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THE BUILDING AND COMMUNITY SYSTEMS
RESOURCE-ALLOCATION MODEL
FINAL REPORT

Prepared for:

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SECTION I

INTRODUCTION

The Division of Buildings and Community Systems, (BCS) Office of Conservation and Solar Applications, Department of Energy is charged with the responsibility of developing energy saving technologies for non industrial applications. A very large number of projects are competing for BCS's limited development funds. Most of these have enough technical merit to justify study, but only a limited number can or should be developed. Some of the projects address technologies with limited marketability or probability of success. The energy savings from these is too small to justify government assistance. Other projects address very marketable technologies with a high probability of success. These are attractive to the public sector and would be developed even without government funds. BCS and EEA have developed the Threshold Evaluation Methodology to weed out projects of either sort.

The projects which survive this filtering process are all serious contenders for BCS funding. Two resource allocation issues remain — first, which projects to fund if it is not possible to support all of those which survive the filter and, second how many projects to fund in one area to maintain the duplication of effort at an optimum level. BCS has undertaken the development of a resource allocation methodology to answer these questions.

The problem of developing a technique for determining the optimum research portfolio has two general phases. In the first phase a methodology must be developed for evaluating one portfolio. Several important issues are involved -- for example, what is the impact of government research on research in the private sector and what measure should be used to assess portfolio worth. In addition to policy questions of this sort, there are basic mathematical problems. In particular, to design an algorithm for efficiently estimating the impact of competition between projects on the worth of the whole portfolio.

The second phase of the problem is more purely a technical problem. The number of possible portfolios is very large, and it is simply impossible to evaluate them all at any reasonable expense. The problem left is to develop a technique for isolating those portfolios which are clearly superior and clearly inferior so that the single portfolio evaluation methodology need only be applied to the former set. In the methodology developed for BCS a search technique was developed for this purpose.

This document presents the current state of the resource allocation methodology. It is organized along the lines of developmental phases discussed above. Section II deals with the technique used to evaluate a single portfolio. Section III describes the algorithm used to select the portfolios for evaluation. Subsequent sections describe the data used in the initial application of the methodology and the results obtained.

SECTION II

EVALUATING A SINGLE PORTFOLIO

Research projects can compete on two levels. They can compete for resources and in the market place. If several projects produce technologies which exclude each other's use, then the value of the success of more than one of the projects is not the sum of the values of each project competing separately. For example, if two water heaters are simultaneously developed and can be used in exactly the same markets, then only the better of the two will be used. The return of the research done on the poorer technology is zero and the value of the entire research package is the net value of the better technology less the cost of developing the poorer.

This sort of argument does not imply that there is no value in funding other than the single best project in each area. Research is speculative; it is not possible to determine which project will have the best results before the research is done. It is possible for a project which was not perceived as the best at the time of allocation, to produce a technology which is preferable to the ones which result from the more desirable projects. The worth of the suboptimal projects is a function of the likelihood of the product proving better than the higher ranked projects. For the simple case where "success" and "failure" are discrete quantities the value of funding suboptimal projects is as in the example below.

Example

Assume there are three projects, A, B, and C with probabilities of success P_A , P_B , and P_C respectively. Further assume that if the projects succeed, they will yield energy savings of V_A , V_B , and V_C respectively. If the projects fail, no energy savings will be accrued. The expected energy savings from each project is defined as the probability of success times the value of succeeding. That is, $P_A V_A$, $P_B V_B$, and $P_C V_C$. Assume, for discussion, that $P_A V_A > P_B V_B > P_C V_C$. That is, the savings expected from project A are greater than the savings which are expected from project B which are greater than the savings expected from project C. These conditions are summarized below.

Project	Success		Failure	
	Probability	Value	Probability	Value
A	P_A	V_A	$1-P_A$	0
B	P_B	V_B	$1-P_B$	0
C	P_C	V_C	$1-P_C$	0

Given: $P_A V_A > P_B V_B > P_C V_C$

- If only one project is to be funded, A is the best choice, since it will yield the highest energy savings. The expected value of the package is the value of only project A succeeding times the probability of A succeeding:

$$V_A P_A$$

- If two projects are to be funded, the best package is A&B. The expected value of the package is the expected value of A taken alone plus the value of project B succeeding alone times the probability of B succeeding and A failing: $V_A P_A + V_B P_B (1 - P_A)$.
 - If all projects are funded the expected value of the package is the expected value of A&B taken together plus the value of C succeeding times the probability of C only succeeding: $V_A P_A + V_B P_B (1 - P_A) + V_C P_C (1 - P_A) (1 - P_B)$.
-

This simple example shows the general value of funding more than one project to address a particular market. It also shows that when success and failure are discrete quantities with measurable probabilities, evaluation and ranking of portfolios is a fairly simple matter. This will not always be the case as is seen in the following section.

In the real world, research projects rarely have discrete outcomes. They do not simply succeed or fail -- there is a continuum of outcomes ranging from enormous net benefit to substantial loss. In projects which are oriented toward the development of a technology which must compete for a market, any outcome which makes the new technology less desirable than its alternatives is total failure, and it is not important just how much less desirable the new technology is. If however, the new technology is better, it is very important to know just how much better.

Ideally, the outcome of a project should be defined probabilistically. That is, the frequency distribution of the net

benefit determined by some estimation technique. The results would take the form shown in Figure II-1. Short of this ideal, the outcome should be expressed in terms of a vector of outcomes and an associated vector of probabilities as in the example Table II-1, which conveys basically the same information as in Figure II-1.

For this stage of the resource allocation methodology it was necessary to use data obtained from outside sources. The primary source was the data evaluation sheets used in the BCS Threshold Evaluation Methodology. Because these were developed for a purpose other than that of the resource allocation methodology they are less than ideal. In particular they consist of a very small number (2) point estimates with associated probabilities. Experience with the data has shown that these two points tend to be toward the extremes of the true distribution. Therefore, they were not used directly as input to the allocation methodology, but were used as the basis for estimating a continuous frequency distribution. This is not an ideal approach, but is adequate at this state.

