal benefits attributable to the entire coal conversion program that must be implicit in the decision to invest in any set of coal demonstration plants. These benefits will not be readily measurable, nor will they influence the choice of candidate processes in the portfolio. In this report, the revenue stream, R, is taken as the sole measure of benefit. However, an approach to how benefit might be modified to take account of societal benefits and, at the same time, fit into the portfolio model are discussed in another report, "An Approach to Government/Industry Investment Participation in Coal-Based Energy Projects," (English and Smith, 1977).

The model variables, R, O, I, and T, are illustrated in Figure 1-2. Revenue represents plant revenue generated during the operation phase. This revenue is determined by multiplying an assumed product price (in $/MM BTU) times the quantity of output for each particular plant. Costs include capital or investment costs, I, and operating costs, O. These are straightforward estimates made by experts familiar with each process. The investment cost represents plant investment costs and is made up of plant design, capital equipment, and construction costs.

A unique treatment of a time cost is incorporated in the Econergy model. A time lag, ΔT, gives rise to the time cost curve. If the time over which investment occurs exceeds anticipated or planned schedules, there will be a delay in start-up of the plant and correspondingly a slippage in the starting time for generation of revenues.

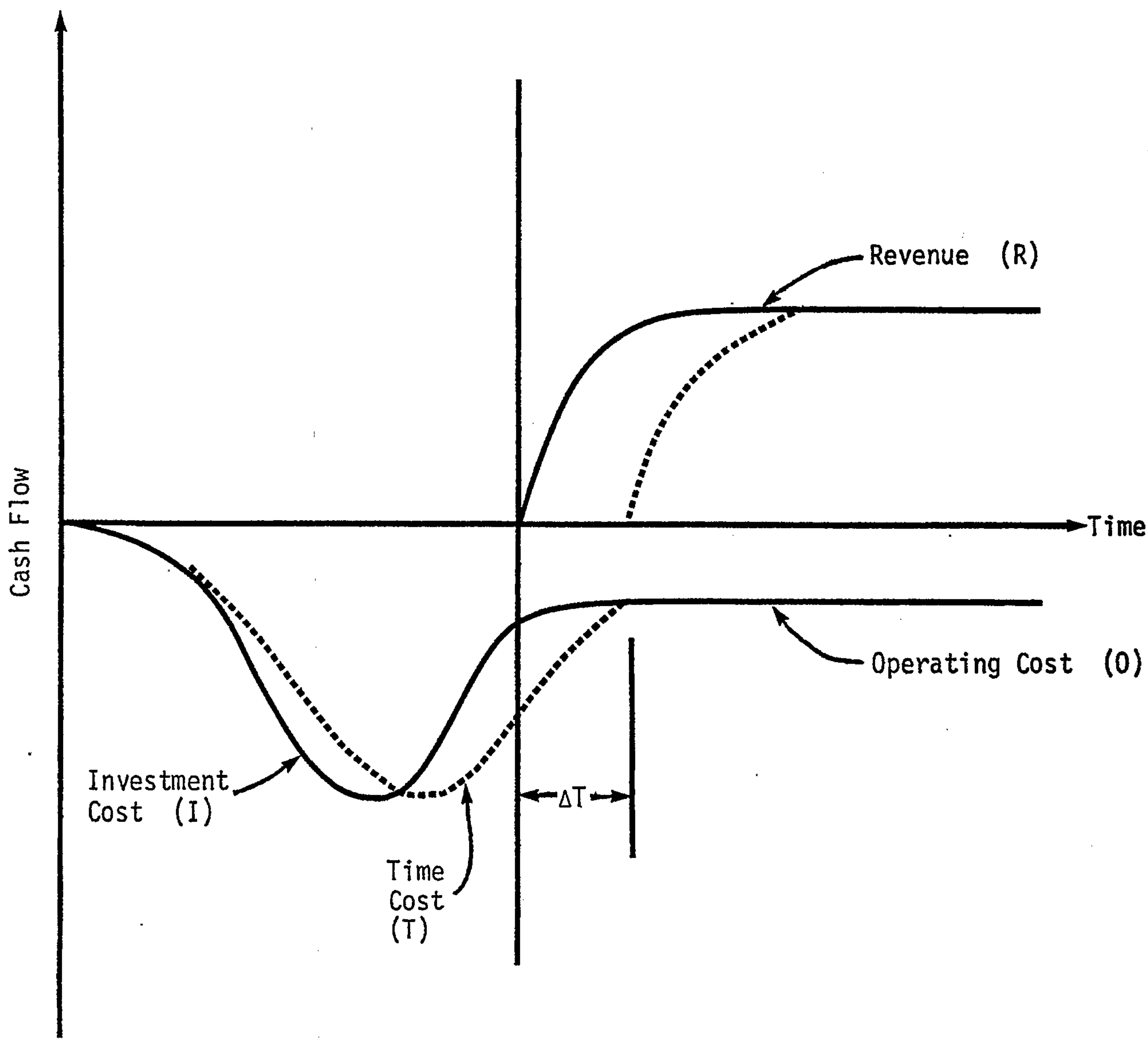


Figure 1-2 Model Variable Cash Flows

The relevant time period for the cash flow streams is an assumed operating life for each coal conversion facility. Revenues and costs are all discounted using an appropriate discount rate to *present worths*. These are sometimes called *discounted cash flows* (DCF). The sum of the discounted cash flows for the model variables determines present worth of net benefits. These benefits may be determined for a single coal conversion process or for a group of processes.

Revenue and cost data for each process are developed from commercial scale designs. Commercial scale data is used to indicate the investment decision for demonstration scale plants because demonstration scale designs are not necessarily intended to be economic. Demonstration facilities tend to have high capital costs relative to designed plant capacity because the objectives of a demonstration plant are quite different than the economic objectives of a commercial facility. Since demonstration plants are used to test different coals and various process operating conditions, they require a proportionately larger amount of instrumentation and mechanical equipment than would a commercial design of similar plant capacity. Therefore, all process and economic data used in this report will reflect commercial scale designs for each coal conversion process.

1.2.2 Risk Measures

The Econergy portfolio model incorporates a measure for two risk types -- technical and economic. Technical risk may be viewed in two ways. First, there is a risk of technical infeasibility. A process design may be ill-conceived in terms of mass flow rates, heat transfer characteristics, etc. so that a prohibitive amount of process redesign would be required for successful operation. The second technical risk is concerned with operational reliability. Given that the process is well-designed, the process may still be unreliable on an operational basis. This risk translates into an unacceptably low process stream factor. Apart from the question of process economics, operational reliability may be a critical factor in product requirements for potential users of coal conversion products.

Economic risk relates to underlying process economics. Operating costs and/or investment costs for a process may be too high to achieve a reasonable rate of return based on a competitive market price for the product. Consideration may be given to sophisticated price roll-in techniques which can offset the presumed higher price of synthetic products vis-a-vis natural energy sources.

Economic risk is described in the portfolio model in terms of three distinct components.

- Cost overrruns during the capital investment phase.
- Benefit underruns during the revenue producing phase.
- Schedule slippages resulting in penalties reflected in the form of higher capital costs and a deferred revenue stream.

On the one hand, capital and operating cost overruns can come from simple underestimation of costs. Such estimates may be in error due to supply bottlenecks, or due to escalation of construction and labor prices in excess of the general inflation rate. On the other hand, a major source of increased costs can be a consequence of unforeseen technical difficulties. For example, during construction a particular innovative fabrication method may not work as expected, thus necessitating substitution of a more costly alternative system. Such construction cost overages are normally accompanied by schedule slippages and so may be assessed in terms of the total loss identifiable with the particular system component that occasioned the slippage.

In order to reflect accurately the risks associated with individual processes, it is necessary to develop realistic measures of process characteristics. In the Econergy portfolio model, these risks are treated by using the weighted values of the judgement of experts, based on a 0 - 10 scale, for the independent effects of each stage or component of a coal conversion system. A number of experts with broad backgrounds in various aspects of coal conversion technology have been consulted. Appendix A lists interviews held to determine the process risks. This risk assessment uses two sets of information, process descriptors and weights for model variables. Process descriptors categorize technical risks associated with individual processes. The weights are process independent and they map the importance of various technical risks into the four model variables, i.e., revenue, operating cost, investment cost, and time cost associated with each process. The specific process risk descriptors which have been defined are listed in Section 2.4.

1.2.3 The Unnormalized Benefit/Risk Map

Benefits, as described in Section 1.2.1, and risks, as described in Section 1.2.2, provide the two sets of measures that may now be plotted on an unnormalized benefit/risk map, Figure 1-3. Instead of the expectation and variance of a security's rate of return as described in Section 1.1, it is appropriate in applying portfolio theory to coal conversion facilities to use actual values of benefit and risk as scales for the coordinate axes. Thus, benefits are plotted as dollars on the horizontal axis. The vertical or risk axis, measuring variance, is a function of the square of the benefits, and so the units would be in dollars squared; however, since "dollars squared" do not have an intuitive meaning, and because only comparative risk is of interest in comparing portfolios, the risk axis units are scaled 0 - 100 on the unnormalized benefit/risk map. The benefits and scaled risk of every portfolio can be plotted so that each one is represented by a single point on the map.

1.2.4 The Normalized Benefit/Risk Map

The Econergy portfolio model, as described above, was based on the determination of both actual benefits and risks associated with each candidate portfolio. This is, of course, precisely what would be desired if each portfolio required the same level of investment. In that case, only the actual return or benefit, as well as actual risk, would be of interest. However, if capital investments for the portfolios being compared are different, then these differences must be taken into account.

For example, suppose an individual is interested in comparing two investment alternatives, A and B, where A requires an investment of $2,000 and

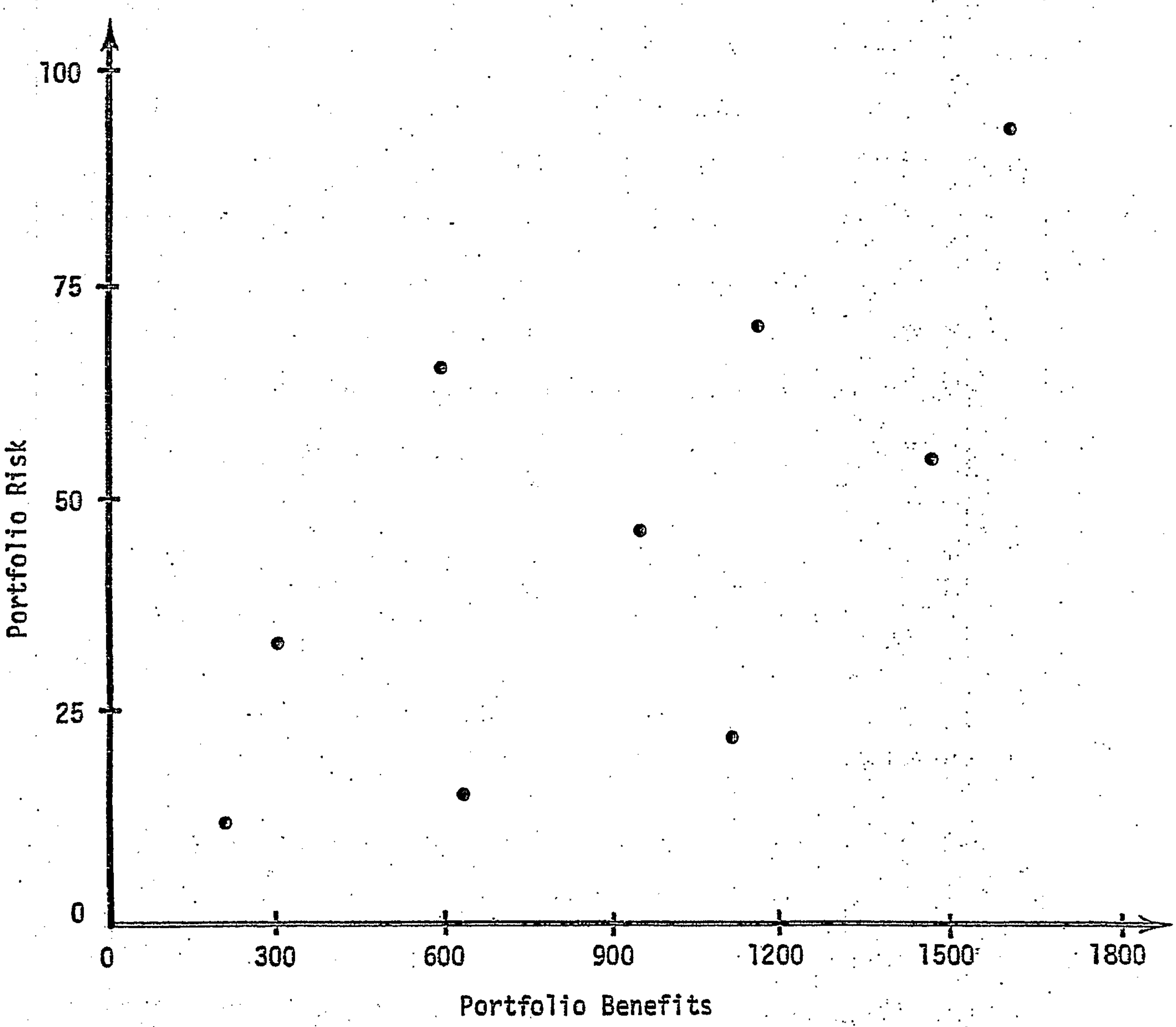


Figure 1-3 Unnormalized Benefit/Risk Map

B an investment of $5,000. One cannot simply look at the estimated net proceeds from each investment in order to compare them. Rather, some reflection of the different investment amounts must also be considered. If the present worth (PW) of the net proceeds in each case is normalized by the respective initial investment, the relative attractivess of each alternative can be meaningfully compared. If the PW of *net* proceeds for investment A is $4,000 and for B it is $6,000, the net return per dollar invested for A would be 1.0 ((4,000 - 2,000)/2,000) and for B, the net return per dollar invested would be 0.2. If all other things were equal, investment A would be the clear choice even though the absolute net proceeds of B are 50% larger than those of A.

In a similar manner, the *relative* attractiveness of each portfolio can be compared by examining its normalized benefits. This simply requires dividing each portfolio net benefit by its portfolio investment cost to give a non-dimensionalized measure of benefit. Thus, normalized benefit is *net benefit per dollar of investment*.

In comparing two portfolios which are the same except for an additional process in one portfolio, i.e., one portfolio is a subset of the other, it may be necessary to examine the incremental benefits of that one process in comparison with the incremental investment. Using the example above of investments A and B, let us assume that A is a subset of B. The increment of investment necessary to go from A to B is $3,000 and the PW of the incremental net proceeds are $2,000. The normalized incremental net benefit is -0.33 which means that the extra benefit from the extra investment is not making the required rate of return at which the estimated cash flows were discounted to determine the PW of the investment.

The normalized benefit would be 0 if the discounted net proceeds were just equal to the investment. That would be the case when the rate of return on investment is just equal to the discount rate. Of course, it would be possible for the incremental net proceeds to exceed 0, and in that case, the proper investment decision would be determined by the investment objective. One possible objective would be to maximize rate of return, while the other would be to maximize the amount of investment outstanding given that the rate of return on that investment exceeded the required discount rate. Suppose that the PW of the net proceeds for B is \$8,000 instead of \$6,000. In that case, the normalized incremental benefit would be 0.3 (rather than -0.33) and the normalized net benefit for B would be 0.6 (rather than 0.2). In terms of the first objective, maximizing rate of return, investment A (1.0) would still be preferred. In terms of the second objective, however, investment B is preferred since the normalized benefit for the entire investment exceeds zero and the normalized incremental benefit also exceeds zero. Thus, not only is it necessary to examine the normalized net benefits of each portfolio relative to its next best competitor, but also *extra net benefits* relative to the *extra investment* required to scale up from a smaller to a larger portfolio.

