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Energy Conversion and Utilization
Technologies Division

MASTER

Washington, D.C. 20585

1981 WORK-ELEMENT APPRAISAL
ENERGY CONVERSION AND UTILIZATION
TECHNOLOGIES PROGRAM

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ABSTRACT

The Division of Energy Conversion and Utilization Technologies (ECUT) has employed a work element appraisal methodology that enables a systematic comparison of the various research and development (R&D) work elements within its program. The work element analysis is dependent upon the potential of the R&D to affect future energy savings, critical fuel substitution, and other public benefits such as environmental impacts. This report summarizes the process and results of the application of this appraisal methodology to the ECUT work elements proposed for FY 1983 funding.

The context of the appraisal is outlined to clarify its role and purpose in the planning and budgeting cycle. Implementation of the process, including the data development and the appraisal review session, is also discussed, along with the impact of the appraisal results on ECUT's total planning system and on the preparation of the FY 1983 budget.

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EXECUTIVE SUMMARY

The mission of the Division of Energy Conversion and Utilization Technologies (ECUT) of the U.S. Department of Energy (DOE) is to conduct long-term, high-risk applied research and exploratory development activities that are designed to improve the energy technology base used in industry. ECUT recognizes the need to systematically and objectively appraise its proposed research and development (R&D) efforts for allocation of its limited resources to those activities that show the greatest potential to contribute to national energy goals. To meet this need, a work element appraisal methodology has been developed to rate candidate ECUT work elements according to an explicitly defined benefit/cost analysis.

The methodology application begins with an analysis of energy consumption flow patterns in each of the end-use sectors to identify energy-inefficient processes or systems and to collect appraisal data. Also, long-term research opportunities that show promise for energy savings and/or critical fuel substitution are identified. These research opportunities, or work elements, are then subjected to a three-part, highly structured, quantitative analysis that comprises the appraisal methodology. Figure 1 shows the factors used as inputs to each part of the appraisal.

The first part of the appraisal includes calculating a Figure of Merit (FOM) (the ratio of an energy-savings benefit to the proposed R&D dollar cost) for each work element at three possible funding levels. The energy-savings benefit is numerically determined through consideration of the potential quantity and type of fuel saved in the years 1990 and 2000, the market penetration of the technology, the relative capital and

FIGURE 1. 1981 ECUT Work Element Appraisal Methodology

operating costs to the user, the probability of achieving the technological goals, and potential commercial barriers, such as institutional, social, and environmental constraints.

In the second part a Public Benefits Assessment (PBA) Score, which is more subjective and more difficult to quantify, is determined. It measures any additional environmental, economic, social or institutional public benefits that are expected to result from use of the proposed technology. These two parts are then combined to derive a Work Element Rating Score.

The third part provides for consideration of factors that determine the appropriateness of DOE funding support of the research in each work element. The extent to which other governmental or private organizations are involved in the same area of research is evaluated. Also, documented federal policies or legislation that define a federal role in the research are reviewed. These factors are analyzed to produce an overall division-wide ranking of the ECUT Work Elements.

The results of the 1981 rating calculations are highlighted in Table 1, which shows the number of work elements in each ECUT project and the percentage of those work elements rated in the top, middle, and bottom thirds of the appraisal rating scores. Integration of the appraisal methodology into the overall planning process for the ECUT Division has already provided important information. The data required by the methodology will aid in the preparation of planning documents, such as the Multi-Year Program Plans, and the appraisal results already have been used in preparation of the FY 1983 ECUT budget. The appraisal process also has provided the ECUT planners and program managers with data to assist them in daily decision making.

TABLE 1. 1981 ECUT Work Element Rating Highlights

Project	Number of Work Elements*	Percentage of Work Elements in Each Category		
		Top Third(%)	Middle Third(%)	Bottom Third(%)
1. Engine Combustion Technology	4	0	100	0
2. Closed Cycle Power Systems	8	75	25	0
3. Direct Heating and Conversion	8	0	13	87
4. Physical Processes	10	20	50	30
5. Chemical Processes	12	16	42	42
6. Materials	24	50	21	29
Total	66			

*Includes 29 technically distinct Work Elements proposed at different funding levels.

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1.0 INTRODUCTION

This document summarizes the process and results for the 1981 appraisal of research and development (R&D) work elements in the Energy Conversion and Utilization Technologies (ECUT) Program of the Office of Energy Systems Research. Background on the appraisal methodology and the ECUT program is included, as well as a discussion of the impact of the appraisal results on the ECUT research planning system and preparation of the FY 1983 budget. Finally, the effects of the appraisal's major quantitative components (the Adjusted Energy Savings, the Public Benefits Assessment, and the funding level) on the final results are summarized.

WORK ELEMENT APPRAISAL BACKGROUND

To create an ongoing capability to allocate funds to R&D projects with the greatest potential to achieve national energy goals, a project appraisal methodology was first implemented by the Division of Conservation Research and Technology (CONRT) of the Energy Research and Development Administration (ERDA) in FY 1977. The methodology's utility was demonstrated by the results obtained from the first application. The methodology offered a consistent, structured, systematic approach to appraising the merits and cost of R&D projects prior to committing research funds.

Since the initial implementation of the methodology by CONRT, the appraisal process had been adapted for use by the Division of Power Systems (DPS) and the Office of Coal Utilization (OCU). The 1981 ECUT appraisal method is a further refinement of these previous applications, but its basic function--to systematically compare the ECUT work elements on the basis of their ability to contribute to future fuel savings and other public benefits, as well as the appropriateness of Federal R&D support--remains unchanged.