The consequence of adopting a model of project benefit which recognizes that there are degrees of success is that portfolios can no longer be ranked on the basis of the expected worth of the individual projects. This means that it is necessary to evaluate a great many more portfolios in order to determine the optimum. Referring to the last example, the best portfolio of one project is still just A, but the best portfolio of two may be A&B, B&C, or A&C. In the continuous case it is necessary to evaluate four multi project portfolios rather than the two it was necessary to evaluate in the discrete case.

Figure II-1

CONTINUOUS FREQUENCY DISTRIBUTION
OF ENERGY SAVINGS

Table II-1

DISCRETE FREQUENCY DISTRIBUTION
OF ENERGY SAVINGS

<u>ENERGY SAVINGS</u>	<u>PROBABILITY</u>
0.	.00
0.5	.03
1.0	.13
1.5	.34
2.0	.34
2.5	.11
3.0	.01

In a small problem like the example, it is not difficult to exhaust all of the possibilities, but as the number of projects in a group increases, the number of portfolios which must be evaluated in an exhaustive search quickly exceeds any practical limit. The number of portfolios is related to the number of projects by $2^n - n - 1$ where n is the number of projects. At the rate of one portfolio per second, the time needed for computation exceeds one year when there are only 25 projects.

Clearly, exhaustive search is not a practical technique for portfolio ranking for any but the simplest cases. Section III of this report presents the techniques developed for the BCS resource allocation methodology to deal with the problem of dimensionality.

In allocating resources BCS is not concerned with the gross benefits due to funded projects. Instead, the measure of worth is the incremental benefit of the BCS project over the research which would be done without BCS intervention less the cost of research to BCS. Graphically, the shaded area is the net benefit.

The issue of which non-BCS results with which to compare each project is not a simple one. In the project evaluation task each BCS project is compared to itself. That is the benefit of one project given BCS support as compared to the benefit which would result from the same project had it been entirely to the private sector. For projects which do not compete for markets with other projects this is a good interpretation. It is not entirely correct when there is market interaction. Each project should be compared against the composite benefit of all non-BCS research in competitive technologies. For example, a BCS project in refrigerators

Figure II-2

NET BENEFIT

should be required to produce a better refrigerator than any which will result from the combined efforts of all interested private researchers which would be made in the absence of BCS interest.

This assumption which is conservative in its estimate of the impact of BCS research, was coupled to another, equally conservative assumption about the impact of BCS funding on development in the private sector. There has been a great deal of discussion whether government involvement in research will adversely or favorably effect the amount of research done in the private sector. There are good arguments for both sides, and in reality, either sort of impact may prevail in certain cases. In the resource allocation methodology, the most conservative assumption was made. That is, that any

government research in a specific market area will totally inhibit private sector involvement.

This assumption does not reflect EEA's judgment, but was made to insure that the benefits of the BCS program are not overstated. Certainly, the results of the resource allocation calculation are somewhat understated. A consequence of this assumption is that the results show that BCS should not enter an area with a minimal involvement. If this is done, the amount of private research inhibited is greater than the value of the BCS research. Consequently, the decision to undertake the effort shows a negative net benefit. If, however, the BCS effort is larger, the inhibitory effect can be overcome and the net benefit becomes positive.

If the assumption that government research inhibits the private sector is relaxed, the benefits attributable to the BCS effort will increase, but the ranking of the portfolios by either rate of return or total energy savings will not be changed.

Overall, the evaluation of a single portfolio follows the scheme of Figure II-3. First, the frequency distribution of the gross energy savings due to BCS research is estimated. Then, the value of the private sector program is evaluated for the case where there is government not doing research in the area and the case where the government is doing research in the area. Finally, the distributions of benefits for the separate projects are combined and the impact of government funding on the private sector subtracted to obtain the frequency distribution of net benefit. The expected net benefit can be calculated from this distribution.

Figure II-3

SINGLE PORTFOLIO EVALUATION SCHEME

SECTION III

EVALUATION OF ALTERNATE FUNDING LEVELS

As an input to the threshold evaluation methodology and to the resource allocation model, estimates are prepared of the rate of market penetration and the probability of technical success for projects at an assumed funding level. Generally, the assumed funding level is the BCS "current" level. Presumably, funding a project at some level other than the current will effect the outcome of the research. The effect of additional funds should be to either shorten the time needed for completion of a project or to increase the probability of success. Conversely, a lower funding level could delay completion or decrease the probability of success.

In order to obtain the maximum impact from a fixed budget it is necessary to develop estimates of the marginal effect of alternate funding strategies for each project and to tradeoff the value of additional funding between projects. Estimates of the impact of funding on project worth can be extremely complex or fairly simple. Ideally, each project would be studied separately. In some projects, tasks along the critical path^{1/} would not substantially accelerate completion. In others, the opposite conditions would prevail and the return on additional funds could be very large.

^{1/} Collicutt, R.E. and Reader, R.D., "O.R. Program for BISRA", Operational Research Quarterly, 18.3, pp. 219-242.

It is possible to build models of individual projects and to develop fairly precise measures of the relationship between funding level and project duration. It is more difficult to relate probability of success to funding level through some very credible work has been done in this area by the British Iron and Steel Research Association (BISRA).^{1/} Still, the expense in time and money of building individual models for each project would be quite large and inappropriate to this stage of development of the resource allocation model. Here, it is better to work with an aggregate model which describes typical rather than specific relationships.

The key input to the resource allocation methodology is the frequency distribution of net benefit. This is a derivative of with and without BCS market penetration curves and the probability of success. An acceleration of the date of first penetration shifts with BCS market penetration curve to the left as shown in Figure III-1. This represents an increase in the energy savings due to BCS. It is manifested in the distribution of net benefit curve as shown in Figure III-2.

An increase in probability of success does not effect the maximum possible net benefit, but it does increase the probability that a high level of benefit will be achieved. This increases the expected energy savings due to the research.