The same technique must be used for normalizing risks to account for portfolio scale relative to the risks involved both for the average value of risk and for extra risk associated with the extra investment required.

However, risks have been shown on the benefit/risk map in terms of variances of the benefit. Because variance involves the square of the variables, it must be normalized by dividing by the investment cost squared. Again, this results in a non-dimensionalized measure of risk. A typical normalized benefit/risk map is shown in Figure 1-4. An identifiable difference between an unnormalized and normalized benefit/risk map is the numerical range of the scales for each axis. Due to the normalization of benefits and risks, the normalized axis scales are 0 to 1.0 on Figure 1-4. Any portfolio which has normalized benefits larger than zero also has a rate of return larger than the discount rate used in determining the PW of the process cash flows.

Now, in examining the positions of two portfolios, say 1 and 2, on the normalized benefit/risk map, 1 would be preferred, in general, if its portfolio point is downward and to the right of the point for portfolio 2. Assuming portfolio 1 is a subset of 2, the portfolio point which represents the incremental (Δ) benefit and risk is shown as 3. If the point for the incremental change is not as good as 1 or 2 -- as is shown -- there is no ambiguity as to proper portfolio choice. Suppose point 4 represents another portfolio of which 1 is a subset. The normalized incremental (Δ) benefit and risk is shown as 5. There is some ambiguity as to whether the proper choice is 1 or 4 in this case. The way in which this ambiguity can be resolved is to examine the trade-off between normalized benefits and risks. An investor's attitude toward risk is discussed in the following section.

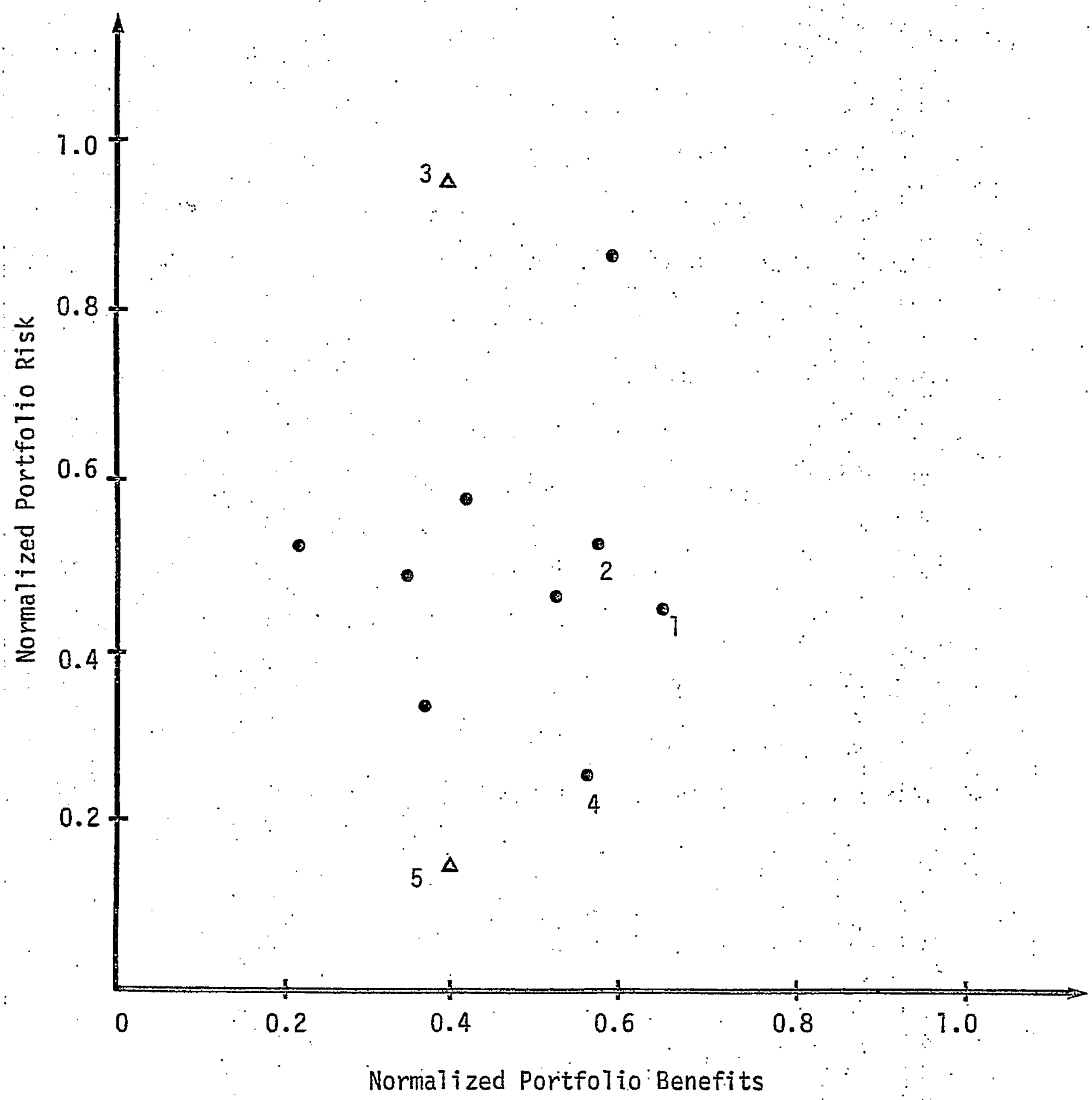


Figure 1-4 Normalized Benefit/Risk Map

1.2.5 Risk Attitude and Decisionmaking

Implicit in all mathematical programming techniques for analyzing data is the fact that the ultimate choice is still controlled by the decisionmaker. Large amounts of data are synthesized into a form in which only a few logical alternatives exist. The trade-off between these possible alternatives depends on the attitude of the decisionmaker.

In the present context, ERDA, as the decisionmaker, must select the set of coal conversion processes to be funded for demonstration scale development. Using the Econergy model, portfolios consisting of various combinations of commercial scale processes may be analyzed. Use of the Econergy portfolio model allows synthesis of large amounts of process data in order to obtain a small number of logical alternatives. These portfolio results can then be plotted on both normalized and unnormalized benefit/risk maps. As explained above, the normalized map is the appropriate decision making tool. In some instances, however, the unnormalized benefit/risk map is helpful in making the portfolio selection by illuminating the actual magnitude of the portfolio benefits and risks.

Figure 1-5 is a normalized benefit/risk map with the same portfolio data as Figure 1-4. In addition, a range of possible risk attitudes is shown relative to portfolio point 1.

Each decisionmaker's attitude towards a trade-off between risk and benefit may be approximated by a straight sloping line. There will be a range of slopes representing the range of individual risk attitudes. However, for most corporate managers responsible for large capital

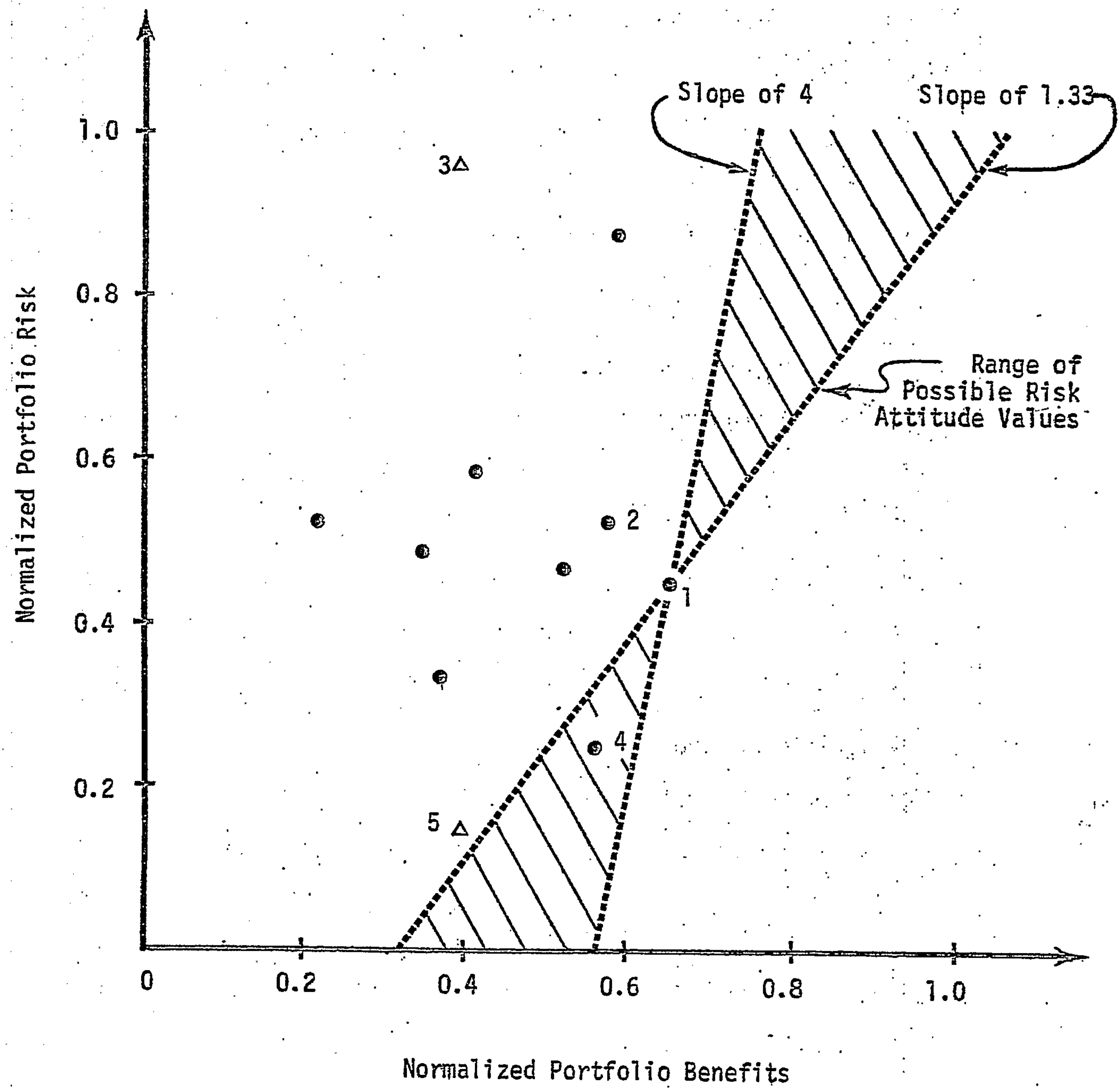


Figure 1-5 Range of Typical Risk Attitude Values

investments, typically, the range will lie between 1.33 and 4. The line with the higher slope (of 4) represents a decisionmaker who feels it worthwhile to assume a larger amount of risk than would a more conservative decisionmaker, to achieve a specified level of benefits. It is presumed that the risk attitude of the decisionmakers in ERDA will fall somewhere within this range.

Risk attitude lines can slide at a constant angle along the benefit axis. A decisionmaker would slide the appropriate risk attitude line from the right hand side of the figure to the left until the line intersects the first portfolio point. In terms of the trade-off between normalized benefits and risk, that portfolio would be the best choice.

In Figure 1-5, the two risk attitude lines representing reasonable limits of risk attitude have been moved along the benefit axis from the right hand side of the figure toward the left until intersecting Portfolio 1. A decisionmaker with a risk attidue of 4 would select Portfolio 1. The risk attitude line with a slope of 1.33, however, first intersected Portfolio 4. This means that a decisionmaker quite concerned about risk (slope of 1.33) would select Portfolio 4 in preference to Portfolio 1.

If the decision between two portfolios based on normalized benefits and risk is a close trade-off, examination of other decision factors is warranted. For example, the relative position of the two portfolios on the unnormalized benefit/risk map shows the absolute effect of each portfolio on the ERDA Fossil Energy program; the individual processes in each portfolio can be examined to see which processes are the same and which different; analysis of the incremental benefits, risks, and investments can be made; the balance of energy product types can be determined; and finally, the demonstration plant budget requirements can be examined. Each of these factors affects the ultimate decision and may require consideration. A decision structure for categorizing these diverse factors is developed in the following section.

1.2.6 Program Decisionmaking

The essential decision being addressed is which coal conversion processes should be funded for demonstration scale development. This decision is one of national importance and is impacted by several factors. A conceptual diagram for the decision is illustrated in Figure 1-6. Arrows are used to emphasize the ultimate direction of information flow, although there is information exchange in both directions during the iterations required for a program decision with respect to even a single process.

The program decision diagram is divided into four levels. The highest level of the decision diagram, the program decision, is based on the second level which is the desired program structure. This, in turn, is based on portfolio results for potential coal conversion processes and program budget levels. The lowest level represents basic data determined from coal conversion process characteristics and process budget requirements.

External criteria represent the additional information which may be used in determining both program budgets and ultimately, program structure. Certainly a major input here is the response of OMB to specific budget

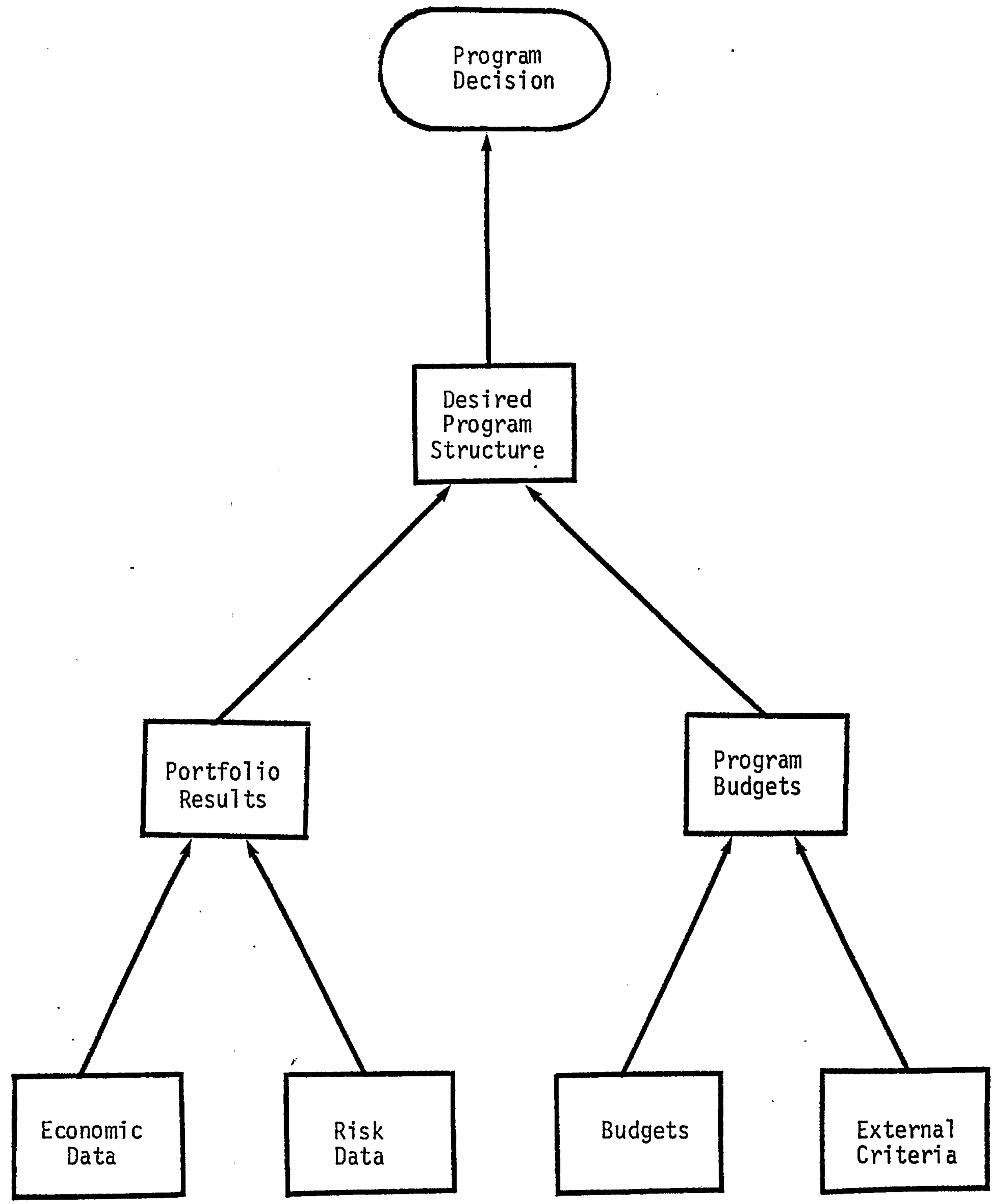


Figure 1-6 Program Decision Diagram

requests. In addition, Congress may have a predilection for certain coal conversion processes over others because of geographical considerations, environmental pressures, etc.