ECUT PROGRAM DESCRIPTION

The ECUT Division was created within the DOE Conservation Program in FY 1980 to establish an advanced technology R&D activity in the areas of energy conversion and utilization. The long-range goal of ECUT is to promote energy conservation in all energy-use sectors by supporting research to improve efficiency and fuel-switching capability in energy conversion and utilization. This research complements other DOE conservation programs by focusing on technology base research needs and on generic technologies applicable to the end-use sectors. The ECUT program has two major objectives:

- to develop a technology base to support future development of energy conversion and utilization systems with major improvements in energy productivity and capability for alternate fuel utilization.
- to develop advanced concepts in energy conversion and utilization technologies, to enhance their technical feasibility, and to estimate their conservation potential.

The design of the ECUT Program research efforts is drawn from an overall energy technology model that defines four principal elements: supply, conversion, storage and utilization, all of which represent the flow of energy from source to eventual point-of-use. ECUT is concerned with two of these elements, conversion and utilization, and has established two corresponding program elements: Energy Conversion Technology (ECT) and Energy Utilization Technology (EUT).

ECT covers technologies relevant to systems that convert energy from one form to another regardless of whether the conversion process is centralized or decentralized. The EUT program element, on the other hand, covers technologies relevant to energy use in all sectors and thus focuses on the processes and materials affecting the direct energy service provided in buildings, industry, and transportation systems.

The ECT and EUT Program Elements are, in turn, divided into six research projects. Within these projects twenty-nine work elements were submitted for appraisal, as shown in Figure 2. ECUT operates on a decentralized project management basis, with two Program Element Managers at DOE Headquarters coordinating the efforts of six Field Project Managers. These projects are managed at several national laboratories, with the actual R&D activities accomplished at the labs, universities, and in private companies.

To meet national and DOE energy-use goals; each ECUT project has developed individual R&D objectives for its research:

- Engine Combustion Technology - to develop improved design and performance analysis techniques that accelerate the introduction of innovative design concepts in internal combustion engines, resulting in 20 to 30% efficiency improvements by the year 2000.
- Closed-Cycle Power Systems - to improve component design technologies to support development of stirling, rankine and closed-cycle brayton power systems and their application to high-efficiency energy conversion systems such as

FIGURE 2. ECUT Division Research Organization

thermal-activated heat pumps, multifuel capable power generators, residential/commercial total energy systems, and industrial cogeneration.

- Direct Heating and Conversion Systems - to develop improved design and performance analysis techniques for high-efficiency boilers and furnaces, resulting in 40% efficiency improvements by the year 2000, to enhance fuel-flexibility and to develop component design technologies for direct energy conversion processes.

Energy Utilization Technology has the following project objectives:

- Physical Processes - to advance the state-of-the-art for technologies and processes dependent on improvements in generic physical processes (such as heat transfer and separation) for increased energy efficiency. Specifically, to prove technical feasibility of a 1% efficiency increase and improved reliability and durability of heat exchangers in severe environments by 1990. To identify and begin exploratory development of separation technologies to cut energy consumption in industrial distillation and evaporation processes.
- Chemical Processes - to develop advanced, less energy-intensive techniques and reaction sequences for the production of desired products and commodities. To identify and begin exploratory development of catalysts and reaction sequences that reduce energy consumption in the production of specific chemical commodities by 50% by the year 2000.
- Materials - to develop new materials that have superior performance characteristics for energy conservation applications and innovative materials production processes that have significant potential for reducing energy consumption. To improve lubricants to reduce frictional losses by 2% by 1990 and to undertake exploratory development to perfect insulating materials having twice the heat flow resistance of conventional insulations by 1985.

Each project is further broken down into a series of more specific R&D activity groupings called work elements, each of which is associated with a particular technology. A brief description of the proposed R&D in each of the 29 candidate work elements is presented in Appendix I. Appendix II contains a tabular summary showing the end-use sectors for which the work element R&D has target applications. The appraisal methodology was applied at the work element level. The ECUT appraisal methodology prioritizes these work elements on the basis of their potential to contribute to both the overall national energy-use goals and to the objectives of the projects described above.

THE ROLE OF WORK ELEMENT APPRAISAL

The success of the ECUT program will depend on both the conservation potential of the projects it funds, and the effectiveness with which they are carried out. Therefore, the ECUT R&D activities must be structured with systematic and objective planning inputs that permit its resource allocation process to select research with the greatest potential contribution to national energy objectives. Further, the R&D components of the program must be a goal-oriented set of efforts that are cohesively integrated so that their collective results will impact broad end-use sectors. The 1981 ECUT Work Element Appraisal process has been specifically designed as the analytical tool to insure that these conditions are met and that ECUT is established as a well-conceived and effective R&D program.

A general strategy has been followed in designing the research efforts for ECUT. It includes the following sequence of steps:

- identification of target areas in the U.S. energy flow network where inefficient energy conversion and use occurs, or where significant use of critical fuels is present

- identification of advanced technology concepts with potential for improved energy efficiency or for increased use of alternate fuel resources in the targeted energy flows
- identification of technology base R&D needs and opportunities associated with these advanced concepts
- analysis and prioritization of relevant concepts based on their need for federal R&D support and their contribution to ECUT program goals and objectives
- formulation of Program Element plans designed to meet the technology base needs and support development of the most attractive concepts.

The Work Element Appraisal Methodology described in this document is designed to assist in implementing each of those strategic steps.

Integration of the appraisal methodology into the overall planning process for the ECUT Division will have important impacts. The data required by the methodology will aid in completion of planning documents, such as the MultiYear Program Plans, and the appraisal results will be used in the FY 1983 budget preparation. Figure 3 shows the appraisal's strategic position in the annual planning and budgeting cycle. The results of the appraisal, primarily the work element rating scores, provide direct inputs to the Program Memorandum document for FY 1983-87, which is the formal initiation of the annual planning cycle. The Program Memorandum explains ECUT's mission, identifies technological options to achieve this mission, and describes the strategy developed by ECUT to produce desired accomplishments. Also, the Memorandum is used to describe candidate projects for which budgets are prepared and reviewed and is an input for the DOE Internal Review Budget.