Separate models are necessary to simulate the impact of funding level on project duration and probability of success.

^{1/} Collcutt, R.H. and Reader, R.D., Ibid.

Figure III-1

ACCELERATION DUE TO ENHANCED FUNDING

Figure III-2

INCREASE IN BENEFIT DUE TO ENHANCED FUNDING

Work in both areas has been done by, again, BISRA. BISRA is a semi-public research agency whose purpose is to develop advanced metal manufacturing and working technologies for British industry. They have done extensive analysis of the worth and efficiency of their program over the past several years.

They have derived forms like those in Figures III-3 and III-4 to model, respectively, the relationship between the number of people involved in a project and the "work content" and the relationship between the number of people on a project and the probability of success. Their concept of work content relates directly to project duration. If a project can be completed in X weeks with one unit of work, it can be completed in X/2 weeks with two units of work. However, the level of effort needed to complete two units of work may be much more than twice the level of effort required to complete one unit of work due to decreasing returns to project scale.

For example, the project shown in Figure III-3 can be completed in one unit of time by one person. Adding on more people would raise the work content to 1.19 and hence reduce the duration of the project to $\frac{1.00}{1.19}$ units of time. In order to complete the project in half the time, a staff of 18 would be needed.

Work by BISRA has shown that the curve shown in Figure III-3, is a reasonable approximation for a typical research project. The relationship is given in normalized units of work. Assuming that number of researchers is a valid proxy for project costs, the BISRA relationship can be applied to BCS projects to estimate the impact of additional funding on project duration. Taking the change in project duration as a measure of the acceleration of the date of initial market penetration, the BISRA work can be used to directly relate BCS funding level to net

Figure III-3

WORK CONTENT VERSUS PROJECT SIZE

Figure III-4

PROBABILITY OF SUCCESS VERSUS PROJECT SIZE

energy savings. For the purposes of the resource allocation methodology acceleration was assumed to follow the relationship:

$$Y = 1.00 + .268 \ln(X)$$

where: Y = the total work content of
the project

X = relative size of the project

Note that, while this relationship is probably an adequate description of the duration of a research project, there is no basis for assuming that it is applicable to a demonstration project.

In addition, or in place of accelerating the completion of a project enhanced funding can increase the probability that a project will succeed. The relationship shown in Figure III-4 is of a form theoretically derived by BISRA and calibrated empirically corresponding to their research projects. Assuming that a similar relationship holds for BCS projects, the relationship was reconstituted in terms of funding level to give the following formula for probability of success as a function of funding level.

$$Y = -.01575 + .48552 \ln(X)$$

where: Y = the probability of success

X = project size

In the application of the resource allocation methodology included in this report, it was assumed that enhanced funding would only effect probability of success. The reasoning is that the estimates of market penetration which form part of the resource allocation data base generally show initial penetration in the very near future, and there is very little potential for acceleration. As the data is upgraded, the

acceleration impact of enhanced funding can be phased back into the analysis.

The models of funding level impact used in the analysis are simple and reasonable, but more work needs to be done in this area. The BISRA work which verified the theoretical forms for use with BISRA projects should be repeated for BCS projects and any discrepancies between the theoretical and the actual should be studied.

SECTION IV

SEARCH TECHNIQUE

The search technique builds the optimal overall portfolio by sorting in three different stages. Initially the projects are ranked individually within the group. Secondly, a portfolio is formed for each group such that the addition of a project to the portfolio results in the optimal portfolio value at that level. Finally a sort across groups is initiated that results in an optimal overall portfolio being formed.

The convention adopted for this report will be project (group, funding level) so that $A(1,2)$ represents project A in group 1 at the second funding level. Brackets, $\{ \}$, denotes a portfolio. For purposes of discussion let us consider group α containing projects A, B, C and D. A is defined at funding levels 1, 2 and 3, B at funding levels 1 and 2, C at funding level 1 only and D at funding levels 1, 2, 3 and 4.

The initial search is done on the group level to determine the single best project. For each project in the group the expected net benefit of the project, at its first funding level is calculated. The projects are then ranked according to their expected net benefits. Assume for group α the projects are ranked as follows: $A(\alpha,1)$, $B(\alpha,1)$, $C(\alpha,1)$ and $D(\alpha,1)$.

The second search is also done on the group level to determine the optimal portfolio of projects for the group at any point. Each successive portfolio replaces the previous portfolio and represents the highest portfolio value at that point.

Successive portfolios are formed by adding a new project from the group or by replacing an old project at a new funding level from the group to the previous portfolio. This is repeated until all projects at all funding levels have been added.

After the projects have been ranked according to their expected net benefit, the project with the highest expected net benefit is chosen as the first portfolio. To determine the second portfolio, a project at its present funding level is added to the first portfolio and the net benefit is calculated. This is done for all of the projects in the group each at its present funding level. The portfolio with the largest net benefit becomes the second portfolio. Successive portfolios are calculated in the same manner. If a project has not been in the portfolio previously it is simply added to the portfolio. If however, a project is already in the portfolio it can be replaced by itself at a higher funding level. When all of the projects at each funding level have been added the search is finished.