The four factors -- economic and risk data, budgets and external criteria -- represent incompatible objectives, i.e., to the extent one factor is optimized, another factor is compromised. For example, benefits should be maximized but this has the effect of increasing risk which should be minimized. On the other hand, budgets act as a constraint on the maximization of benefits. The external criteria are not completely predictable and have the effect of being somewhat arbitraty disturbances on what otherwise could be a fairly rational decision process. Although all four of these factors affect program decisions in different ways and tend to complicate the decision process, program decisions must still be made.

In accordance with this reality, the Econergy portfolio model has been applied to twenty-one coal conversion processes. The following sections describe the data requirements of the model and the portfolio results.

2. DATA REQUIREMENTS

> The data requirements of the processes used in the Econergy portfolio model are given and discussed in some detail. The process economic data include capital and operating costs as well as revenue based on a unit energy price. Economic assumptions such as the discount rate, process life and financing method are included. Finally, process risk descriptors are listed.

2.1 Process Economic Data

Process economic data includes investment cost and operating cost cash flows for commercial scale coal conversion facilities. The economic data were assumed to be given in mid-year 1976 dollars. The current time for present worth calculations was taken as mid-year 1976 also.

Total investment costs include plant engineering, land acquisition and preparation, capital equipment, plant construction, start-up and administration, royalties and working capital. In addition, all offsites and maintenance areas should be included up to the battery limits. The battery limits do not include the mine facility, but it is assumed that coal is delivered to the plant from an external source.

The same definition of investment costs was used for evaluating each process to the extent that data were available and identifiable. The model currently accepts a single total investment figure. If individual investment cash flows are available in terms of amounts and timing, the model could easily be adapted to this more detailed situation. In lieu of detailed investment cash flows, the model computes these individual cash flows from average capital investment percentages assuming a five year design and construction period.

Total operating costs include coal, labor, chemicals and catalysts, insurance and property taxes, repairs and replacements, utilities, other items and plant by-product credits. The operating costs are the yearly cash flows required to keep the plant on stream.

The model accepts a single yearly operating cost. An assumption is made regarding partial operation of the plant in the last year of the five year construction period. Again, if more detailed cash flow assumptions were available, these could easily be handled in the model. The plant is assumed to operate for 20 years.

Both investment and operating costs are used to evaluate the economics of a process on a project basis. This method obviates any differences due to financing by assuming 100% equity investment in distinction to evaluating the absolute profitability of a single investment. With 100% equity funding, no debt interest charges arise. A pretax basis for comparison is used, so depreciation, a non-cash flow, is also unnecessary.

2.2 Plant Capacity and Revenue Calculation

Data describing the commercial scale plant capacity in terms of thermal output is required. These data should specify the plant products, their thermal content, and the expected output for each product.

The revenues for each process are calculated at an assumed market price of \$4.00/MM BTU. With equivalent unit revenues for each process, the effect of differing operating costs will have a significant impact on project economics. The calculations for all processes (except utility fuel gas processes) were made with the following equation.

$$\text{Revenue} = \text{Plant capacity (BTU/Day)} \times 330 \text{ Days/Year} \times \$4.00\text{/MM BTU}$$

The revenue calculations for the utility fuel gas processes were calculated as follows.

$$\text{Revenue} = \text{Plant capacity (kW)} \times 3411 \text{ BTU/kW-hr} \times 8760 \text{ hr/yr} \times 0.8 \text{ (load factor)} \times \$4.00\text{/MM BTU}/0.379 \text{ (efficiency)} \quad (2\text{-}1)$$

A 37.9% efficiency corresponds to 9000 BTU's required input for every 3411 BTU's electric output.

2.3 Economic Assumptions

Portfolio net benefits were calculated using process economic data listed in Appendix C. The calculations were based on the following assumptions.

- Cash flows - discounted at 10%
- Project economics - 100% equity
- Project life - 20 years of operation
- Construction period - 4 years
- Testing period - 2 years
- Economic data - mid-year 1976 dollars

The portfolio model takes the following considerations into account in determining the net benefits for each portfolio.

- Process Revenues, operating costs and investment costs are considered separately for each process.
- The effects of possible schedule delays and investment cost overruns are included.

2.4 Process Risk Data

Process risk data is used to evaluate the technical risk associated with each process. In addition, the degree of similarity or dissimilarity between processes is determined from the process risk data. The Econergy model currently accepts 13 different kinds of process descriptor data for each process. The 13 process risk descriptors are listed in Table 2-1. The possible values for each of these process descriptors are shown in Appendix B along with their associated risks. As in the investment and operating cost sections of the model, it would be possible to adapt the model to include additional process descriptors or to redefine some of the current descriptors.

A detailed sample calculation for two pipeline gas processes in Appendix D shows the way in which economic and risk data are used by the portfolio model. This sample calculation illustrates the use of the investment and operating cost cash flows and plant capacity in determining the present worth of the four model variables: revenue, operating costs, investment costs and time costs. In addition, the sample calculation uses risk data

1. PROCESS TYPE
2. PROCESS STATUS
3. COAL PRETREATMENT TECHNIQUE
4. FEEDSTOCK TECHNIQUE
5. GASIFIER TYPE
6. LIQUEFACTION TYPE
7. REACTOR TEMPERATURE
8. REACTOR PRESSURE
9. REACTOR COMPLEXITY - NO. OF STAGES
10. REACTOR COMPLEXITY - NO. OF UNIT PROCESSES
11. MECHANICAL RELIABILITY - REDUNDANCY
12. PROCESS TECHNICAL FEASIBILITY
13. SCALE-UP REQUIRED FOR DEMONSTRATION PLANT

Table 2-1 Process Risk Descriptors

to determine individual process risks and the interactive risk which occurs between processes. These intermediate results are then used to calculate the portfolio benefits and risks.

3. MAJOR FACILITY PROJECT MANAGEMENT PROGRAM RESULTS

> The results of examining twenty-one coal conversion processes, incorporated in appropriate portfolios, are discussed in detail. Because the number of combinations of processes is so large, ten groupings of processes were selected as program structures to meet policy objectives for ensuring that a desired combination of processes is necessarily included in the MFPM Demonstration Plant Program. These baseline portfolios are plotted both on normalized and unnormalized benefit/risk maps to show which are preferred. Sensitivities of portfolio results are discussed by showing the effects of interchanging various processes in the portfolios. Also, the effect of mixing the assumed unit market prices for different coal conversion products is illustrated.

3.1 Introduction

Twenty-one coal conversion processes have been examined to select the most appropriate set of processes for the Major Facility Project Management Division of Fossil Energy. These processes represent a variety of high, medium, and low BTU gasification processes, a direct combustion process, and several combined liquefaction/gasification processes. The processes are listed in Table 3-1. Each process was examined individually and in combination with others with respect to process benefits and process risks.

Process benefits were determined from projected commercial scale process revenues, operating costs, and capital investments. Process risks were determined first on a technical basis in terms of process type, maturity, complexity, scale-up, etc. The technical risks were then translated into economic risks in terms of the variability of operating cost and

PROCESS NAMES	
1.	COGAS
2.	SLAGGING LURGI
3.	HYGAS
4.	SYNTHANE
5.	TEXACO
6.	INDUSTRIAL FUEL GAS A
7.	INDUSTRIAL FUEL GAS B
8.	INDUSTRIAL FUEL GAS C
9.	SMALL SCALE FUEL D
10.	SMALL SCALE FUEL DX
11.	SMALL SCALE FUEL E
12.	SMALL SCALE FUEL F
13.	UTILITY FUEL GAS G
14.	UTILITY FUEL GAS H
15.	UTILITY FUEL GAS I
16.	UTILITY FUEL GAS J
17.	UTILITY FUEL GAS K
18.	ATMOS FLUIDIZED BED
19.	COALCON - NEW COST
20.	SRC II
21.	FISCHER - TROPSCH

Table 3-1 Coal Conversion Processes

capital investment estimates, and the possibility of project schedule delays.

The fundamental methodology is described in Section 1, Methodology for Selection of Fossil Energy Processes, and is based on the principles of portfolio theory whereby risks in an investment of capital can be reduced by means of diversification. This principle applies to the problem facing ERDA where investment in a number of different fossil energy conversion processes is to be made. The investment objective is to determine the set of coal conversion processes which maximizes the program benefits and also achieves, through diversification, an acceptably low level of program risk.

3.2 Portfolios of Coal Conversion Processes

3.2.1 Program Structure

The computer model calculates portfolio benefits and risks for any specific combination of coal conversion processes and a portfolio is defined to be just such a combination of processes. These portfolio definitions, in general, are to be supplied by the user since the computer model does not have a mathematical optimization procedure to select the best processes automatically. Without such an optimization procedure, however, there were so many possible process combinations (millions) that it would have been impossible to examine them all. Therefore a rationale for selecting trial combinations was essential in order to reduce the problem of portfolio evaluation to a manageable size. The approach required definition of portfolios comprising various sets of product types that may be desirable within a particular budget level for a program of demonstration plants. Such a demonstration plant program is termed a *program structure*. One such program structure, for example, might be made up of two pipeline gas plants, four fuel gas plants, one direct combustion plant, and one liquefaction/gasification plant.

Ten program structures are shown in Table 3-2(a), (b). Each of these program structures was suggested by one or more ERDA personnel. Coalcon was included specifically in four of the program structures to reflect the existing Coalcon contract. In the fifth through the tenth programs, the liquefaction/gasification product category was not restricted to the Coalcon process. Each of the ten program structures represents a different combination of synthetic fuel products, and encompasses realistic funding alternatives for the Major Facility Project Management Division. The ten programs are not exhaustive but do typify the presently perceived objectives of ERDA with respect to demonstration scale coal conversion facilities.

3.2.2 Baseline Portfolios

Trial portfolios were examined explicitly in relationship to these program structures. In each program structure there was a number of competing processes available for each product type. In the case of pipeline gas products, for example, five different processes were available. Thus, even with a well defined program structure, there was a large number of feasible process combinations which had to be considered. Portfolio results were calculated for each of these process combinations or trial portfolios. The best portfolio from the trial portfolios was selected

Product Type	Program 1	Program 2	Program 3	Program 4	Program 5
Pipeline Gas	Pipeline A	Pipeline A		Pipeline A	Pipeline A
	Pipeline B			Pipeline B	
Fuel Gas	Industrial A		Industrial A		Industrial A
	Small Scale A	Small Scale A	Small Scale A		Small Scale A
	Small Scale B	Small Scale B	Small Scale B		Small Scale B
	Utility	Utility	Utility		Utility
Direct Combustion	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed
Liquefaction/ Gasification	CBF	CBF	CBF	CBF	Liquef/Gas A

Table 3-2(a). Program Structures 1-5

Product Type	Program 6	Program 7	Program 8	Program 9	Progam 10
Pipeline Gas	Pipeline A	Pipeline A	Pipeline A	Pipeline A	Pipeline A
	Pipeline B		Pipeline B	Pipeline B	
Fuel Gas	Industrial A	Industrial A	Industrial A	Industrial A	Industrial A
			Industrial B		
	Small Scale A	Small Scale A	Small Scale A	Small Scale A	
	Small Scale B	Small Scale B	Small Scale B	Small Scale B	
	Utility		Utility		
Direct Combustion	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed	Atmospheric Fluid Bed
Liquefaction/ Gasification	Liquef/Gas A	Liquef/Gas A	Liquef/Gas A		Liquef/Gas A
	Liquef/Gas B		Liquef/Gas B		

Table 3-2(b) Program STructures 6-10

for each program structure and was defined as the *baseline portfolio* for that program. Because each program structure limited the number of feasible process combinations to 15 - 20, it was possible to select the optimal portfolio for that set of product types. The processes selected were optimal in the sense that a value judgement was maximized with respect to a trade-off between process benefits and process risks for the entire group of processes in the portfolio. The baseline portfolio was determined by examination of both the normalized and unnormalized benefit/risk maps. The portfolio selection was made to maximize the MFPM program benefits relative to an acceptable level of risk. Any portfolio other than the baseline portfolio represented sets of processes that would offer a degraded level of benefits, increased risks, or both.

3.2.3 Budget Constraints

The portfolios were mapped without regard to any budget limitations. Realistically, only limited funds are available for the development of demonstration scale plants for promising coal conversion processes. In addition, the funds which are made available have to be justified in the on-going governmental budgeting procedure. The baseline portfolios for the ten program structures may assist the MFPM budgeting exercise from two points of view.

First, quantitative justification for a larger program is possible. The argument is especially compelling if, in addition to an increase in program benefits, a reduction in relative program risk would occur as a consequence of additional plant funding. Second, assuming a firm budget constraint, the best program structure for that level of expenditure can be determined.

3.3 Program Results for Twenty-One Coal Conversion Processes

3.3.1 Baseline Portfolio Results

The ten baseline portfolio results are shown on a normalized benefit/risk map, Figure 3-1. Using the risk attitude lines, it is possible to compare the baseline portfolio results for the ten program structures and to determine the most suitable MFPM program structure and associated baseline portfolio.

The clear choice is Baseline Portfolio 5 which is the optimal selection of coal conversion processes for Program Structure 5. The choice is unambiguous because no other baseline portfolios fall within the risk attitude band. If there had been portfolios within this band, the correct choice would have required a trade-off decision between portfolio benefits, portfolio risk, balance of energy output between product types, and demonstration plant funding requirements.