After approval by DOE and the Office of Management and Budget (OMB), the Internal Review Budget becomes a part of the President's FY 1983 budget, which is then submitted to Congress. Finally, the approved budget becomes the basis for the actual operating plans for both the ECUT headquarters administration and the project managers in the field.

During the year, management reviews are conducted to assess the managerial and administrative aspects of each project. These reviews use the appraisal methodology results and other planning documents to examine the managerial approach and effectiveness of specific projects and contracts. Thus, the appraisal methodology produces measurements that are helpful not only in planning, but also in the review process, as inputs that assist the program managers in their daily decision-making.

FIGURE 3. ECUT Annual Planning Cycle

2.0 WORK ELEMENT APPRAISAL METHODOLOGY

The work element appraisal process is a method of identifying and describing the expected future benefits or payoffs from an R&D activity, as they relate to organizational objectives and to the costs to conduct the research work. Assessing the benefits and costs is done systematically and quantitatively even though knowledge of those benefits and costs and the resources needed to perform the work is limited. Appraisal of work elements is accomplished before the proposed work is selected for funding. In contrast to this process, evaluation of research activities is accomplished during and after the work progress for the purpose of management control and impact review.

Each ECUT work element may be proposed for funding at up to three funding levels, minimum, basic, and enhanced. To avoid confusion, subsequent discussion of the appraisal process will use the term "work element proposal" to refer to a specific funding level, as well as to one of the areas of technology research shown in Figure 2. Thus, a single R&D work element from Figure 2 proposed for funding at two separate levels will be considered to be two separate work element proposals in this analysis.

APPRAISAL METHOD OVERVIEW

The ECUT Program considered 4 basic steps in its 1981 work element appraisal and budgeting process:

1. development and submission of work element appraisal data
2. review of the work element data forms by a Headquarters (Hq) DOE Appraisal Review Panel
3. calculation of work element scores for relative comparisons of benefits, impacts, and costs
4. development of FY 1983 ECUT budget and Program Memorandum.

The first three steps of this process represent the Work Element Appraisal component. The appraisal results are used as an input to the fourth step in which specific research work elements are selected at specified budget levels to make up the ECUT R&D activities for the Program Memorandum. This document only describes the appraisal process; budgeting results are presented in the Program Memorandum document.

The FY 1983 appraisal methodology consists of an analysis structure based on criteria and data that assess the potential of achieving national energy-efficiency goals through applied engineering R&D. These data are reviewed in an interactive appraisal session attended by the project managers and an appraisal panel. At the session, the panel examines and verifies the data submitted, which are used in a two-stage analysis approach involving first, the numerical calculation of a work element rating score, and second, estimation of the appropriateness of federal R&D. This last factor, together with the rating, are used to provide an overall work element ranking. The rating scores and ranked work elements within each of the Division's six project areas are subsequently considered by the ECUT Hq staff to develop program budget composition.

The components of the first stage calculations and the individual appraisal criteria are shown in Figure 4. The analytical appraisal calculations are represented by the Work Element Rating (WER). Two components, the Figure of Merit (FOM) and the Public Benefits Assessment (PBA), are combined to produce these rating scores. For each work element, the FOM is calculated using data on each of the criteria shown as input to the FOM section of the illustration. The benefits, or Adjusted Energy Savings (AES), are computed based on the efficiency and fuel type changes resulting from ECUT research. The effects of product marketability are included through the Maximum Market Penetration and Market Entry Date criteria. A Commercial Potential Score is obtained from the User Cost, Technical Risk, and Commercial Barriers factors. The last criterion, R&D Cost, is the denominator of the FOM ratio.

APPRAISAL METHOD DATA AND CALCULATIONS

Calculation of the FOM for each work element is based on explicit data concerning expected energy savings and R&D costs, which are developed by the project managers. The PBA calculation is accomplished by the ECUT headquarters Appraisal Review Panel through a subjective scoring of written material, which is also submitted by the project managers to describe their claims of public benefits.

Both the FOM and PBA results are then normalized and these normalized values are added together for each work element using the Work Element Rating equation to calculate the final rating scores. The details of these steps are given in this section.

Figure of Merit (FOM) Calculation

The FOM for ECUT work elements consists of a benefit-to-cost ratio, where the benefits are considered to be a measure of projected energy savings and the costs are a measure of the ECUT R&D cost necessary to obtain the energy savings benefits. Energy savings are computed as AES, which is a fuel-specific weighted calculation designed to give important numerical rewards to energy savings for particular critical fuel types.

FIGURE 4. 1981 ECUT Work Element Appraisal Methodology

The AES is comprised of two terms, one for the year 1990 and one for the year 2000. The R&D cost is computed as the average of work element budget requests (by the project managers) for the years FY 1983, FY 1984, and FY 1985. Therefore, the FOM may be expressed as

$$\text{FOM} = \frac{\text{AES}}{\text{R\&D Cost}} = \frac{\text{AES}_{(1990)} + \text{AES}_{(2000)}}{\text{R\&D Cost}_{(\text{avg. FY83, FY84, FY85})}} \quad (1)$$

Adjusted Energy Savings (AES)

The AES calculation is computed by considering the projected energy savings for a work element by individual fuel type. A numerical weighting factor is given to each fuel type used so that savings of particular critical fuels are given a higher value in the AES calculation than savings of fuels having a lower importance.