In group α , project $A(\alpha,1)$ had the largest expected net benefit therefore portfolio one will be $\{A(\alpha,1)\}$. To determine the second portfolio we consider the following portfolios: $\{A(\alpha,2)\}$, $\{A(\alpha,1), B(\alpha,1)\}$, $\{A(\alpha,1), C(\alpha,1)\}$ and $\{A(\alpha,1), D(\alpha,1)\}$. Assume portfolio $\{A(\alpha,1), D(\alpha,1)\}$ has the highest net benefit of the four portfolios considered and hence becomes the second portfolio. $D(\alpha,1)$ is a new project to the portfolio and can be simply added to the portfolio. In determining the third portfolio we consider the following portfolios: $\{A(\alpha,2), D(\alpha,1)\}$, $\{A(\alpha,1), D(\alpha,1), B(\alpha,1)\}$, $\{A(\alpha,1), D(\alpha,1), C(\alpha,1)\}$ and $\{A(\alpha,1), D(\alpha,2)\}$. Assume portfolio $\{A(\alpha,2), D(\alpha,1)\}$ has the largest net benefit hence it becomes the third portfolio. In this case project A at the

second funding level has replaced A at the first funding level. To find the fourth portfolio we precede in the same manner considering portfolios: $\{A(\alpha,3) D(\alpha,1)\}$, $\{A(\alpha,2) D(\alpha,1) B(\alpha,1)\}$, $\{A(\alpha,2) D(\alpha,1) C(\alpha,1)\}$ and $\{A(\alpha,2) D(\alpha,2)\}$. Assume $\{A(\alpha,2) D(\alpha,1) C(\alpha,1)\}$ has the highest net benefit of the four portfolios, hence it is our fourth portfolio. In defining group α we stated that project C existed only at funding level one. When we consider projects in the fifth funding level $C(\alpha,2)$ is not a possibility. We repeat this search technique until all the projects at all funding levels have been considered. For group α project A is at 3 funding levels, project B at 2 funding levels, project C at 1 funding level and project D at 4 funding levels resulting in 10 portfolios. Figure IV-1 shows how the portfolio of group α was built.

The final search is initiated after all of the groups have been ranked at the two previous stages. The result is an overall portfolio, similar to the group portfolios, but containing projects from all the groups. The portfolio at any point represents the optimal overall research portfolio.

As the group portfolios were formed the marginal rate of return of the current project added to the portfolio and the cumulative rate of return of the new portfolios were calculated. The cumulative and marginal rates of return will be used in selecting projects to be added to the overall portfolio. Each group also has a subgroup of "core projects". The "core projects" are those projects in the group portfolio that have the maximum cumulative rate of return for the group.

When deciding what project is to be added to the overall portfolio next we consider the current project in each group. If the group being considered is not presently in the overall

PREFACE TO FIGURE IV-1

Figure IV-1 is a simple decision tree. The lone portfolio is the current portfolio. The current portfolio was chosen out of the portfolios to consider. The underscored portfolio in the portfolios to consider is the next portfolio to be chosen. The vertical lines represent the possibilities to be considered at any portfolio level. The vertical line with the arrowhead indicates the path chosen.

Figure IV-1
DECISION TREE FOR A GROUP PORTFOLIO

portfolio, we consider the "core projects" and its cumulative rate of return. If however, the group is in the overall portfolio we simply consider the first project from the group portfolio that hasn't yet been added to the overall portfolio and the marginal rate of return of that project. For each group we consider either the core portfolio and its cumulative rate of return or the current project and its marginal rate of return. The current project or core projects with the largest rate of return is chosen to be added to the overall portfolio. This is repeated until all the projects at all funding levels from all groups have been added to the overall portfolio.

If the group portfolio that is to be added to the overall portfolio contains a new project it is simply added to the overall portfolio. However, if the group portfolio has an old project at an enhanced funding level it replaces itself at the lower funding level in the overall portfolio.

It must be remembered that project ranking within a group is important. It is impossible to consider a project in the group portfolio unless all projects prior to it have been added to the overall portfolio. The only exception being when we initiate a group and we consider its "core portfolio". The "core projects" must be considered together and can not be taken individually.

As an example consider three groups α , β , ψ . Assume they have been ranked at the two previous stages as described earlier. The results of the three groups are summarized in Table IV-1, Table IV-2 and Table IV-3.

The first step in building the overall portfolio is to consider the "core portfolio" and its cumulative rate of return

TABLE IV-1
SUMMARY OF GROUP α

<u>Portfolio</u>	<u>Marginal Rate of Return</u>	<u>Cumulative Return</u>
$\{A(\alpha, 1)\}$	6.8	6.8
$\{A(\alpha, 1) \ D(\alpha, 1)\}$	364.0	18.9
$\{A(\alpha, 2) \ D(\alpha, 1)\}$	72.8	23.8
$\{A(\alpha, 2) \ D(\alpha, 2) \ C(\alpha, 1)\}$	15.2	22.8
$\{A(\alpha, 2) \ D(\alpha, 2) \ C(\alpha, 1)\}$	- 1.85	14.2
$\{A(\alpha, 2) \ D(\alpha, 2) \ C(\alpha, 1)\}$	0.0734	11.7
$\{A(\alpha, 2) \ D(\alpha, 2) \ C(\alpha, 1) \ B(\alpha, 1)\}$	0.525	10.4

core
portfolio

TABLE IV-2
SUMMARY OF GROUP β

<u>Portfolio</u>	<u>Marginal Rate of Return</u>	<u>Cumulative Return</u>	
$\{G(\beta, 1)\}$	35.5	35.5	
$\{G(\beta, 1) \cup H(\beta, 1)\}$	284.7	56.2	core portfolio
$\{G(\beta, 2) \cup H(\beta, 1)\}$	39.5	44.9	
$\{G(\beta, 3) \cup H(\beta, 1)\}$	40.2	44.6	
$\{G(\beta, 3) \cup H(\beta, 1) \cup J(\beta, 1)\}$	7.82	37.1	