The unnormalized benefit/risk map, Figure 3-2, shows the absolute present worth dollar impact of a portfolio. Examining these unnormalized results, the superiority of Baseline Portfolio 5 is again illustrated. It might be pointed out, however, that on the basis of Figure 3-2, the benefits of Baseline 6 are larger than those of Baseline 5. The following reasoning indicates that Baseline 5 is still the proper choice. Using the incremental analysis technique discussed in Section 1, a comparison of

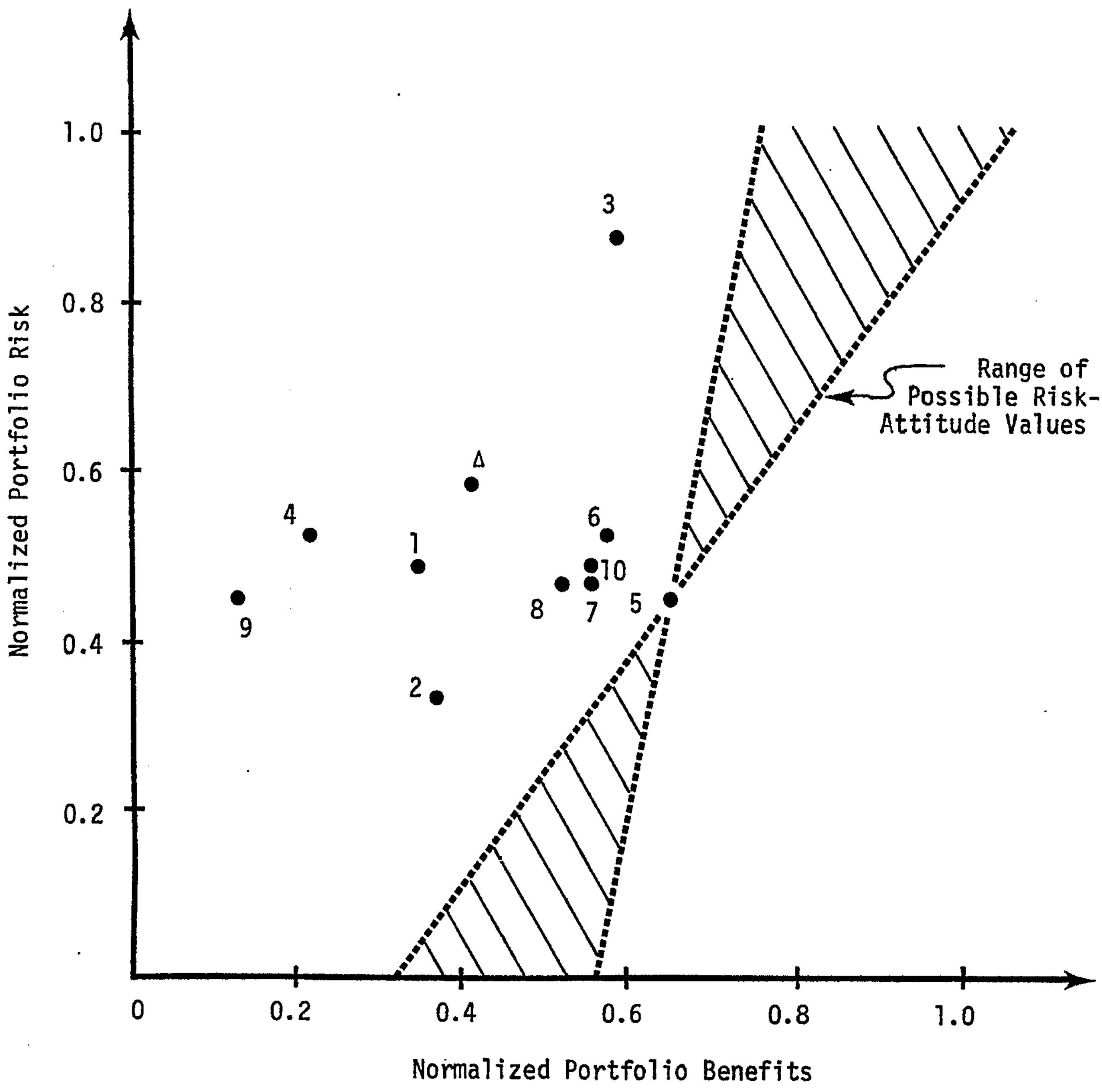


Figure 3-1 Normalized Benefit/Risk Map of Ten Baseline Portfolios

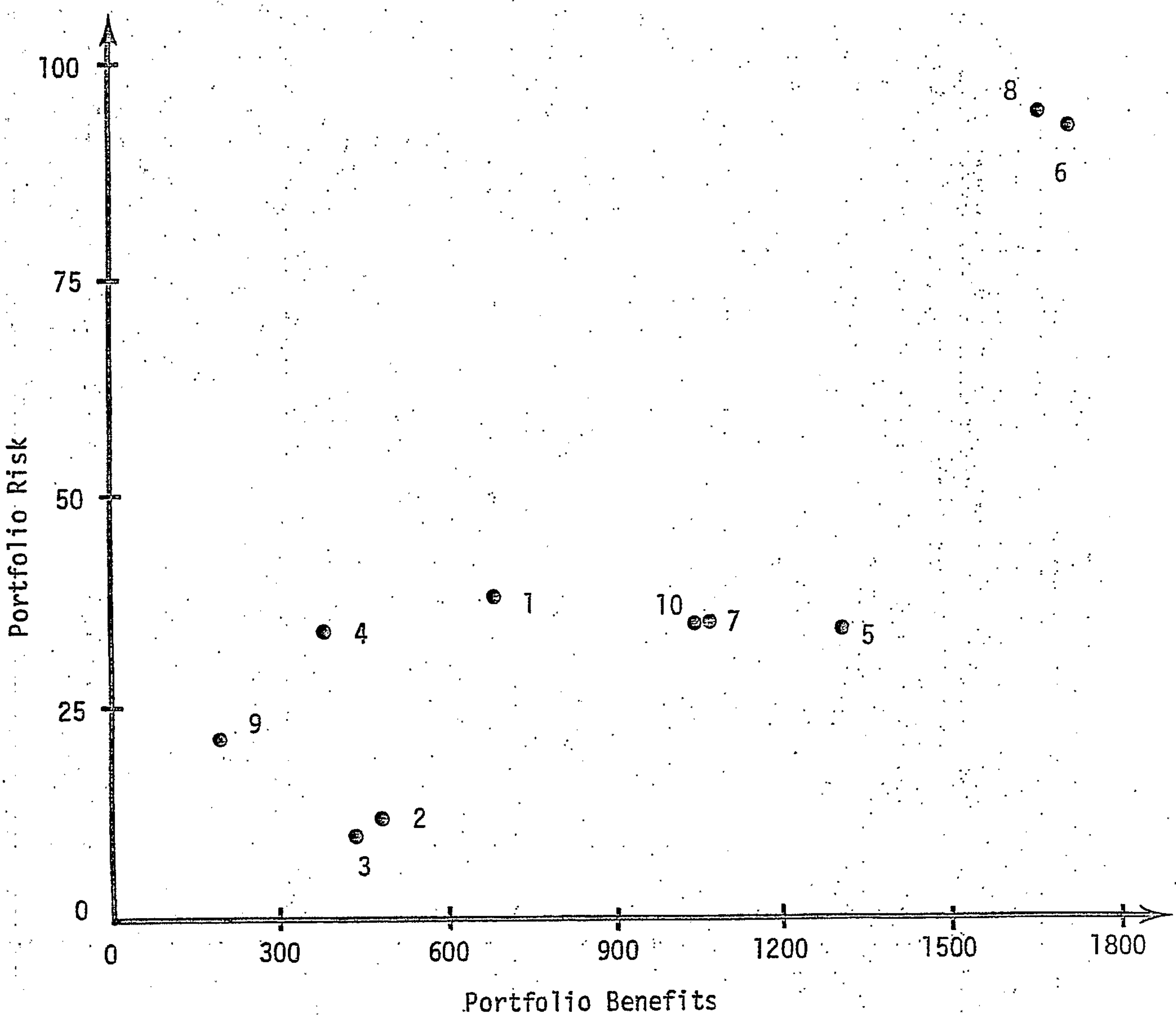


Figure 3-2 Unnormalized Benefit/Risk Map of Ten Baseline Portfolios

Baseline 5 and Baseline 6 can be made using data obtained from Appendix E, Ten Baseline Portfolio Results.

	Unnormalized Portfolio Benefits, B ($ MM)	Unnormalized Portfolio Risk, R ($ MM)^2	Present Worth of Comm. Scale Investment, C ($ MM)
Baseline 5	1302.8	1810.8×10^3	1997.5
Baseline 6	1700.8	4632.2×10^3	2972.9
Δ Result	398.0	2821.4×10^3	975.4
$\Delta B/\Delta C$	0.41		
$\Delta R/\Delta^2 C$*		0.58	

Table 3-3 Incremental Analysis of Baseline 5 and 6

The Δ Result line shows the change or increment in moving from Baseline 5 to Baseline 6 in terms of the increase in benefits, risks and commercial scale investment, respectively. $\Delta B/\Delta C$ and $\Delta R/\Delta^2 C$ are the normalized benefits and risk attributable to the extra $975 MM investment. These incremental, normalized values were plotted as a point labeled Δ in Figure 3-1. The incremental benefit/risk point shows that the extra investment

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$*\Delta^2 C = C^2(6) - C^2(5)$

necessary to move from Baseline 5 to Baseline 6 is unwarranted. Therefore, Baseline 5 represents a much better investment decision than Baseline 6.

In terms of selecting the next best portfolio which might be occasioned by budget constraints or external criteria, the risk attitude lines can be thought of as sliding to the left on the normalized benefit/risk map while maintaining the same angle with respect to the benefit axis. After a decisionmaker determined the appropriate risk attitude line for a decision situation, that line is simply moved to the left until it reaches the next portfolio. It can be seen (by sliding a ruler on Figure 3-1) that, regardless of the decisionmaker's attitude toward risk, Baseline Portfolio 7 is the second best alternative and Baseline 10 is the third best alternative. Baseline 6 is excluded because the incremental analysis above showed that Baseline 6 is relatively unattractive. Baseline 8 would be excluded for the same reason. The baseline portfolio results are summarized in Table 3-4.

Rank	Portfolios
No. 1	Baseline Portfolio 5
No. 2	Baseline Portfolio 7
No. 3	Baseline Portfolio 10

Table 3-4 The Best Three Baseline Portfolios

At this point a better understanding of the portfolio results can be obtained by examining the baseline processes which constitute the baseline portfolios. Moreover, since the MFPM program decision occurs on a process-by-process basis, an assessment of the effects of individual processes in each portfolio is important.

3.3.2 Baseline Processes

The coal conversion processes which make up the baseline portfolios 1 - 10 are called *baseline processes*. The baseline set of processes for each baseline portfolio is the best choice based on available commercial scale data, in the sense that it offers the optimal benefit/risk combination for the associated program structure as discussed in Section 3.2.2. The baseline processes for the ten program structures are shown in Table 3-5(a), (b). This table is analogous to Table 3-2(a), (b) which defined the ten program structures, but the required product types have been replaced by the baseline processes. In addition, the demonstration scale budget requirements for each process and baseline portfolio are included.

The baseline processes were selected by examining the portfolio results for each of the trial portfolios associated with a particular program structure. The trial portfolios were determined initially by selecting a group of processes simply to satisfy the program structure. Then the processes were exchanged, one at a time, so that results for all possible combinations were calculated. (The results of the trial portfolio calculations are discussed in Section 3.4, Sensitivity of Program Results.)

Product Type	Program 1	Program 2	Program 3	Program 4	Program 5
Pipeline Gas	Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249		Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249
Fuel Gas	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41	Small Scale E 21.3 Small Scale F 9.6 Utility K 41	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41		Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41
Direct Combustion	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90
Liquefaction/ Gasification	Coalcon- New Cost 254	Coalcon- New Cost 254	Coalcon- New Cost 254	Coalcon- New Cost 254	SRC II 260.43
Demonstration Plant Total Budget Req'ts. (millions)	$1,224	$ 665	$ 518	$1,050	$ 773

Table 3-5(a) Baseline Portfolios for Ten Program Structures

Product Type	Program 6	Program 7	Program 8	Program 9	Program 10
Pipeline Gas	Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249	Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249
Fuel Gas	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6	Industrial A 112 Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6	Industrial B 102
Direct Combustion	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90
Liquefaction/ Gasification	Coalcon-New Cost 254 SRC II 260.43	SRC II 260.43	Coalcon-New Cost 254 SRC II 260.43		SRC II 260.43
Demonstration Plant Total Budget Requ'ts. (millions)	$1,484	$ 732	$1,596	$ 929	$ 701

Table 3-5(b) Baseline Portfolios for Ten Program Structures

Scanning Table 3-5, an important conclusion stands out and provides the key to examining the benefit/risk results of Figures 3-1 and 3-2. Each baseline process is a consistent choice in the sense that regardless of program structure, the same baseline processes occur in each program. For example, in all programs which include one pipeline gas process, Lurgi is the choice. Similarly, when two pipeline gas processes are required, Slagging Lurgi and HYGAS are always the choices.

Since baseline processes exhibit consistency across program structures, this consistency will be termed baseline process *stability*. Because of this stability, certain conclusions can be reached regarding the relative value of the coal conversion processes within each product category.

- Slagging Lurgi is the preferred pipeline gas process. The second choice is HYGAS.
- Industrial B, Small Scale E and F, and Utility K are the preferred fuel gas processes.
- SRC II is the preferred liquefaction/gasification process and Coalcon is the second choice. In the first four program structures, however, the liquefaction/gasification process choice was constrained to Coalcon.

The atmostpheric fluidized bed process had no competitors within the direct combustion category, and so was not included as the preferred process.

It will be observed that Coalcon does not rank as favorably as SRC. This should not necessarily be interpreted as negatively as it may appear. The costs associated with Coalcon in the portfolio evaluations were based on *ex ante* estimates without regard to costs already sunk into the Coalcon program. Sunk costs should be excluded and, if this were done, Coalcon would be somewhat more attractive although SRC would definitely remain the preferred process. Furthermore, the portfolio development was made without regard to considerations of transaction costs for portfolio modification. Transaction costs are those costs pertaining to penalties for abandonment or modification of a portfolio component. Clearly, there may be serious penalties associated with abandonment of Coalcon at this stage.

The same argument applies to COGAS. Since COGAS is at a much earlier stage in the program, however, the costs of program modification would not be so large as is the case for Coalcon. It is safe to assume that program modification is administratively unattractive. Because of this, the results indicated above may be used instead to focus on questions about the process and economic details for COGAS and Coalcon which contributed to these results.

3.3.3 Analysis of Program Results

Stability of the baseline processes allows decisions about program structure to be made with confidence that future decisions about new processes will not invalidate previous decisions. For example, suppose Program 7 were selected due to budget constraints, although Program 5 was recognized as preferable. If the budget constraints were subsequently loosened, Program 7 could be modified to Program 5 simply by adding the Utility K fuel gas process. All the other processes are identical. Therefore, baseline process stability provides the possibility of initially funding an optimal core program based on a limited budget and then adding additional baseline processes as more funding becomes available. The resulting program will not only still be optimal but will have increased benefits and lower risk per dollar invested.

In addition to providing consistent program decisions, baseline process stability allows individual portfolio results to be easily analyzed. In order to understand why one portfolio of processes is better than another, it is possible to examine the results in two ways. First, portfolio results can be compared in terms of the processes which differ between portfolios. Second, the underlying process economics and risks can be examined to understand at a deeper level what contributes to the differences between portfolio results. These techniques can be used to compare baseline portfolios for different programs or to determine why a trial portfolio is not as attractive as the baseline portfolio for a particular program structure.