In equation form, the AES for each ECUT work element application in 1990 and 2000 is written as follows:

$$\text{AES}_{\text{yr}} = \left[\frac{\text{Old Fuel Use}}{\text{yr}} \times \left[\frac{\text{Old Fuel Mix Weighting Factor}}{\text{yr}} \right] - \left[\frac{\text{New Fuel Use}}{\text{yr}} \times \left[\frac{\text{New Fuel Mix Weighting Factor}}{\text{yr}} \right] \right] \quad (2)$$

where: Old = projected fuel mix without ECUT Research

New = projected fuel mix with ECUT Research

yr = 1990 or 2000

In this equation the subtraction between adjusted energy consumption before and after ECUT research determines the AES due to the impact of ECUT technologies. The calculation includes the effect of changes in both total fuel use and in the mix of fuel types. Thus, the equation accounts for fuel savings through both efficiency improvements and also from fuel switching.

The Old and New Fuel Use values in Equation 2 are computed by fuel type from the variables shown in Figure 4. The total Fuel Use of a technology application market is first defined by dividing the projected energy demand in the market by the average conversion or use efficiency for the Old and New technologies. Energy service demand was obtained from the Reference Energy System (Brookhaven National Laboratory 1979). The portion of this use affected by a new ECUT technology is then obtained through multiplication of the total Fuel Use by a market penetration fraction. This fraction is obtained using the other AES factors in Figure 4. First, a market penetration is estimated using data on the Maximum Market Penetration and the Market Entry Date for each ECUT technology. Then, this figure is multiplied by a Commercial Potential Score, which is developed from data on User Cost, Technical Risk, and Commercial Barriers.

The Fuel Weighting Factors in Equation 2 are the numerical values selected for the particular Old and New Fuel types used. If fuel switching occurs, then the New Fuel Mix Weighting Factor would be different from the Old Fuel Mix Weighting Factor. The numerical Fuel Weights were chosen to be consistent with DOE fuel conservation goals, which are shown in Figure 5, in order from highest to lowest priority. This prioritization shows, for example, that near-term (1990) oil savings are more valuable than either mid-term (2000) oil savings or near-term savings for any other fuel (including fuel switching away from oil). The fuel savings priority list was constructed by the Appraisal Panel to reflect DOE goals for fuel savings that were current at the time of appraisal.

The numerical values for the Fuel Weighting Factors, also chosen by the Appraisal Panel to be consistent with this priority structure, are shown in Figure 6. The higher magnitudes in the table indicate more valuable fuel types and thus more valuable fuel savings. Fuel switching priorities are indicated by the differences in weighting factors that result from use of Equation 2. For example, saving 1 quad of oil by switching to

HIGHEST PRIORITY

OIL SAVINGS BY 1990
 OIL TO COAL/OTHER SWITCHING BY 1990
 OIL TO SYNFUEL SWITCHING BY 1990
 OIL SAVINGS BY 2000
 OIL TO COAL/OTHER SWITCHING BY 2000
 GAS SAVINGS BY 1990
 ELECTRICITY SAVINGS BY 1990
 GAS/ELECTRICITY SAVINGS BY 2000
 GAS TO COAL/OTHER SWITCHING BY 1990
 OIL TO SYNFUEL SWITCHING BY 2000
 OIL TO ELECTRICITY SWITCHING BY 1990
 ELECTRICITY TO COAL/OTHER SWITCHING BY 1990
 OIL TO GAS SWITCHING BY 1990
 GAS TO SYNFUEL SWITCHING BY 1990
 ELECTRICITY TO SYNFUEL SWITCHING BY 1990
 ELECTRICITY/GAS TO COAL/OTHER SWITCHING BY 2000
 SYNFUEL SAVINGS BY 2000
 OIL TO GAS SWITCHING BY 2000
 ELECTRICITY TO SYNFUEL SWITCHING BY 2000
 SYNFUEL SAVINGS BY 1990
 SYNFUEL TO COAL/OTHER SWITCHING BY 2000
 COAL/OTHER SAVINGS BY 2000
 COAL/OTHER SAVINGS BY 1990
 GAS TO ELECTRICITY SWITCHING BY 1990

LOWEST PRIORITY

FIGURE 5. ECUT Fuel Saving Priorities

coal in 1990 would be better ($100 - 10 = 90$) than switching to gas ($100 - 60 = 40$). These numerical weights are consistent with the priorities in Figure 5.

R&D Cost

The denominator of the FOM calculation is obtained by simply averaging the R&D cost figures for each work element for the three fiscal years from 1983 to 1985. The computation of the denominator is shown mathematically as:

$$\text{R\&D Cost} = \frac{\text{R\&D Cost(FY83)} + \text{R\&D Cost(FY84)} + \text{R\&D Cost(FY85)}}{3}$$

(3)

The three-year averaging method was chosen because it provides a relative indication of R&D costs, which are generally level through the life of a basic research activity. This equation is modified to account for cost values that are zero in any of the three years

YEAR	FUEL TYPE					
	PETROLEUM W _P	GAS W _G	COAL W _C	ELECTRICITY W _E	SYNFUEL W _S	OTHER W _O
1990	100	60	10	55	20	10
2000	80	50	15	50	30	15

$$\text{ADJUSTED ENERGY SAVINGS} = \sum \left(\text{FUEL SAVINGS} \right) \times \left(\text{FUEL WEIGHTING FACTOR} \right)$$

NOTE: ELECTRICITY WEIGHTING FACTOR WAS OBTAINED FROM THE WEIGHTING FACTORS AND FUEL PROPORTIONS FOR THOSE FUELS USED TO GENERATE ELECTRICITY. THE FUEL PROPORTION FOR A FUEL TYPE IS DEFINED AS THE NUMBER OF PRIMARY QUADS OF THAT FUEL USED FOR ELECTRICITY GENERATION DIVIDED BY THE TOTAL QUADS OF PRIMARY FUEL USED.