TABLE IV-3
SUMMARY OF GROUP ψ

<u>Portfolio</u>	<u>Marginal Rate of Return</u>	<u>Cumulative Return</u>	
$\{K(\psi, 1)\}$	46.4	46.4	core portfolio
$\{K(\psi, 2)\}$	18.2	26.9	
$\{K(\psi, 2) \cup L(\psi, 1)\}$	4.4	23.5	
$\{K(\psi, 2) \cup L(\psi, 2)\}$	1.17	17.6	
$\{K(\psi, 2) \cup L(\psi, 3)\}$	0.2	11.3	

for each group since all groups are new to the overall portfolio. For group α $\{A(\alpha,2) D(\alpha,1)\}$ is the core portfolio and 23.8 is the cumulative rate of return. For group β , $\{G(\beta,1) H(\beta,1)\}$ is the core portfolio and 56.2 the cumulative rate of return. For group ψ $\{K(\psi,1)\}$ is the core portfolio and 46.4 is the cumulative rate of return. $\{G(\beta,1) H(\beta,1)\}$ has the largest cumulative rate of return and hence is the first to be added to the overall portfolio. To determine the next project to be added we repeat the same procedure. Group α has not been added to the overall portfolio yet, so we still consider its core portfolio and cumulative rate of return $\{A(\alpha,2) D(\alpha,1)\}$, 23.8. Group β has been added to the overall portfolio, so we consider the next portfolio in the group and its marginal rate of return $\{G(\beta,2) H(\beta,1)\}$ 39.5. For group ψ we must consider the core portfolio and cumulative rate of return $\{K(\psi,1)\}$ 46.4. Group ψ has the largest rate of return hence $\{K(\psi,1)\}$ is the second group portfolio to be added to the overall portfolio. If we were to follow the search another step we would consider: $\{A(\alpha,2) D(\alpha,1)\}$ 23.8; $\{G(\beta,2) H(\beta,1)\}$ 39.5; $\{K(\psi,2)\}$ 18.2. Obviously $\{G(\beta,2) H(\beta,1)\}$ has the greatest rate of return and hence it will be added to the overall portfolio. $\{G(\beta,1) H(\beta,1)\}$ is already in the overall portfolio so $G(\beta,2)$ simply replaces $G(\beta,1)$. The decision tree for the building of the overall portfolio is shown in Figure IV-2. The procedure is continued until all group portfolios have been added to the overall portfolio, in this example the search technique would repeat sixteen times.

The search technique sorts over three stages. First the individual projects are ranked within the group by expected net benefits. Secondly, group portfolios are built adding projects in the group to the portfolio one at a time. Lastly, an overall portfolio is created by adding core portfolios or group portfolios to the overall portfolio.

PREFACE TO FIGURE IV-2

Figure IV-2 is a simple decision tree. The lone portfolio is the current portfolio. The current portfolio was chosen out of the portfolios to consider. The underscored portfolio in the portfolios to consider is the next portfolio to be chosen. The vertical lines represent the possibilities to be considered at any portfolio level. The vertical line with the arrowhead indicates the path chosen.

Figure IV-2
DECISION TREE FOR THE OVERALL PORTFOLIO

SECTION V

SUMMARY OF RESULTS

Table V-1 gives the overall portfolio described in Section IV. Each entry contains rank, project number, funding level, group number, research cost of addition, net benefit, marginal benefit, marginal rate of return and cumulative rate of return. If an entry or entries is enclosed in a rectangle it indicates that those projects represent the core portfolio for the group. Projects in the core portfolio have the same rank.

The research cost of addition is the additional cost of the current project. It is measured in millions of 1977 dollars. The net benefit represents the cumulative energy cost savings of the portfolio attributable to DOE. Both research costs and energy savings due to private funding have been deducted. It is measured in millions of 1977 dollars discounted at 10 percent per year. The marginal benefit is the energy cost savings of the current project attributable to DOE, also measured in millions of 1977 dollars discounted at 10 percent per year. The marginal rate of return is defined as the marginal benefit divided by the research cost of addition. The cumulative rate of return is defined as net benefit divided by total research cost.

Table V-2 lists the projects in numerical order with their group number. An entry in the funding level column indicates the rank of that project, at the given funding level, in the overall portfolio Table V-1. Looking at the first entry of

Table V-2 we can see that project 4 of group 2 at the first funding level is ranked number 21 in Table V-1. If an entry is followed by an asterisk, *, it indicates the project at that funding level is a member of the core portfolio for the group. If the entry is underlined it indicates that the marginal benefit for the project at that funding level is negative. If there is no entry for a project at a given funding level the implication is that the project isn't defined at that funding level.

TABLE V-1

FINAL RANKING OF PROJECTS
(Overall Portfolio)