The difference in portfolio results, for example, between Programs 5 and 7 (see Figures 3-1 and 3-2), can be attributed solely to Utility K, which is the only different baseline process in the two programs. (In comparing portfolio results, it is natural to first determine the difference in processes which contribute to the results, then examine the underlying economic and risk data.) Individual process benefits and risks are shown in

Appendix F. With this data, the numerical difference in portfolio results can be illustrated. The benefits and risks for Program 5, Program 7, and Utility K are shown in Table 3-6.

	Unnormalized Portfolio Benefits ($ MM)	Unnormalized Portfolio Risk ($ MM)^2	Normalized Benefits	Normalized Risk
Program 5	1302.8	1.81×10^6	0.65	0.45
Program 7	1054.6	1.72×10^6	0.55	0.47
Utility K	248.2	0.03×10^6	2.88	4.07

Table 3-6 Benefits and Risks - Program 5 and Program 7

Portfolio benefits are linear, so the benefits of adding Utility K to Program 7 are equivalent to the benefits of Program 5, i.e., 248.2 + 1054.6 = 1302.8. The portfolio risk of Utility K and Program 7 does not add up to the portfolio risk of Program 5 however, i.e., $0.03 \times 10^6 + 1.72 \times 10^6 < 1.81 \times 10^6$, because the interactive risk between Utility K and the other processes is not accounted for simply by adding the individual portfolio risk of Utility K.

The interactive risk among a set of coal conversion processes occurs because the processes are not completely independent technically of one another even though they are different in many respects. The interactive risk typically represents about 10% of the total portfolio risk. For example, the sum of the individual process risks for Program 5 is

1.63×10^6 ($ MM)^2 whereas the portfolio risk of Program 5 is 1.81×10^6 ($ MM)^2. The difference of 0.18×10^6 ($ MM)^2 is the interactive risk for Program 5.

Normalized benefits and risks are also shown in Table 3-6. The normalized benefits of Program 5 are larger than those of Program 7 as is shown in Figure 3-1. The normalized risk or risk per dollar of investment is less, however, which illustrates the effects of diversification. The normalized risk of Program 7 is 0.47 while the normalized risk of Program 5 is 0.45. In other words, although the portfolio (total) risk of Portfolio 5 is about 5% larger than that of Portfolio 7 simply because more dollars are outstanding, the additional diversification which occurs by adding Utility K, more than offsets this incremental risk and, in fact, actually reduces the risk per dollar invested by more than 4%.

In order to examine underlying process economics and risks, these data are shown in Table 3-7 for each process being considered. It is emphasized that the data are not necessarily well supported and will not be until process conceptual designs have been completed and better process costs are available. In the first two columns, process results for net benefits and individual risks are given. These results were calculated by the portfolio model in which a portfolio was defined as a single process. For simplicity, the units of the individual risk column are in $ MM but this is actually the square root of the process risks. The last three columns contain the basic input economic data for each process.

By scanning the utility fuel gas data, it is clear why Utility K was chosen.

PROCESS NAMES	PROCESS RESULTS Unnormalized Net Benefits ($ MM)	Unnormalized Individual Risks ($ MM)	ECONOMIC INPUT DATA Revenue ($ MM/YR)	Operational Costs ($ MM/YR)	Investment Costs ($ MM/YR)
Pipeline Gas					
COGAS	-164	890	314	115	1144
Slagging Lurgi	93	225	316	103	920
HYGAS	154	914	330	117	825
Synthane	- 46	884	312	85	1201
Texaco	-299	551	335	190	1087
Fuel Gas					
Indust Fuel Gas A	- 51	84	106	63	263
Indust Fuel Gas B	42	69	66	32	102
Indust Fuel Gas C	-170	344	127	99	343
Small Scale D	5	10	26	15	47
Small Scale DX	- 10	5	9	7	22
Small Scale E	4	5	11	6	21
Small Scale F	6	4	8	4	10
Utility Fuel Gas G	164	72	88	29	72
Utility Fuel Gas H	-254	222	63	52	367
Utility Fuel Gas I	34	37	29	15	23
Utility Fuel Gas J	-167	558	177	125	448
Utility Fuel Gas K	248	174	141	50	117
Direct Combustion					
Atmos Fluidized Bed	-106	85	151	126	250
Liquefaction/Gasification					
Coalcon - Old Cost	385	553	329	130	450
Coalcon - New Cost	244	613	329	152	525
SRC II	1016	1240	750	193	1414
Fischer-Tropsch	37	1313	549	191	1769

Table 3-7 Individual Process Benefits, Risks, and Economic Data

Utility K has the largest net benefits and moderate risk. In fact, the net benefits are 50% larger than the next utility process, Utility G, although Utility G also has considerably lower risk. The data, however, may raise questions as to the credibility of the economic data for Utility K. The operating costs and investment costs are quite low relative to the revenue for Utility K when these data are examined for other utility fuel gas processes as well as for other product types.

The other product types have interesting data characteristics which help to explain why certain processes are baseline processes and why the baseline portfolio results are distributed as they are.

- SRC II has the highest process benefits, $1016 MM, of any process. Since Baseline Portfolio 9 is one of the few portfolios which does not include SRC II, this helps to explain why this portfolio has the lowest benefits, normalized and unnormalized, of any baseline portfolio.

- The difference in process benefits for Coalcon - Old Cost and Coalcon - New Cost is $141 MM. By increasing the estimate of investment and operating costs, Coalcon benefits have been reduced by over 30%. The difficulty with these increased costs is that Coalcon is the only process which has already had over a year of MFPM funding to develop a demonstration facility. It is highly possible that other process cost estimates will have to be increased also as more detailed engineering designs and instrumentation configurations become available.

- HYGAS has the largest benefit of any pipeline gas process but it also has the highest risk. The primary reason HYGAS has the largest benefit is that it has the lowest investment cost. The only other pipeline gas process with a positive net benefit is Slagging Lurgi. The other three processes have a negative net benefit because they have relatively high investment costs compared with their revenue producing potential. The significance or negative net benefit is reflection of a portfolio's success in achieving the assumed rate of return of 10%.

- Industrial Fuel Gas B has positive process benefits and the lowest risk. The plant capacity of B is about half that of A or C but the investment and operating costs are about one-third the costs of either A or C. The proportionately lower costs for B accounts for its having the best process benefits.

- The small scale industrial fuel gas processes are so small that portfolio results are relatively unaffected whether these processes are included or not. Because the demonstration scale funding is also small, at least Small Scale E or F should be funded.

- The Atmostpheric Fluidized Bed has negative process benefits due to high operating costs. The risk associated with the process is quite small, however, so the process does not overly detract from portfolio results. By including AFB, the portfolio risk remains essentially unchanged while the portfolio benefits are reduced about 6%.

3.3.4 Baseline Budgets

The total RD & D cost of funding demonstration plants for the baseline portfolios is shown in Tables 3-5(a), (b). The demonstration plant cost of each process is also shown. Insights into the ten program structures also can be gained when the program budget requirements for demonstration scale plant funding are analyzed.

- Program 5 requires about $775 million while Program 8 is more than twice as much -- $1,484 million. Program 5 is less expensive than most of the other programs and still offers the best benefit/risk combination.

- The difference in funding levels between Program 5 and Program 7 is $41 MM or about 5%. This difference is due to one process, Utility K. The additional experience to be gained in developing a utility fuel gas demonstration facility would seem to outweigh the incremental budget difference.

- The difference between Program 7 and the next best alternative, Program 10, is also about 5% and the same argument applies. In this case, Program 10 excludes both small scale industrial fuel gas plants as well as the utility fuel gas plant.

Programs 6 and 8 require approximately $1,500 MM for demonstration plant funding while Programs 5, 7, and 10 require about half as much or $750 MM. It may be desirable fo fund a larger demonstration plant program, say $1,500 MM, for several reasons. First, in the smaller programs, only two processes (one pipeline gas and one liquefaction/gasification) account for over 65% of the demonstration plant budget. Better program diversification may be achieved with a larger number of major processes. Second, there are sufficient process differences among the potential candidates being considered in this report and in other potential processes to warrant multiple funding of pipeline gas and liquefaction/gasification processes. A demonstration plant program of $1,500 MM could easily include two pipeline gas plants and two liquefaction/gasification plants. The diversification effects of multiple plant funding are highlighted in Section 3.4.3, Portfolio Risk and Diversification.

- Programs 6 and 8 are the preferred portfolios based on available data if a $1,500 MM demonstration plant program is desired. The programs are the same except for Industrial Fuel Gas A which is included in Program 8.

In addition to the numerical values for demonstration plant funding given in Tables 3-5(a), (b), it is helpful to see a graphical display of the proportionate share of the total budget required by each process. Figure 3-3 highlights program budget differences with a pie chart. The size of each pie represents the budget level for a particular program and the color values represent the different product types.

In the MFPM program it is desirable to achieve some degree of balance among the funding levels for the different product types. Achieving this goal would provide an important type of diversification in overall funding for the MFPM program.

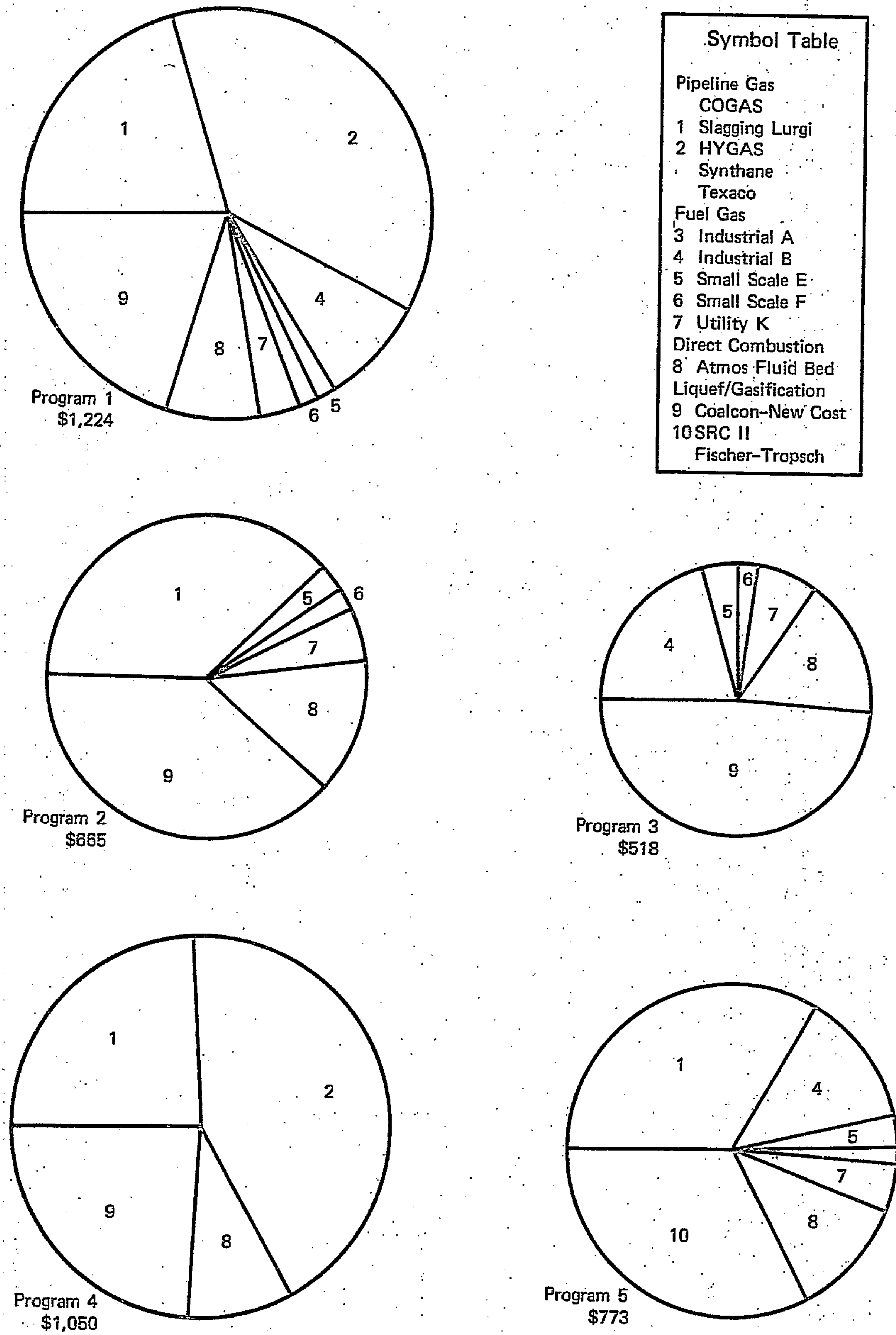

Figure 3-3(a) Budget Analysis – Baseline Portfolios 1-5

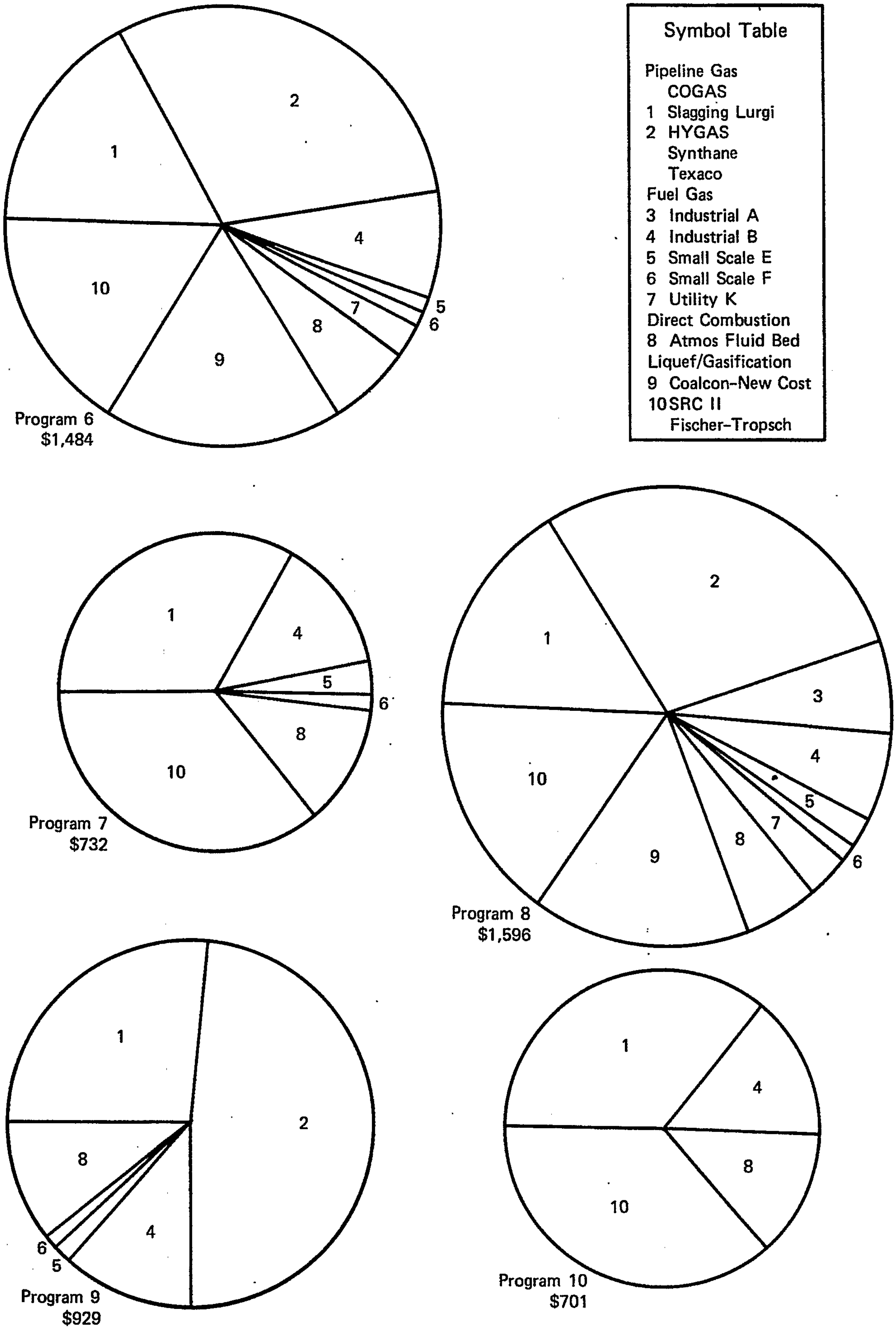

Figure 3-3(b) Budget Analysis - Baseline Portfolios 6 -10

With this viewpoint, and quite apart from a consideration of portfolio results, Programs 2, 5, 6, 7, 8, and 10 represent portfolios with balanced funding. Contrasted with these programs are the others, Programs 1, 3, 4, and 9. Program 3 has no pipeline gas so the program results depend primarily on Coalcon, in that Coalcon forms 50% of the portfolio. Programs 1, 4, and 9 all include two pipeline gas processes. In fact, for these five programs, at least 55% of the funding is allocated to pipeline gas. The question that must be considered in these cases is whether over half of the MFPM program should be predicated on a single product type.