FIGURE 6. 1981 ECUT Fuel Savings Weighting Factors

because a work element's R&D is completed before FY 1985. When one zero term occurs, the denominator above is changed to equal two, and for two zero terms, the denominator is set to equal one.

Public Benefit Assessment (PBA) Calculation

This process is a subjective scoring judgment wherein the Appraisal Panel members select a numerical score from a predesigned scale to indicate the degree of "nonenergy" public benefits associated with a particular work element. Written descriptions of these benefits are provided by the project managers in the following four categories: environmental, economic, social, and institutional. This written material is used as evidence by the panel to give a fair subjective judgment in the scoring process. For each work element, a score in each of the four categories above is determined by each panel member. These four scores are added to obtain the overall PBA score as shown below:

$$PBA = S_v + S_e + S_s + S_i \quad (4)$$

where: S_v = environmental impact score

S_e = economic impact score

S_s = social impact score

S_i = institutional impact score

The final PBA scores for each work element are then obtained as the average of the individual panel member scores.

Work Element Rating (WER) Calculation

As mentioned earlier, the FOM and PBA results for each work element are normalized prior to computing the WER. This computation is done by dividing each value by the maximum FOM or PBA. The resulting numbers will all be between zero and one and are expressed mathematically for the FOM as:

$$FOM_n = \frac{FOM}{FOM_{max}} \quad 0 \leq FOM_n \leq 1 \quad (5)$$

The PBA results for each work element are normalized in a similar fashion, resulting in the expression:

$$PBA_n = \frac{PBA}{PBA_{max}} \quad 0 \leq PBA_n \leq 1 \quad (6)$$

This normalization is done to account for the fact that the FOM and PBA values are measured on different numerical scales, which precludes their direct combination to determine the Work Element Rating.

The Work Element Rating is determined as a linear combination of the normalized FOM and PBA scores. The WER equation is shown below:

$$WER = FOM_n + 0.15 \times PBA_n \quad (7)$$

where: FOM_n = the normalized FOM score, $0 \leq FOM_n \leq 1$

PBA_n = the normalized PBA score, $0 \leq PBA_n \leq 1$

The PBA_n coefficient of 0.15 was established by the Appraisal Review Panel to indicate the relative importance of the PBA_n term in the overall rating. Since both the normalized FOM and PBA values are on a scale between zero and one, the PBA coefficient will give the desired relative importance for each of the individual work element data values.

R&D Appropriateness Factors

Two types of factors are considered by the ECUT Appraisal Panel to evaluate the appropriateness of DOE funding support for each ECUT work element proposal. First, the extent of research support for a work element research area by other governmental and private organizations is reviewed. Also, explicit federal policies or legislation that specify a federal role in the research are considered. These factors are analyzed to finalize the overall division-wide ECUT Work Element Ranking. Since this ranking process is an ongoing part of the ECUT budget formulation, final ranking results for the FY 1983 budget are not available for this document.

APPRAISAL METHOD IMPLEMENTATION

The four step appraisal and budgeting process was conducted according to the schedule below:

1. Development/submission of work element data (Dec. 1980 - Jan. 1981)
2. Work Element Data Review by the Hq DOE ECUT Appraisal Panel (Jan. 15, 16 1981)
3. Work Element Rating Calculations (Feb. - March 1981)
4. FY 1983 Program Memorandum Development (Spring 1981).

These steps were each accomplished by a specified group of appraisal participants, who were each assigned particular functions in the appraisal process. Moreover, standard procedures were developed to implement each step in a clear and objective fashion.

Roles of the Participants

Each of the major steps above was accomplished by participants with the responsibilities and roles shown as follows in Table 2:

TABLE 2. ECUT Appraisal Participant Roles

<u>STEP</u>	<u>PARTICIPANT</u>	<u>FUNCTION</u>
1.	Project Managers	Prepare work element appraisal data and adjust initial rating
2.	Appraisal Review Panel	a. Review work element data b. Prepare final Division-wide ranking
3.	Systems Analysts	a. Assist project managers/panel members in preparation for and conduct of the data review b. Calculate work element scores
4.	ECUT Hq Staff	Prepare FY 1983 Program Memorandum

The process of implementing these roles was the responsibility of the Systems Analysis team; however, overall appraisal guidance was provided by the ECUT Appraisal Review Panel. The particular individual members for each of the roles above are given in Table 3.

Appraisal of Data Collection and Analysis Procedures

Data collection for the appraisal calculations was facilitated by use of standardized data forms to obtain work element numerical estimates (Step 1 above). The forms were used to provide basic energy use and technology R&D information to the appraisal panel and for ease in completing the calculations. A complete set of data forms was filled out for each work element by the responsible project manager. The set of forms contained one sheet for each of the appraisal criteria mentioned earlier and shown in Figure 4. Some forms contained quantitative data values, whereas others were completed with subjective score values to represent engineering judgments.

TABLE 3. 1901 ECUT Appraisal Participants

Appraisal Panel Members	E. Karl Bastress	Department of Energy
	James Eberhardt	Department of Energy
	John Eustis	Department of Energy
	Marvin Gunn	Department of Energy
	Robert Massey	Department of Energy
	Michael D. Shapiro*	Department of Energy
	Albert Streib	Department of Energy
	*Panel Coordinator	
ECUT Project Managers	Joseph A. Carpenter	Oak Ridge National Laboratory
	Robert E. Holtz	Argonne National Laboratory
	Paul F. Massier	Jet Propulsion Laboratory
	Jovan Moacanin	Jet Propulsion Laboratory
	William Robinson	Sandia Livermore Laboratory
	William H. Theilbar	Idaho National Laboratory
Systems Analysis Staff	W. Bradford Ashton	Pacific Northwest Laboratory
	Carl H. Imhoff	Pacific Northwest Laboratory
	Theodore L. Willke	Pacific Northwest Laboratory

As Step 2 indicates, these data forms were reviewed by the Appraisal Panel in a two-day review meeting. Each project manager presented his research program proposals and the panel raised questions about data that seemed incorrect or controversial. Some data items for the AES calculation were misinterpreted prior to and during the review session. As a result, several new forms for the final AES calculations were developed after the review meeting and distributed to the project managers for submission of revised data. The Systems Analysis group then reviewed and clarified the revised data in preparation for the data analysis phase.