RANK	PROJ	LR	OPP	ASS COST OF ADD	NET BEN	MARG BEN	MARG ROR	CUM ROR
1	67	1	3	.110	125.9	125.9	1144.2	1144.2
2	67	2	3	.999	1023.4	902.6	902.6	926.6
3	238	1	4	.225	1070.9	42.5	139.9	802.1
3	238	2	4	.309	1162.2	91.3	436.4	752.7
4	233	1	5	1.25	1354.8	192.6	142.6	468.1
4	299	1	5	.125	1448.0	93.2	745.9	479.6
4	233	2	5	.351	1596.1	148.1	421.8	472.6
5	70	1	1	1.15	1440.4	-155.7	-125.4	315.7
5	212	1	1	.240	1536.3	146.5	510.3	333.4
5	240	1	1	1.24	1903.1	316.3	256.1	317.4
5	70	2	1	.403	1970.5	57.4	157.5	308.0
5	70	3	1	.046	1977.9	7.35	159.9	306.9
6	273	1	5	1.11	2036.0	58.1	52.5	263.5
6	272	1	5	.925	2141.6	105.6	114.2	252.7
7	158	1	7	.700	2181.1	39.5	56.4	237.7
8	236	1	2	1.67	2240.3	59.2	35.5	206.5
8	150	1	2	.075	2261.7	21.3	294.7	207.1
9	236	2	2	.434	2278.9	17.2	39.6	200.7
10	236	3	2	.100	2282.9	4.03	40.2	199.3
11	303	1	6	.099	2286.2	3.32	33.2	197.8
12	31	1	3	5.71	2324.9	38.7	6.77	134.7
12	155	1	3	.200	2397.7	72.3	364.0	137.3
12	155	2	3	.500	2441.4	43.7	72.8	135.1
13	298	1	1	.650	2454.0	12.6	19.4	131.1
14	158	2	7	2.35	2495.3	42.8	15.2	118.5
15	272	2	5	.046	2497.6	.799	17.3	119.3
16	83	1	8	.820	2510.0	12.5	15.2	114.4
17	251	1	6	1.0	2523.7	13.6	13.6	110.0
18	235	1	4	.300	2526.5	2.77	9.25	108.7
19	235	2	4	.204	2528.7	2.22	10.9	107.9
20	297	1	5	1.02	2537.2	8.51	9.34	103.7
21	4	1	2	.530	2541.7	4.54	7.33	101.5
22	298	2	1	.097	2542.3	.592	5.07	101.1
23	271	1	5	.925	2547.8	5.50	5.94	97.8
24	62	1	9	11.1	2590.2	42.4	3.24	66.1
24	62	2	9	2.49	2632.3	42.0	15.9	63.2
25	72	1	3	1.46	2639.8	7.48	5.14	61.2
26	73	1	7	.560	2642.3	2.48	4.43	50.5
27	297	2	5	.449	2643.9	1.51	3.60	59.9
28	251	2	5	.100	2644.2	.299	2.39	59.3
29	251	3	5	.380	2647.0	2.35	1.24	58.7
30	56	1	9	5.5	2658.3	11.3	2.01	52.4
31	72	2	3	.102	2658.5	.195	1.32	52.3
32	81	2	8	5.20	2668.1	9.62	1.35	47.7
33	73	2	7	1.27	2669.5	1.39	1.09	46.6
34	303	2	5	.300	2669.7	.232	.775	45.4
35	237	1	4	.325	2669.9	.178	.461	46.1
36	63	1	9	10.5	2674.7	4.30	.452	39.0
37	63	2	9	7.36	2706.3	11.6	4.02	35.4
38	53	3	9	2.87	2714.3	3.05	2.31	34.2
39	271	2	5	.046	2714.4	.015	.327	34.2
40	58	1	5	1.50	2715.3	.916	.254	32.7
41	23	2	2	2.50	2715.5	.191	.073	31.7
42	300	1	1	.450	2715.4	-.035	-.073	31.6
43	73	3	7	2.70	2714.3	-.611	-.226	30.6
44	179	1	9	10.9	2710.1	-4.77	-.433	27.2
45	250	1	5	.560	2709.3	-.323	-.489	27.0
46	33	3	3	1.70	2708.9	-.391	-.525	26.6
47	58	2	5	.238	2708.7	-.158	-.348	26.5
48	300	2	1	.050	2708.7	-.035	-.705	26.5
49	304	1	1	.350	2708.0	-.642	-.755	26.3
50	55	1	9	15.7	2694.3	-13.2	-.343	22.7
51	51	1	9	10.9	2695.2	-9.53	-.337	22.7
52	51	2	9	2.91	2693.7	-11.52	-.513	22.2
53	302	1	5	.510	2693.1	-.564	-.325	20.1
54	304	2	1	.051	2693.1	-.048	-.343	20.1
55	304	3	1	.132	2693.0	-.091	-.395	20.1
56	302	2	5	.099	2692.9	-.073	-.356	20.1
57	53	1	6	1.03	2681.3	-1.04	-.356	19.3
58	75	1	3	3.04	2674.9	-7.35	-.938	18.8
59	75	2	3	.345	2673.9	-.959	-.994	18.6
60	230	1	3	.350	2672.5	-.350	-1.00	18.6
61	230	2	3	.551	2671.9	-.551	-1.00	18.5
62	230	3	3	.199	2671.7	-.199	-.307	18.0
63	230	4	3	.001	2671.4	-.301	-1.00	18.4

TABLE V-2
RANKED ORDER BY PROJECT NUMBER AND FUNDING LEVEL

<u>Project</u>	<u>Group</u>	<u>FUNDING LEVEL</u>				
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
4	2	21				
53	6	<u>57</u>	<u>64</u>			
58	6	40	<u>47</u>			
61	9	<u>51</u>	<u>52</u>			
62	9	24*	24*			
63	9	36	37	38		
65	9	<u>50</u>				
66	9	30				
67	3	1*	2			
70	1	5*	5*	5*		
72	3	25	31			
73	7	26	33	<u>43</u>		
75	8	<u>58</u>	<u>59</u>			
81	8	12*	32			
83	8	16	41	<u>46</u>		
158	7	7*	14			
160	2	8*				
165	8	12*	12*			
179	9	<u>44</u>				
212	1	5*				
230	3	<u>60</u>	<u>61</u>	<u>62</u>	<u>63</u>	
233	6	4*	4*			
235	4	18	19			
236	2	6*	9	10		
237	4	35				
238	4	3*	3*			
240	1	5*				

TABLE V-2.
Continued

<u>Project</u>	<u>Group</u>	<u>FUNDING LEVEL</u>				
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
250	6	<u>45</u>				
251	6	17	28	29		
271	6	23	39			
272	5	6*	15			
273	5	6*				
297	6	20	27			
298	1	13	22			
299	6	4*				
300	1	<u>42</u>	<u>48</u>			
302	6	<u>53</u>	<u>56</u>			
303	6	11	34			
304	1	<u>49</u>	<u>54</u>	<u>55</u>		

* Indicates project at that funding level is a core project

- Indicates project at that funding level has a negative marginal rate of return.

SECTION VI

GROUP RESULTS

Tables VI-1 to VI-9 are the group portfolios for each group. An entry contains the project number, funding level, group number, research cost of addition net benefit, marginal benefit, marginal rate of return, cumulative rate of return. If a project or projects is enclosed in a rectangular box it indicates that those projects represent the core portfolio for the group.

The research cost of addition is the additional cost of the current project. It is measured in millions of 1977 dollars. The net benefit represents the cumulative energy cost savings of the portfolio attributable to DOE. Both research costs and energy savings due to private funding have been deducted. It is measured in millions of 1977 dollars discounted at 10 percent per year. The marginal benefit is the energy cost savings at the current project attributable to DOE, also measured in millions of 1977 dollars discounted at 10 percent per year. The marginal rate of return is defined as the marginal benefit divided by the research cost at addition. The cumulative rate of return is defined as net benefit divided by total research cost. The non-DOE benefit represents the energy cost savings attributable to private funding.