The analysis of program results may be summarized by the following:

- Baseline portfolio results indicated Baseline Portfolios 5, 7, and 10 were the best alternatives, in that order, for MFPM funding at the $750 MM MFPM funding level.
- Baseline Portfolios 6 and 8 were the best alternatives for MFPM funding at the $1,500 MM MFPM funding level.
- When demonstration plant funding requirements are included in the analysis, these conclusions are even more strongly supported.

3.4 Sensitivity of Program Results

3.4.1 Sensitivity to Process Economics and Risk

Baseline portfolios were selected after evaluating all possible process combinations or trial portfolios for each program structure. In this way the optimality of the baseline portfolios is guaranteed. Sensitivity of the portfolio results was calculated by substituting one non-optimal process at a time into the baseline portfolio for each program structure. The sensitivity results for Baseline Portfolio 5 are plotted in Figure 3-4. Sensitivity results for the other baseline portfolios are in Appendix G.

These results show the percentage change in unnormalized portfolio benefits and risks caused by the substitution of each non-optimal process. Conversely, the results indicate how much change in the estimate of process economics and risk would be required for a non-optimal process before the decision about the baseline process would have to be reevaluated. The symbols used to identify the processes are shown in the symbol table. In addition, the baseline processes are listed.

The origin of the axes in Figure 3-4 represents Baseline Portfolio 5. The sensitivity axes divide the figure into four quadrants. It is significant that no points lie in the lower right hand or fourth quadrant. Any point in the fourth quadrant would mean that there was a group of processes with lower risk and higher benefits which, by definition, would violate the optimality of the baseline portfolio. The majority of points lie in the upper left or second quadrant. All of the portfolios represented by these points are completely dominated by the baseline portfolio, i.e., these portfolios would have higher risk as well as lower benefits.

The points in the first and third quadrant represent portfolios where the benefits and risks would either be higher (quadrant I) or lower

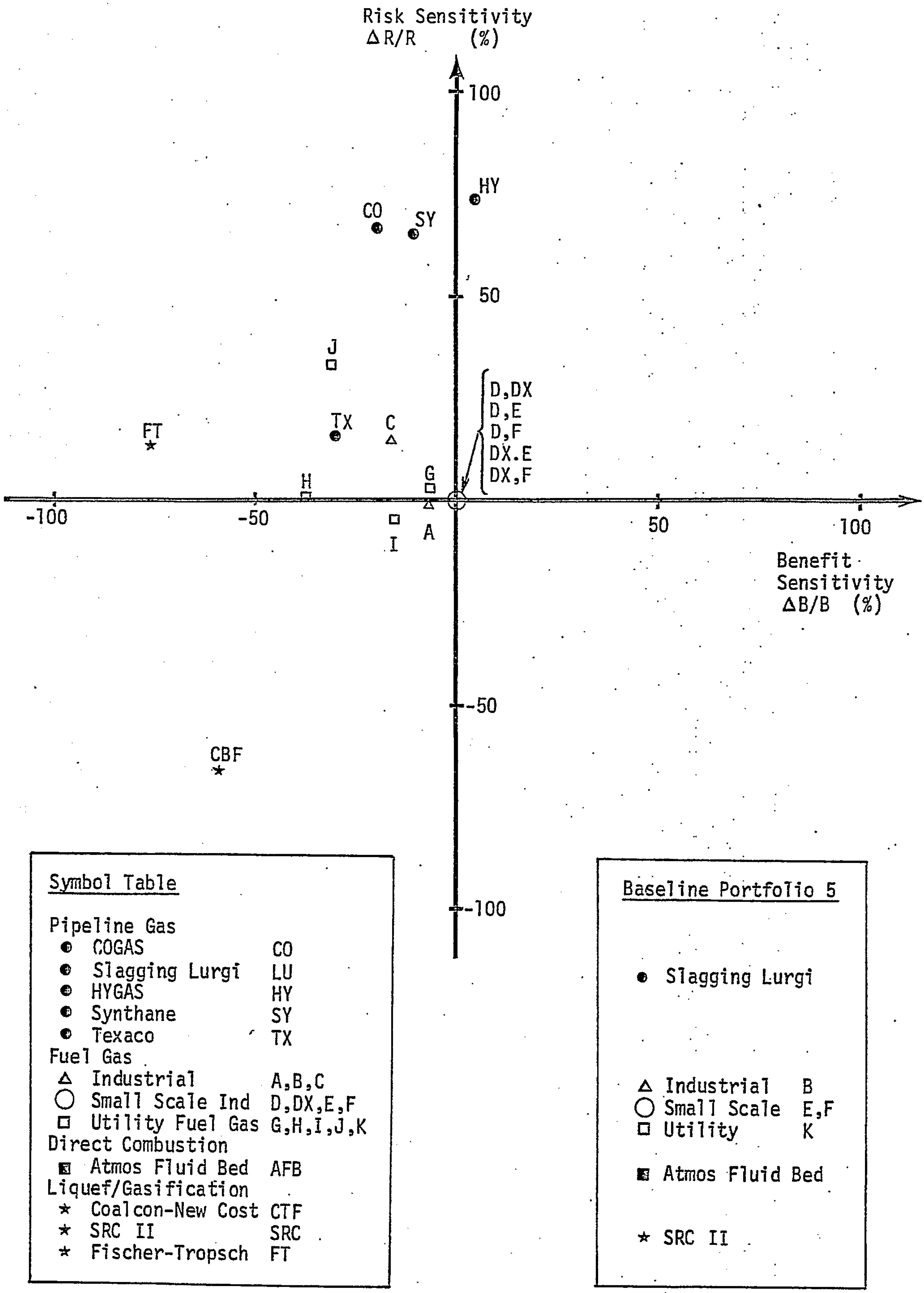

Figure 3-4 Sensitivity of Program 5 to Process Economics and Risk

(quadrant III). It is in these quadrants that the risk attitude of the decisionmaker can be taken into account. For example, replacement of Slagging Lurgi by HYGAS would increase portfolio risk by nearly 75%, but the benefits would also be increased by only 10%. In quadrant III, substitution of Coalcon for SRC II would reduce portfolio benefits by about 60% but would also reduce risk by about 60%. Actually, an examination of the technical risk data in Appendix C shows that Coalcon and SRC II have a similar degree of technical risk. The large difference in individual process risk results from the significantly better economics of SRC II. The benefits of the SRC II process are more than four times as large as the benefits of Coalcon. These increased benefits, however, also increase the risk of SRC II because there is a concomitantly larger potential for economic loss.

The point labeled G represents the change in portfolio results if Utility G were substituted for Utility K. There is only a 10% change in portfolio risks and benefits. Because there is some doubt regarding the credibility of the cost estimates for Utility K (as discussed in Section 3.3.3), it may be worthwhile to examine more detailed data for the two processes.

The circle at the origin represents the portfolio sensitivities to small scale fuel gas process substitutions. These processes are literally so small in scale that they do not affect the portfolio results significantly. An expanded scale which does reflect these results is included in Appendix G.

3.4.2 Sensitivity to Product Market Price

The revenue for each process was calculated using \$4.00/MM BTU as the price for each product type, whether it was pipeline gas, fuel gas or liquefied product. A constant price was used simply as a basis for comparing the different processes. It was recognized that eventual fuel prices will, first of all, probably be quite different for each product type and, secondly, that they will depend on fluctuating market forces which will result in changing market prices over the operating life of commercial scale plants.

In order to test the sensitivity of the baseline portfolios to different fuel prices, a different price was assumed for two product types, fuel gas and liquefied product. First, the ten baseline portfolio results were calculated using \$3.00/MM BTU for fuel gas with \$4.00/MM BTU for the other products. The results are shown in Figure 3-5. Then, the ten baseline portfolios were calculated with \$3.00/MM BTU for the liquefied product with \$4.00/MM BTU for the pipeline and fuel gas. These results are shown in Figure 3-6.

Figure 3-5 shows that, in general, the basic relationship between the baseline portfolios remains unchanged. Baseline 5, 7, and 10 are still the appropriate candidate portfolios for funding. The extent to which the portfolio's position is changed on the normalized benefit/risk map simply depends on the proportion of the portfolio's total BTU output which is attributed to fuel gas.