The approved appraisal data were then used by the Systems Analysis staff to compute the Work Element Rating Scores. Next, the Appraisal Panel reviewed these results to determine the final Division-wide Work Element Ranking. To complete this ranking, the panel considered the R&D Appropriateness Factors data, which were included on the work element data forms.

In the final step, the ranking results are used by the ECUT Hq staff as input to the FY 1983 ECUT budget, which is described in the FY 1983 Program Memorandum.

3.0 APPRAISAL RESULTS

An important result of the 1981 ECUT Work Element Appraisal concerns the reactions of the appraisal panel, project managers and analysis staff to the appraisal process. They indicated that all the participants obtained a much better mutual understanding of the ECUT Division goals, management strategy, and work element content. The more specific numerical results of the appraisal calculations are contained in the remainder of this section. Additional observations on the appraisal process are given as conclusions and recommendations.

WORK ELEMENT RATING RESULTS

Although each of the 29 ECUT work elements in Figure 2 could have been appraised at 3 funding levels, only one of the project managers submitted proposals at all levels. As a result, the 1981 ECUT Appraisal considered a total of only 66 work element proposals. The work element rating calculation for each of these proposals has three basic components, which are presented in this section along with the WER values. As Equation 1 shows, the FOM_n term in Equation 7 is obtained from two values, AES and R&D Cost, whose quotient is then normalized. The third term is PBA_n , which is determined using Equations 4 and 6. The values for these three terms plus the WER results are given for the 66 ECUT work element proposals by ECUT project groups in Table 4. Each work element and its funding level are shown along with the numerical results for the following appraisal parameters: AES, R&D cost, FOM, FOM_n , PBA_n , WER score, and the WER rating.

A plot that shows the relationship between the WER Score and the corresponding WER rating for each work element proposal is shown in Figure 7. This result indicates that the top six proposals show significant differences from each other and from the remaining proposals in terms of their WER Score. The lower 60 work element proposals have scores that are much closer to each other.

Further characteristics of these data are presented in Table 5, where the rated work element proposals are displayed in a matrix format under their corresponding ECUT projects. Along with each work element name, the funding level (M, B, E) and FY 1983 funding requirements (in \$K) are shown. Work elements were removed from the table if they appeared in a position below the rating for the same work element funded at a higher level; hence only 52 work element proposals are listed.

This table highlights the results for the work elements grouped by ECUT project. These results show that several Materials work element proposals rated very high, while several others were relatively low. The Direct Heating and Conversion scores were uniformly lower, whereas Engine Combustion was rated in the middle area. Closed-Cycle work element proposals were all reasonably high. Finally the Chemical and Physical Process results were not as well clustered as the others.

ANALYSIS OF THE WORK ELEMENT RATINGS

Two types of analyses are given in this section to provide additional insight into the appraisal results. First, a statistical summary of project scores for the key appraisal variables is presented. The summary is followed by a table that displays a breakdown of the work element rating list by project area.

Figures 8-12 present a summary of the average, minimum, and maximum data values, grouped by ECUT project area, for each main appraisal variable (AES, R&D cost, FOM_n ,

TABLE 4. 1981 ECUT Appraisal Calculation Results

Work Element	Proposed Funding Level ^(a)	Adjusted Energy Savings (AES)	Cost (\$m) (3 yr avg)	Figure of Merit (AES/Cost)	Figure of Merit (Norm)	Public Benefits (Norm)	Work Element Rating (WER)	WER Rank
Engine Combustion Technology								
Otto Cycle Engines	MIN/BAS ENH	101.90 120.20	2.400 3.300	42.5 36.4	.08 .07	.90 .90	.21 .20	26 29
Diesel Engines	MIN/BAS ENH	87.18 101.91	2.600 3.370	33.5 30.2	.06 .06	.84 .84	.19 .18	32 34
Closed Cycle Power Systems								
Stirling Cycle Engines	MIN/BAS ENH	96.53 118.68	1.067 1.300	90.5 91.3	.16 .17	.69 .69	.27 .27	16 15
Closed Cycle Brayton Technology	MIN/BAS ENH	21.83 27.26	.500 .600	43.7 45.4	.08 .08	.49 .49	.15 .16	40 39
Rankine Cycle Technology	MIN/BAS ENH	39.48 48.62	.400 .500	98.7 97.2	.18 .18	.50 .50	.25 .25	18 19
Advanced Closed Cycle Technology	MIN/BAS ENH	27.40 32.80	.267 .367	102.6 89.4	.19 .16	.56 .56	.27 .25	14 21
Direct Heating and Conversion								
Data and Design Methods Development	MIN/BAS ENH	3.66 12.11	.550 1.100	6.7 11.0	.01 .02	.77 .77	.13 .14	49 44
Advanced Concepts for Dirty Fuels	MIN/BAS ENH	3.08 12.55	.533 1.333	5.8 9.4	.01 .02	.61 .61	.10 .11	57 55
Retrofit and Fuel Flexibility	MIN/BAS ENH	3.14 9.51	.533 1.333	5.9 7.1	.01 .01	.65 .65	.11 .11	56 54
Direct Thermal-Electrical Conversion	MIN/BAS ENH	15.85 40.58	.900 1.733	17.6 23.4	.03 .04	.58 .58	.12 .13	52 47
Physical Processes								
Heat Transfer	MIN/BAS ENH	135.87 140.59	2.137 3.872	63.6 36.3	.12 .07	.60 .60	.21 .16	27 38
Feedstock Preparation	MIN/BAS ENH	1.61 1.64	.237 .270	6.8 6.1	.01 .01	.37 .37	.07 .07	64 65
Industrial Waste	MIN/BAS ENH	5.38 5.44	.297 .500	18.1 10.9	.03 .02	.80 .80	.15 .14	41 43
Sensors	MIN/BAS ENH	46.26 49.14	.245 .337	188.8 145.8	.34 .27	.45 .45	.41 .33	5 7
Separation	MIN/BAS ENH	14.70 16.10	.320 .633	45.9 25.4	.08 .05	.55 .55	.17 .13	37 48
Chemical Processes								
Electrowinning/Electrodeposition	MIN/BAS ENH	6.43 11.93	.300 1.300	21.4 9.2	.04 .02	.27 .27	.08 .06	62 66
Separation Technology	MIN/BAS ENH	54.74 339.55	.433 .617	126.4 550.3	.23 1.00	.55 .55	.31 1.08	10 1
Biological Processes Development	MIN/BAS ENH	18.39 85.50	.467 1.733	39.4 49.3	.07 .09	.73 .73	.18 .20	33 30
Chemical Feedstocks-Biomass/Waste	MIN/BAS ENH	12.10 63.22	.500 .767	24.2 82.4	.04 .15	.53 .53	.12 .23	51 23
Industrial Organic Chemicals/Plastics/Synthesis	MIN/BAS ENH	16.53 74.93	.200 .867	82.7 86.4	.15 .16	.37 .37	.21 .21	28 24
Nitrogen Fixation	MIN/BAS ENH	2.41 10.04	.533 1.067	4.5 9.4	.01 .02	.52 .52	.09 .10	61 58