TABLE VI-1

GROUP PORTFOLIO FOR GROUP 1

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM ROR</u>
70	1	1	1.15	-155.7	-155.7	-135.4	-135.4
212	1	1	0.240	- 9.28	146.5	610.2	- 6.7
240	1	1	1.24	307.0	316.3	256.1	117.0
70	2	1	0.403	374.4	67.4	167.5	123.7
70	3	1	0.046	381.8	7.35	159.9	124.2
298	1	1	0.650	394.4	12.6	19.4	105.9
298	2	1	0.097	395.0	0.592	6.07	103.4
300	1	1	0.450	394.9	- 0.035	- 0.078	92.5
300	2	1	0.050	394.9	- 0.035	- 0.705	91.4
304	1	1	0.850	394.2	- 0.642	- 0.755	76.2
304	2	1	0.051	394.2	- 0.048	- 0.943	75.5
304	3	1	0.102	394.1	- 0.091	- 0.895	74.0

core
portfolio

The non-DOE benefit for group 1 is 972.3

TABLE VI-2
GROUP PORTFOLIO FOR GROUP 2

<u>PROJ</u>	<u>PL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM ROR</u>	
236	1	2	1.67	59.2	59.2	35.5	35.5	core portfol
160	1	2	0.075	80.6	21.3	284.7	46.2	
236	2	2	0.434	97.8	17.2	39.6	44.9	
236	3	2	0.100	101.3	4.03	40.2	44.7	
4	1	2	0.580	106.4	4.54	7.83	37.2	

The non-DOE benefit for group 1 is 266.1

TABLE VI-3
GROUP PORTFOLIO FOR GROUP 3.

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG BOR</u>	<u>CUM ROR</u>	
67	1	3	0.110	125.9	125.9	1144.2	1144.2	core portfo
67	2	3	0.999	1028.4	902.6	902.6	926.6	
72	1	3	1.46	1035.9	7.48	5.14	403.9	
72	2	3	0.102	1036.1	0.195	1.92	388.5	
230	1	3	0.350	1035.7	- 0.350	- 1.00	343.3	
230	2	3	0.651	1035.1	- 0.651	- 1.00	282.2	
230	3	3	0.199	1034.9	- 0.199	- 0.999	267.6	
230	4	3	0.301	1034.6	- 0.301	- 0.100	248.2	

The non-DOE benefit for group 3 is 584.0

TABLE VI-4

GROUP PORTFOLIO FOR GROUP 4

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM ROR</u>	
238	1	4	0.225	42.5	42.5	138.9	138.9	core portfol
238	2	4	0.209	133.8	91.3	436.4	308.2	
235	1	4	0.300	136.6	2.77	9.25	186.1	
235	2	4	0.204	138.8	2.23	10.9	148.0	
237	1	4	0.385	139.0	0.178	0.461	105.1	

The non-DOE benefit for group 4 is 32.7

TABLE VI-5
GROUP PORTFOLIO FOR GROUP 5

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES. COST</u> <u>OF ADD</u>	<u>NET</u> <u>BEN</u>	<u>MARG</u> <u>BEN</u>	<u>MARG</u> <u>ROR</u>	<u>CUM</u> <u>ROR</u>	
273	1	5	1.11	58.1	58.1	52.5	52.5	core portfol.
272	1	5	0.925	163.6	105.6	114.2	80.5	
272	2	5	0.046	164.6	0.799	17.3	79.1	

The non-COE benefit for group 5 is 104.0

TABLE VI-6
GROUP PORTFOLIO FOR GROUP 6

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG FOR</u>	<u>CUM ROR</u>	
233	1	6	1.35	192.6	192.6	142.6	142.6	core port- folio
299	1	6	0.125	285.8	93.2	745.9	193.8	
233	2	6	0.351	433.9	148.1	421.8	237.6	
303	1	6	0.099	437.2	3.32	33.2	227.0	
251	1	6	1.00	450.8	13.6	13.6	154.1	
297	1	6	1.02	459.3	8.51	8.34	116.4	
271	1	6	0.925	464.8	5.50	5.94	95.4	
297	2	6	0.449	466.4	1.61	3.60	87.7	
251	2	6	0.100	466.7	0.299	2.99	86.1	
251	3	6	0.880	469.6	2.85	3.24	74.5	
303	2	6	0.300	469.8	0.232	0.775	71.2	
271	2	6	0.046	469.8	0.015	0.327	70.7	
58	1	6	3.60	470.8	0.916	0.254	45.9	
250	1	6	0.660	470.4	-0.323	-0.489	43.1	
58	2	6	0.288	470.3	-0.158	-0.548	42.0	
302	1	6	0.610	469.7	-0.564	-0.925	39.8	
302	2	6	0.098	469.6	-0.093	-0.956	39.5	
53	1	6	1.08	468.6	-1.04	-0.966	36.1	
53	2	6	1.21	466.4	-2.21	-1.82	32.9	

The non-DOE benefit for group 6 is 470.1

TABLE VI-7
GROUP PORTFOLIO FOR GROUP 7

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM ROR</u>	
158	1	7	0.700	39.5	39.5	56.4	56.4	core
158	2	7	2.35	82.3	42.8	18.2	27.0	portfoli
73	1	7	0.560	84.7	2.48	4.43	23.5	
73	2	7	1.28	86.1	1.39	1.09	17.6	
73	3	7	2.70	85.5	-0.611	-0.226	11.3	