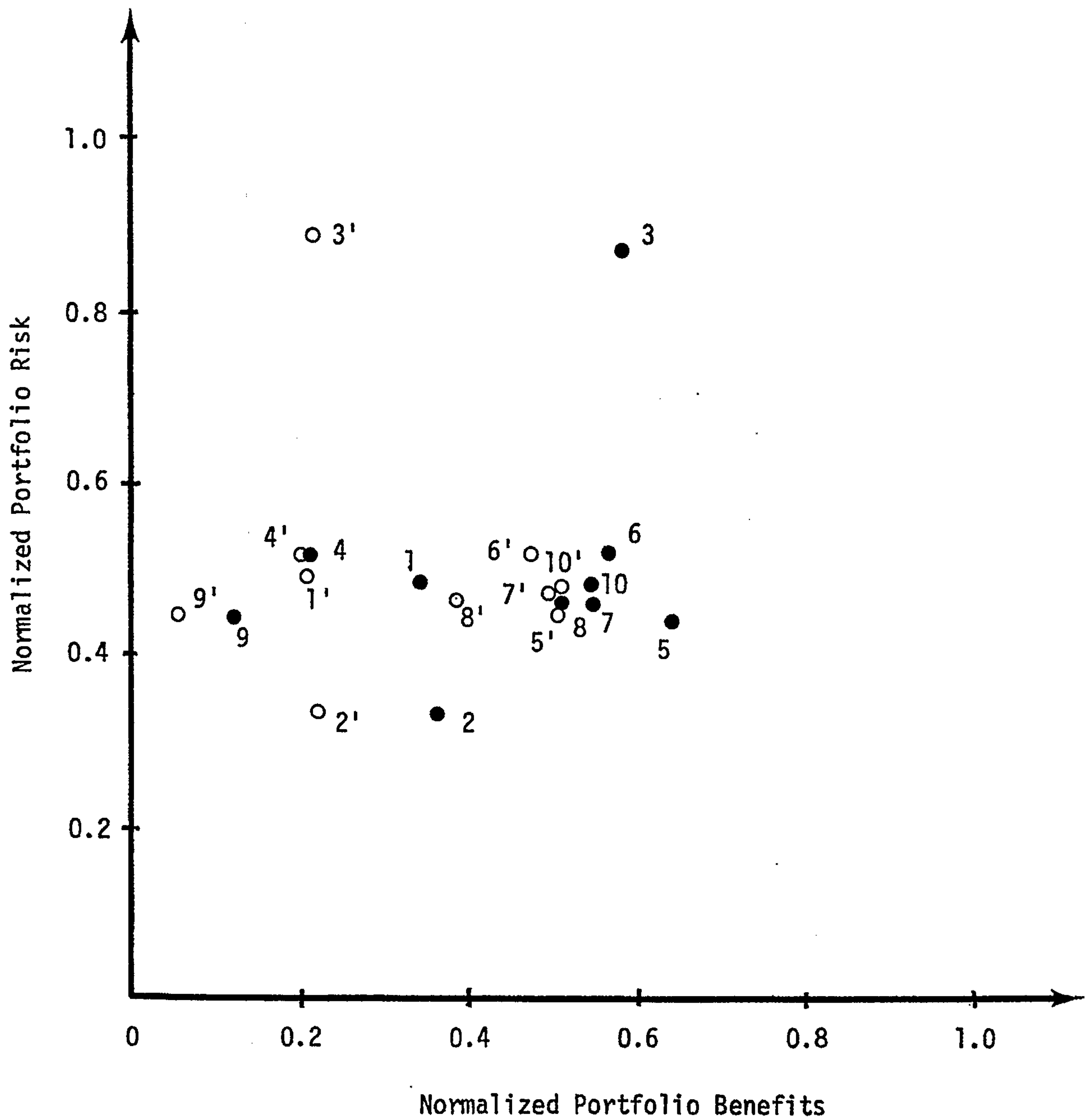

Figure 3-5 Sensitivity of Baseline Portfolio Results to $3.00/MM BTU Fuel Gas

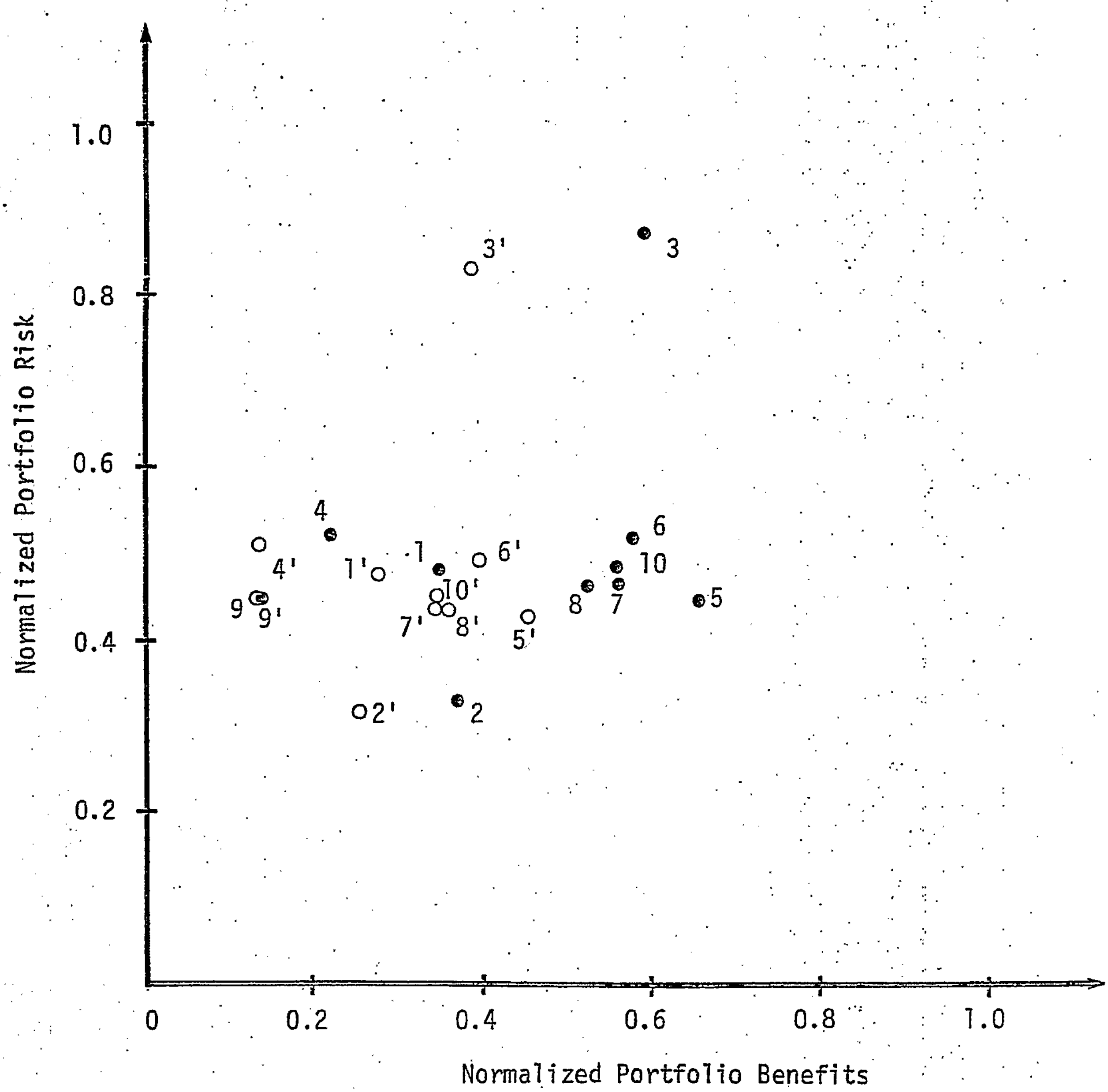

Figure 3-6 Sensitivity of Baseline Portfolio Results to $3.00/MM BTU Fuel Oil

The results of reducing the price on liquefied product, Figure 3-6, are somewhat different. Baseline Portfolio 5 is still the best portfolio but after that, the choices are less clear. There is a tight grouping of Baseline 6, 7, 8, and 10. The reason for this is that all these portfolios are more havily affected by changes in liquefaction product prices. Portfolios 6 and 8 have two liquefaction/gasification processes, SRC II and Coalcon. Portfolios 7 and 10 have only one liquefaction/gasification process, but since they also have fewer fuel gas processes, the liquefaction product makes up a greater percentage of portfolio BTU capacity.

In summary, the choice of the best three Baseline Portfolios, 5, 7, and 10, seems to be insensitive to different market price assumptions for the various coal conversion products.

3.4.3 Portfolio Risk and Diversification

In order to examine the effect of diversification on normalized portfolio risk, a single process, HYGAS, was selected and several portfolios were constructed with a different number of HYGAS process replications in each. The first portfolio had one HYGAS process, the second had two, etc. In all, nine portfolios were calculated. The reason one process was selected was to illustrate the effect of diversification even when the technological aspects of several processes were essentially identical. In addition to process or technological diversification, the fact that the demonstration scale plants will be built and operated by different companies in different parts of the country also leads to diversification. The resulting diversification has been termed *management diversification* and *geographical diversification*.

Normalized portfolio risk has been plotted against the number of HYGAS processes in the portfolios in Figure 3-7.

The normalized risk for one HYGAS process has been taken as 100%. By adding just one more HYGAS process, the normalized risk (or risk per dollar invested) drops by nearly 20%. With four plants in the portfolio, the normalized risk is reduced by more than 25%. With the effects of technological diversification included by multiple funding of different processes, the risk reduction would be even more pronounced. These results represent the basis of a strong case for funding at least two different processes for each product type.

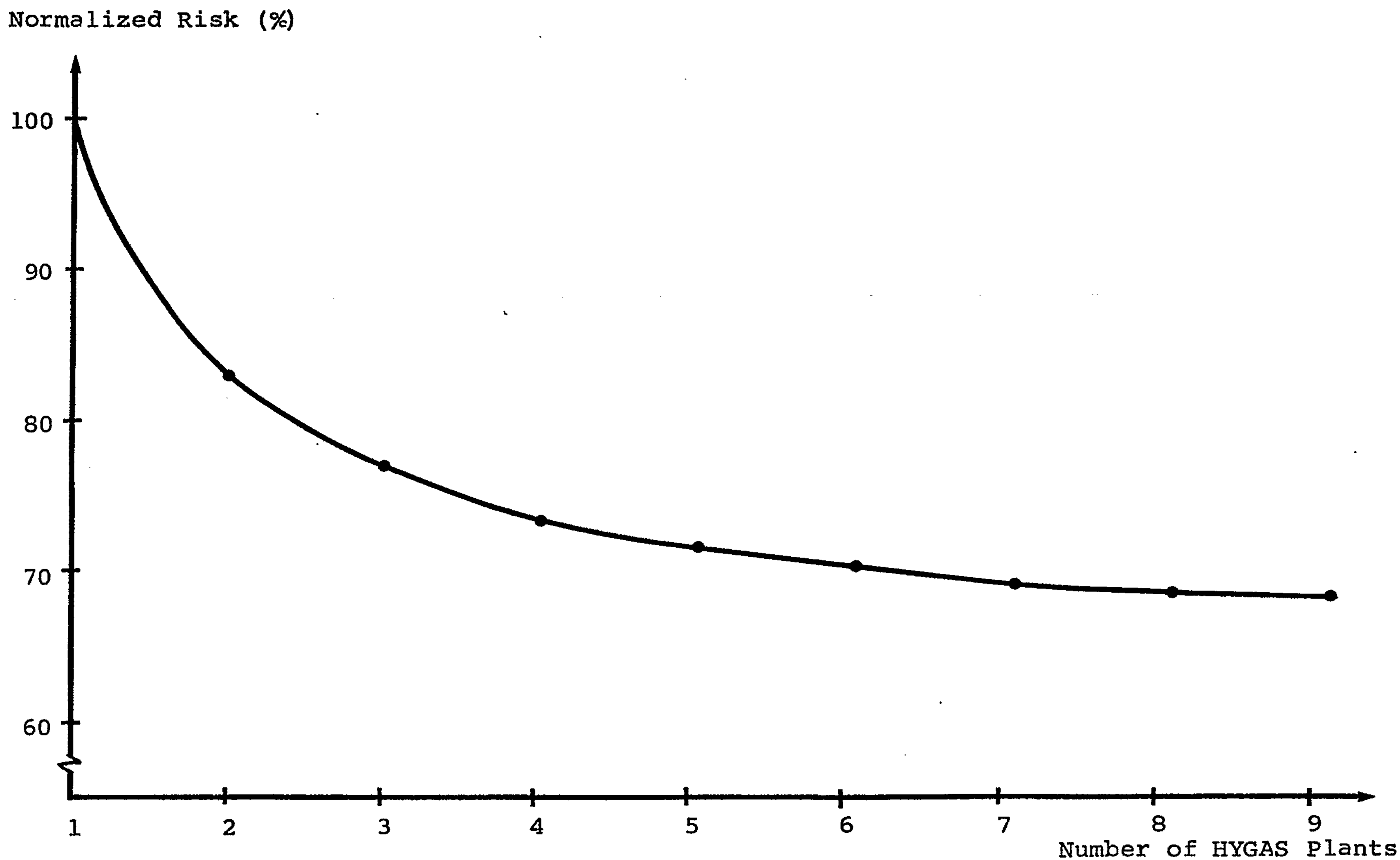

Figure 3-7 Portfolio Risk and Diversification

4. SUMMARY OF RESULTS

The Econergy portfolio model has been developed for evaluating coal conversion processes as candidates for demonstration plant-funding. The group of processes which is selected will form what is, in effect, an investment portfolio for ERDA. The evaluation procedure utilizes information on process economics and process risks. Both kinds of information are combined for each process so that a comprehensive comparison among the individual processes can be made. In addition, information regarding process similarities and dissimilarities is used to provide a comparison of various combinations of the processes. This approach to process evaluation is termed a portfolio approach because it allows the interrelated economic and risk implications of a group or *portfolio* of processes to be considered.

The portfolio model calculations result in two numbers, benefit and risk, which are used to describe uniquely a portfolio of coal conversion processes. These numbers form a point on a two-dimensional plot termed an unnormalized benefit/risk map. By normalizing these data on a per dollar invested basis, the results can be plotted on a normalized benefit/risk map. The benefit/risk information presented in this manner can be used as a significant decisionmaking tool.

4.1 Portfolio Evaluation Criteria

Several evaluation criteria have been developed to characterize the program value of a portfolio. These criteria include portfolio benefit and risk and they also reflect other distinctive features about a specific portfolio. In cases where the benefit/risk tradeoffs between two portfolios may be difficult to assess, examination of these additional criteria typically will establish the relative value of each portfolio in the Fossil Energy program. The evaluation criteria are listed in Table 4-1. Examples of the use of these criteria will be illustrated in the following discussion of results.

4.2 Portfolio Results

Ten different combinations of coal conversion processes have been determined to represent a variety of MFPM program goals and budget alternatives. The results for these ten portfolios are shown in Figure 4-1. For judging the benefit/risk merit of a particular portfolio, the primary criteria are the first two listed in Table 4-1, i.e., position and relationship with other portfolios on the normalized benefit/risk map. The preferred portfolios have higher benefits and lower risk and, therefore, lie in the lower right hand corner of the benefit/risk map. On this basis, the best portfolios are, in order, Portfolios 5, 7, 10, 6, and 8.

Each of these portfolios is made up of several coal-conversion processes selected from twenty-one different processes specified by ERDA. The coal-conversion processes result in a variety of product types: pipeline gas, fuel gas, direct combustion and liquefaction product. The processes included in each portfolio were determined to be the optimal processes for each product type. The group of coal conversion processes which make up Portfolios 5, 7, 10, 6, and 8 are shown in Table 4-2.

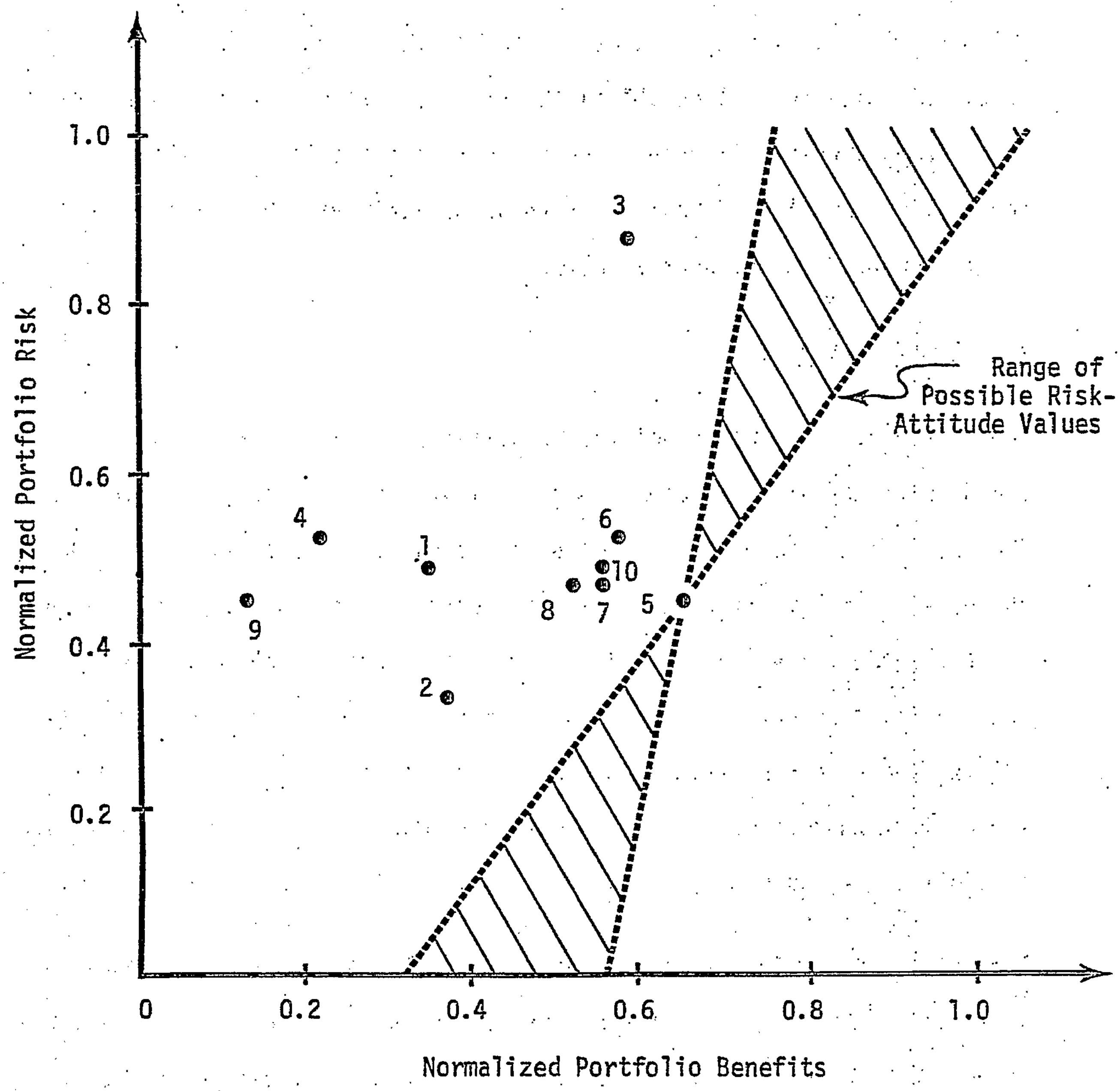

Figure 4-1 Normalized Benefit/Risk Map of Ten Baseline Portfolios

- Position on the normalized benefit/risk map
- Relationship with other portfolios on the normalized benefit/risk map
- Sensitivity of portfolio results to process substitution and economics
- Sensitivity of portfolio results to product market price
- Program balance in terms of demonstration scale budget requirements per coal conversion product type.
- Incremental benefits and risks per additional dollar invested
- Total demonstration plant budget requirements
- Position and relationship with other portfolios on the unnormalized benefit/risk map

Table 4-1 Portfolio Evaluation Criteria

Product Type	No. 1 Program 5	No. 2 Program 7	No. 3 Program 10	No. 4 Program 6	No. 5 Program 8
Pipeline Gas	Slagging Lurgi 249	Slagging Lurgi 249	Slagging Lurgi 249	Slagging Lurgi 249 HYGAS 457	Slagging Lurgi 249 HYGAS 457
Fuel Gas	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6	Industrial B 102	Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41	Industrial A 112 Industrial B 102 Small Scale E 21.3 Small Scale F 9.6 Utility K 41
Direct Combustion	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90	Atmospheric Fluid Bed 90
Liquefaction/ Gasification	SRC II 260.43	SRC II 260.43	SRC II 260.43	Coalcon-New Cost 254 SRC II 260.43	Coalcon-New Cost 254 SRC II 260.43
Demonstration Plant Total Budget Req'ts. (millions)	$773	$732	$701	$1,484	$1,596

Table 4-2 Optimal Processes for the Five Best Portfolios

In addition, the demonstration scale funding requirements are given for the individual processes and for the portfolios.