^(a) MIN = Minimum
BAS = Basic
ENH = Enhanced

TABLE 4. 1981 ECUT Appraisal Calculation Results (contd)

Work Element	Proposed Funding Level ^(a)	Adjusted Energy Savings (AES)	Cost (\$m) (3 yr avg)	Figure of Merit (AES/Cost)	Figure of Merit (Norm)	Public Benefits (Norm)	Work Element Rating (WER)	WER Rank
Materials								
High Temp Waste Heat	MIN	4.23	.227	18.6	.03	.39	.09	59
	BAS	4.48	.247	18.1	.03	.39	.09	60
	ENH	5.03	.508	9.9	.02	.39	.08	63
Buildings Heat Exchangers	MIN	6.02	.293	20.5	.04	.63	.13	45
	BAS	6.61	.325	20.3	.04	.63	.13	46
	ENH	7.04	.400	17.6	.03	.63	.13	50
Buildings Insulation	MIN	4.17	.085	48.8	.09	.56	.17	36
	BAS	14.61	.110	132.8	.24	.56	.33	8
	ENH	21.51	.258	83.4	.15	.56	.24	22
Adiabatic/Diesel/Advanced Heat Engines	MIN	41.59	.243	171.2	.31	.76	.43	4
	BAS	45.03	.308	146.2	.27	.76	.38	6
	ENH	49.73	.672	74.0	.13	.76	.25	20
Electrodes for Aluminum Reduction Cells	MIN	20.21	.200	101.0	.18	.19	.21	25
	BAS	21.02	.225	93.4	.17	.19	.20	31
	ENH	21.56	.450	47.9	.09	.19	.12	53
Tribological Applications	MIN	32.27	.675	48.0	.09	.67	.18	26
	BAS	48.11	1.500	32.1	.06	7	.14	42
	ENH	211.83	2.200	96.3	.18	.57	.26	17
Recycle of Plastics	MIN	71.03	.200	355.2	.65	.73	.76	2
	BAS	77.04	.375	205.4	.37	.73	.48	3
	ENH	82.04	.750	109.3	.20	.73	.31	11
Light Weight Ground Transportation	MIN	14.71	.108	136.2	.25	.44	.31	9
	BAS	15.80	.130	121.5	.22	.44	.29	12
	ENH	86.61	.730	118.6	.22	.44	.28	13