The non-DCE benefit for group 7 is 29.3

TABLE VI-8
GROUP PORTFOLIO FOR GROUP 8

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM ROR</u>	core portfolio
81	1	8	5.71	38.7	38.7	6.77	6.77	
65	1	8	0.200	111.5	72.8	364.0	18.9	
65	2	8	0.600	155.2	43.7	72.8	23.8	
83	1	8	0.820	167.7	12.5	15.2	22.9	
81	2	8	5.20	177.3	9.62	1.85	14.2	
83	2	8	2.60	177.5	0.191	0.073	11.7	
83	3	8	1.70	176.6	-0.891	-0.525	10.5	
75	1	8	8.04	168.6	-7.95	-0.988	6.78	
75	2	8	0.965	167.7	-0.959	-0.994	6.49	

The non-DOE benefit for group 8 is 108.5

TABLE VI-9
GROUP PORTFOLIO FOR GROUP 9

<u>PROJ</u>	<u>FL</u>	<u>GRP</u>	<u>RES COST OF ADD</u>	<u>NET BEN</u>	<u>MARG BEN</u>	<u>MARG ROR</u>	<u>CUM FOR</u>	
62	1	9	13.1	42.4	42.4	3.24	3.24	core portfolio
62	2	9	2.49	84.5	42.0	16.9	5.42	
66	1	9	5.60	95.7	11.3	2.01	4.52	
63	1	9	10.6	100.5	4.80	0.452	3.16	
63	2	9	7.86	132.1	31.6	4.02	3.33	
63	3	9	2.87	140.2	8.05	2.81	3.30	
179	1	9	10.9	135.5	- 0.047	- 0.433	2.54	
65	1	9	15.7	122.2	-13.2	- 0.843	1.77	
61	1	9	10.9	112.6	- 9.63	- 0.887	1.41	
61	2	9	2.93	111.1	- 1.52	- 0.519	1.34	

The non-DOE benefit for group 9 is 32.8

SECTION VII

SUMMARY OF INITIAL DATA

Table VII-1 lists the projects in numerical order with their group number. In addition to the project and group number, an entry contains probability of success, energy cost savings without DOE funding, energy cost savings with DOE funding and the research cost of the project. Benefit with and without DOE is measured in millions of 1975 dollars discounted at 10 percent per year. The research cost is also in millions of 1975 dollars.

Table VII-2 also lists the projects in numerical order with their group number. An entry at a funding level indicates the ratio of the research costs at the enhanced funding level versus the research cost shown in Table VII-1. All projects at the first funding level have a funding level ratio of one. If a project has no entry at a funding level it indicates the project is not defined at that funding level.

TABLE VII-1
INPUT DATA BY PROJECTS

<u>PROJECT</u>	<u>GROUP</u>	<u>PROB.OF SUCCESS</u>	<u>BEN W/O DOE</u>	<u>BEN W/O DOE</u>	<u>RES.COST</u>
4	2	0.43	78.9	105	0.580
53	6	0.49	14.3	19	1.08
58	6	0.42	138.0	167	3.6
61	9	0.08	19.4	81	10.9
62	9	0.12	352.6	1473	13.1
63	9	0.09	105.8	442	10.6
65	9	0.02	106.1	443	15.7
66	9	0.17	57.2	239	5.6
67	3	0.44	2424.5	3227	0.110
70	1	0.5	2457.6	3271	1.15
72	3	0.34	487.7	714	1.455
73	7	0.39	27.4	71	0.560
75	8	0.40	13.6	57	8.04
81	8	0.56	81.2	546	5.71
83	8	0.72	49.8	229	0.820
158	7	0.52	103.7	269	0.700
160	2	0.43	175.8	234	0.075
165	8	0.52	351.6	468	0.200
179	9	0.18	35.0	146	10.9
212	1	0.5	790.3	1059.2	0.240
230	3	0.38	9.31	15	0.350
233	6	0.29	2843.2	4579	1.35
235	4	0.23	32.1	47	0.300
236	2	0.62	792.6	1055	1.67
237	4	0.18	10.6	17	0.385
238	4	0.20	290.7	754	0.225
240	1	0.5	1828.7	2434	1.235

TABLE VII-1
continued

<u>PROJECT</u>	<u>GROUP</u>	<u>PROB. OF SUCCESS</u>	<u>BEN W/O DOE</u>	<u>BEN W/O DCE</u>	<u>RES. COST</u>
250	6	0.20	66.1	80	0.660
251	6	0.39	157.0	190	1.0
271	6	0.37	61.7	160	0.925
272	5	0.5	247.5	642	0.925
273	5	0.5	251.8	653	1.108
297	6	0.37	110.5	178	1.02
298	1	0.5	244.64	394	0.650
299	6	0.37	166.6	696	0.125
300	1	0.5	14.05	17	0.450
302	6	0.37	6.83	11	0.610
303	6	0.37	15.0	20	0.100
304	1	0.5	24.79	33	0.850

TABLE VII-2
FUNDING RATIOS BY PROJECT

<u>PROJECT</u>	<u>GROUP</u>	<u>FUNDING LEVEL</u>				
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
4	2	1				
53	6	1	1.12			
58	6	1	1.08			
61	9	1	1.27			
62	9	1	1.19			
63	9	1	1.74	2.01		
65	9	1				
66	9	1				
67	3	1	10.09			
70	1	1	1.35	1.39		
72	3	1	1.07			
73	7	1	3.28	8.10		
75	8	1	1.12			
81	8	1	1.91			
83	8	1	4.17	6.24		
158	7	1	4.36			
160	2	1				
165	8	1	4			
179	9	1				
212	1	1				
230	3	1	2.86	3.43	4.29	
233	6	1	1.26			
235	4	1	1.68			
236	2	1	1.26	1.32		
237	4	1				
238	4	1	1.93			
240	1	1				

TABLE VII-2

Continued

<u>PROJECT</u>	<u>GROUP</u>	<u>FUNDING LEVEL</u>				
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
250	6	1				
251	6	1	1.10	1.98		
271	6	1	1.05			
272	5	1	1.05			
273	5	1				
297	6	1	1.44			
298	1	1	1.15			
299	6	1				
300	1	1	1.11			
302	6	1	1.16			
303	6	1	4			
304	1	1	1.06	1.18		