Some of the processes were identified by name such as Slagging Lurgi, HYGAS and SRC II. Fuel gas processes were identified by letter such as Industrial B and Utility K. Letter coding was used because contract proposals for fuel gas demonstration plants were being evaluated while this report was in preparation. Atmospheric Flidized Bed is a general process type and Coalcon is the consortium developing the Clean Boiler Fuel demonstration plant.

The portfolios each have a different program structure indicating some-shat different program goals for the MFPM division. For example, Program 5 was defined to include one pipeline gas plant and one liquefaction/ gasification plant. Program 6 includes two pipeline gas plants and two liquefaction/gasification plants. Program 7 includes three fuel gas plants, while Program 10 has only one fuel gas plant. One of the factors which affects the MFPM program decision is the relative number of plants for each different energy product type.

The optimal process selections are stable in that the same processes are selected to meet the same product goals regardless of program structure. This characteristic of process stability provides ERDA the freedom of initially selecting an optimal core program based on a limited budget and then adding more processes as additional funding becomes available. The larger program will not only still be optimal but will have increased benefits and lower risk per dollar invested.

4.3 Sensitivity of Results

The selected processes have been determined by evaluating all possible process combinations for each program structure. In this way, the optimality of the selected processes (termed baseline portfolio) is guaranteed. Sensitivity of the portfolio results was determined by substituting one non-optimal process at a time into the baseline portfolio for each of the ten program structures. Sensitivity of the optimal processes to other candidate processes is shown in Figure 4-2 for the best program structure, Program 5. The results show the percentage change in (unnormalized) portfolio benefits and risks caused by the substitution of each non-optimal process. Symbols used to identify the processes are shown in the symbol table. In addition, the baseline processes are listed.

The origin of the axes in Figure 4-2 represents Program 5. The sensitivity axes divide the figure into four quadrants. It is significant that no points lie in the lower right hand or fourth quadrant. Any point in the fourth quadrant would mean that there was a group of processes with lower risk and higher benefits which, by definition, would violate the optimality of the baseline portfolio. The majority of points lie in the upper left or second quadrant. All of the portfolios represented by these points are completely dominated, i.e., these portfolios would have higher risk as well as lower benefits.

The points in the first and third quadrants represent portfolios where the benefits *and* risks would either be higher (quadrant I) or lower (quadrant III). In these quadrants, the risk attitude of the decisionmaker can be taken into

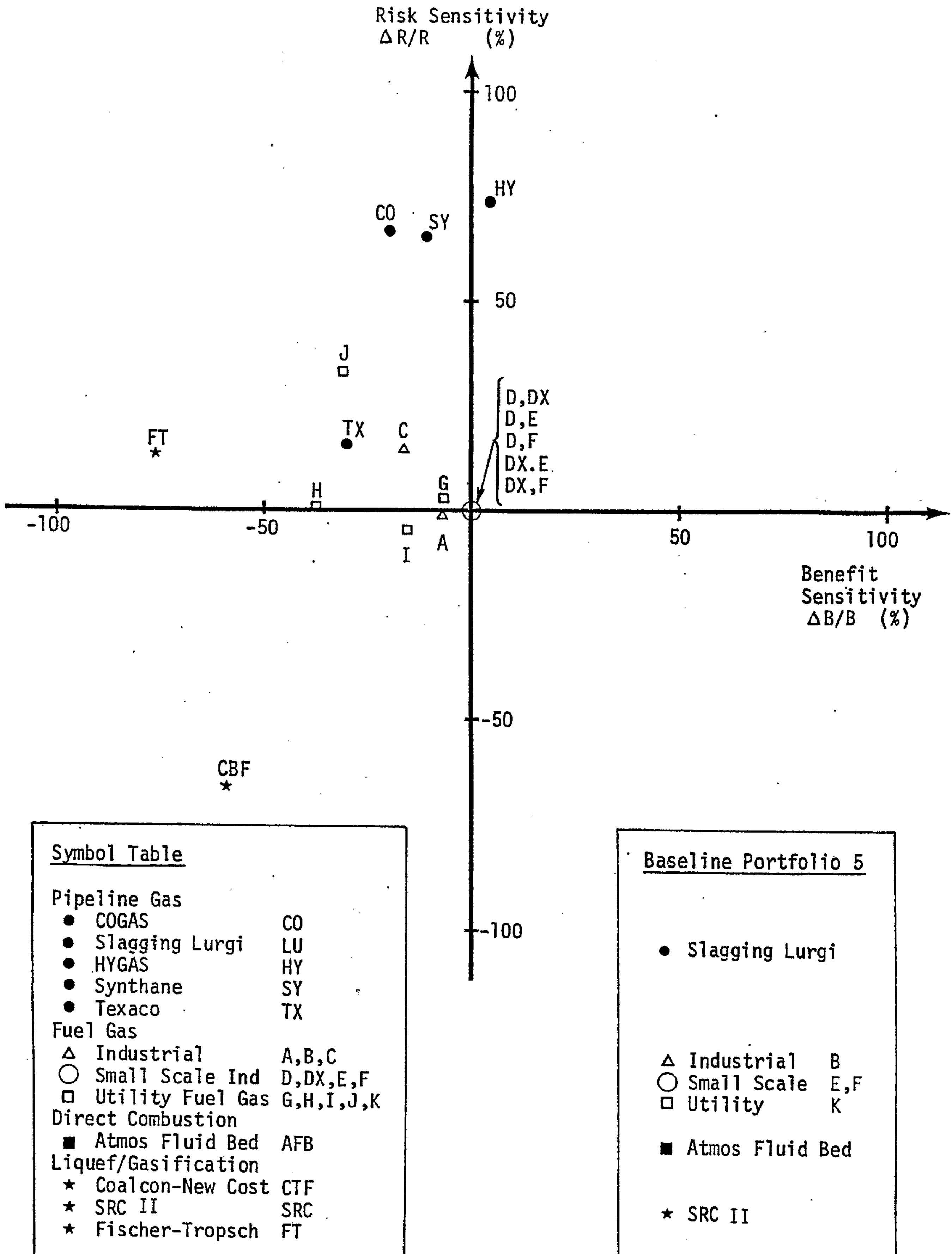

Figure 4-2 Sensitivity of Program 5 to Process Economics and Risk

account. For example, replacement of Slagging Lurgi by HYGAS would increase portfolio risk by nearly 75% while benefits would be increased by only 10%. In quadrant III, substitution of Coalcon for SRC II would reduce portfolio benefits by about 60% but would also reduce risk by about 60%.

In addition to illustrating the effect of process substitution in an absolute sense, Figure 4-2 can be used to illustrate sensitivity of baseline process selection due to process economic and risk data. For example, benefit results for the CBF and SRC II processes indicate that the economics of CBF are less favorable than the economics of SRC II by more than 50%. Alternatively, the economic data for SRC II could be 25% too high while the same data for CBF could be 25% too low and SRC II would still be the preferred process. On the other hand, portfolio results including Utility G are less than 10% different than protfolio results with Utility K. Since this small percentage difference may be due entirely to estimation uncertainty, the recommendation of Utility K as the baseline utility fuel gas process is not strongly supported.

The circle at the origin represents the portfolio sensitivities to small-scale fuel gas process substitutions. These processes are literally so small in scale that they do not affect the portfolio results significantly in any way.

Sensitivity of the portfolio results to product market price was tested. In order to test the sensitivity of the baseline portfolio results to different fuel prices, a different market price was assumed for two product types, fuel gas and liquefied product. First, the ten baseline portfolio results were calculated with \$3.00/MM BTU for fuel gas and \$4.00/MM BTU for the other products, pipeline gas and liquefied product. Then, the ten baseline portfolios were calculated with \$3.00/MM BTU for liquefied product and \$4.00/MM BTU for pipeline gas and fuel gas.

Portfolio benefits were somewhat reduced but, in general, the basic relationship between the baseline portfolios remained unchanged. The overall conclusion was that the recommended portfolios, 5, 7, 10, 6, and 8 were insensitive to different market price assumptions for the various coal conversion products.

4.4 Budget Analysis of Results

Figure 4-3 shows the total demonstration scale budget requirements for Programs 5, 7, 10, 6, and 8 and the portion of the budget allocated to each process. The size of each pie represents the budget level for a particular program and the color values represent the different product types. Each of these five portfolios is balanced in the sense that pipeline gas and liquefaction/gasification are nearly proportionately equivalent with fuel gas and direct combustion making up the remainder. Insights into the five recommended portfolios can be gained by analyzing these program budget requirements.

- Program 5 requires about \$775 million while Program 8 is more than twice as much -- \$1,484 million. Program 5 is less expensive than most of the other programs and still offers the best benefit/risk combination.

- The difference in funding levels between Program 5 and Program 7 is \$41 MM or about 5%. This difference is due to one process,

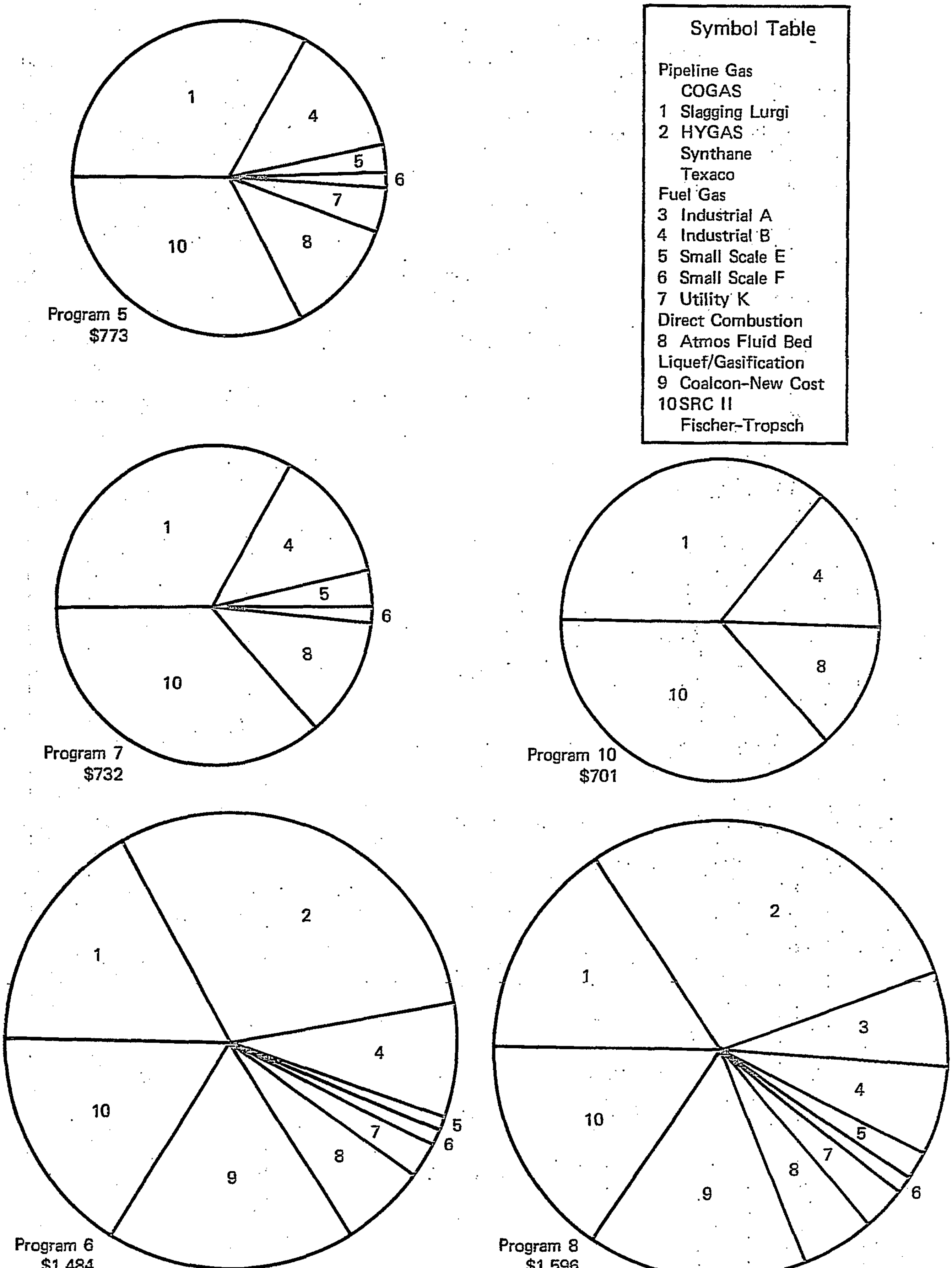

Figure 4-3 Budget Analysis - Baseline Portfolios 5, 7, 10, 6 and 8

Utility K. The additional experience to be gained in developing a utility fuel gas demonstration facility would seem to outweigh the incremental budget difference.

- The difference between Program 7 and the next best alternative, Program 10, is also about 5% and the same argument applies. In this case, Program 10 excludes both small scale industrial fuel gas plants as well as the utility fuel gas plant.

Programs 6 and 8 require approximately $1,500 MM for demonstration plant funding while Programs 5, 7, and 10 require about half as much or $750 MM. It may be desirable to fund a larger demonstration plant program, say $1,500 MM, for several reasons. First, in the smaller programs, only two processes (one pipeline gas and one liquefaction/gasification account for over 65% of the demonstration plant budget. Better program diversification may be achieved with a larger number of major processes. Second, there are sufficient process differences among the potential candidates being considered in this report and in other potential processes to warrant multiple funding of pipeline gas and liquefaction/gasification processes. A demonstration plant program of $1,500 MM could easily include two pipeline gas plants and two liquefaction/gasification plants. The diversification effects of multiple plant funding are highlighted in Section 3.4.3, Portfolio Risk and Diversification.

- Programs 6 and 8 are the preferred portfolios based on available data if a $1,500 MM demonstration plant program is desired. The programs are the same except for Industrial Fuel Gas A which is included in Program 8.

4.5 Recommended Processes

The five portfolios which are recommended as suitable candidates for funding are Programs 5, 7, 10, 6, and 8. Since baseline process selections are stable, several of the same coal conversion processes are in each of the recommended portfolios. Programs 5, 7, and 10 are identical except for the deletion of one or two processes relative to Program 5. Programs 6 and 8 are also identical except for one process. The primary difference is one of MFPM program orientation. In one case (Program 5, 7, or 10), a funding level of $750 MM is required and in the other case (Program 6 or 8), a funding level of $1,500 is required.

Baseline process stability, however, provides the possibility of initially funding an optimally selected core MFPM program based on a limited budget and then adding additional baseline processes as more funding becomes available. The resulting MFPM program would not only still be optimal but would have increased benefits and lower risk per dollar invested.

Recognizing that MFPM program decisions are made on a process-by-process basis, the recommended processes are listed by product type and in order of preference in Table 4-3. Since financial, contractual or political ramifications may invalidate the first choice processes, the second choice processes are also included.

Product Type	Processes
Pipeline Gas	Slagging Lurgi HYGAS
Industrial Fuel Gas	Industrial B Industrial A
Small Scale Industrial Fuel Gas	Small Scale E Small Scale F
Utility Fuel Gas	Utility K Utility G
Direct Combustion	Atmospheric Fluidized Bed
Liquefaction/Gasification	SRC II Clean Boiler Fuel

Table 4-3 Recommended Coal Conversion Processes

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