(a) MIN = Minimum
BAS = Basic
ENH = Enhanced

FIGURE 7. 1981 ECUT Work Element Score

TABLE 5. ECUT Work Element Appraisal Results by Project

RANK	ENGINE COMBUSTION	CLOSED CYCLE POWER	DIRECT HEATING AND CONVERSION	PHYSICAL PROCESSES	CHEMICAL PROCESSES	MATERIALS
1					SEPARATION (E-500)	
2						RECY PLASTIC (M-200)
3						RECY PLASTIC (B-400)
4						AD DIE/HT ENG (M-230)
5				SENSORS (M 8-100)		
6						AD DIE/HT ENG (B-375)
7				SENSORS (E-175)		
8						BUILDING INS (B-185)
9						LT WT GRD TRN (M-175)
10						RECY PLASTIC (E-800)
11						LT WT GRD TRN (B-240)
12						LT WT GRD TRN (E-240)
13	ADV CLOS CYC (M 8-200)					
14	STIRLING CYCL (E-1100)					
15						TRIBOLOGY (E-2200)
16	RANKINE CYC (M 8-400)					
17	RANKINE CYC (E-500)					
18						AD DIE HT ENG (E-525)
19	ADV CLOS CYC (E-300)					
20						BUILDING INS (E-440)
21					FEEDSTOCK BIO (E-700)	
22					IND ORG CHEM PLAS (E-700)	
23						ELECT ALUM RED (M-200)
24	OTTO CYCLE (M/B-2400)					
25				HEAT TRANS (M 8-1710)		
26	OTTO CYCLE (E-2900)					
27					BIOL PROCESS (E-1000)	
28						ELECT ALUM RED (B-250)
29	DIESEL ENG (M/B-2100)					
30	DIESEL ENG (E-3100)					
31				SEPARATION (M 8-160)		
32				HEAT TRANS (E-3050)		
33	CL CYC BRAYTON (E-500)					
34				INDUST WASTE (M 8-190)		
35				INDUST WASTE (E-350)		
36				DATA DES METH (E-800)		
37						BUILD HT EX (M-315)
38						BUILD HT EX (B-350)
39	DIR TH ELEC CONV (E-1400)					
40				SEPARATION (E-400)		
41						BUILD HT EX (E-350)
42						ELEC ALUM RED (E-500)
43	RETRO/FUEL FLEX (E-1000)					
44	ADV CONC DIR FUEL (E-1000)					
45					NITROGEN FIX (E-1000)	
46						HI TEMP WS HT (M-200)
47						HI TEMP WS HT (B-230)
48					ELECTROWIN DEP (M 8-600)	
49						HI TEMP WS HT (E-305)
50				FEEDSTOCK PREP (M 8-80)		
51				FEEDSTOCK PREP (E-80)		
52					ELECTROWIN DEP (E-900)	

PBA_n, and WER). For comparison, the same statistical results are given for the set of all division work elements at the top of each figure. Those projects that, on average, are above and below the division-wide averages for each appraisal variable, can be easily identified.

These figures also show that projects whose work elements scored high (or low) due to their WER scores may have done so based on various important effects in the other variables. For instance, Engine Combustion work elements had a slightly below-average WER score (.19 vs .23, in Figure 12), but had the highest average AES (102, in Figure 8). This project, however, also had the highest R&D cost (2.9, in Figure 9).

Figures 13 and 14 show the relative importance of the PBA_n term versus the FOM_n results in the final WER rating scores (by project average). Each factor's contribution to the final WER score is presented on a percentage basis. For example, Figure 13 shows that 71% of the average Chemical Processes WER score was due to the FOM_n term. The

FIGURE 8. Project AES Score Comparison

FIGURE 9. Project R&D Cost Comparison

FIGURE 10. Project FOM Comparison

FIGURE 11. Project PBA Comparison

FIGURE 12. Project WER Score Comparison

FIGURE 13. Percent of Average Project WER Score Due to FOM Score

FIGURE 14. Percent of Average Project WER Score Due to PBA Score

remaining portion, or 29%, is due to the effect of the PBA_n value and that result appears in Figure 14. These figures indicate that for the high-rated work elements (Closed-Cycle Power Systems, Chemical Processes, and Materials) high scores were achieved largely based on their FOM_n scores. Alternatively, the low-rated project (Direct Heating and Conversion Systems) was affected more by the PBA_n scores. These illustrations also show that ECUT funding decisions reflect an important broad-based justification for the public R&D expenditures, since the scores take into account important benefits that will accrue to the public beyond simply those related to energy savings.

Finally, Table 6 gives a breakdown of all ECUT work elements by project and shows the percent of each project's work elements that fell into the top, middle, and bottom third of the WER rating list.

TABLE 6. 1981 ECUT Work Element Rating Highlights

Project	Number of Work Elements*	Percentage of Work Elements in Each Category		
		Top Third(%)	Middle Third(%)	Bottom Third(%)
1. Engine Combustion Technology	4	0	100	0
2. Closed Cycle Power Systems	8	75	25	0
3. Direct Heating and Conversion	8	0	13	87
4. Physical Processes	10	20	50	30
5. Chemical Processes	12	16	42	42
6. Materials	24	50	21	29
Total	66			

*Includes 29 technically distinct Work Elements proposed at different funding levels.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The ECUT program is responsible for conducting applied research and exploratory development activities that are designed to improve the technology base used by industry for energy conversion and utilization systems. Applied research and exploratory development programs have been recognized for emphasizing long-term, high-risk, new-technology concepts to be evaluated and considered for further development by industry. Because of their very nature, project selection for these programs has generally been on a "hit-or-miss" basis, consisting of a peer review of proposals. In the past, a systematic approach to project selection has been, at best, difficult, primarily because of the uncertainties associated with long-term, high-risk research input data that would be required by a quantitative selection methodology.

The ECUT program recognizes the importance of using systematic project selection approaches that consider research costs and benefits. The 1981 ECUT appraisal method was developed and used as an initial process toward this end. This section presents the major conclusions from the 1981 process and recommendations for improvements in future appraisal methods.

CONCLUSIONS

A review of the 1981 ECUT appraisal process and calculations revealed that the method used has important desirable attributes, but also indicated that some steps or calculations should be improved. The principle conclusions of the process review are summarized below:

1. The 1981 appraisal method provides a clear, consistent, and workable process to rate potential R&D work elements according to their expected benefits and costs. Moreover, the method permitted the ECUT Headquarters and Project Management staffs to meet the Division planning needs in an open and mutually informative way. This effective coordination made the process results even more valuable as a strong foundation to meet future ECUT planning requirements.
2. The appraisal method used has the advantages of being straightforward in design, reproducible in its application to all work element proposals, and consistent with the needs of the ECUT annual planning cycle. It also provides for the important use of engineering judgment at appropriate points in the process.
3. On the basis of individual conversations, the method was acknowledged by the ECUT program and project managers as an important step toward developing a routine annual appraisal methodology. All project managers participated in the data collection and analysis process.
4. The highest scoring work element was from Chemical Processes. However, as a group, the work elements from the Materials and Closed-Cycle Power Systems had the best overall results. At least 50% of their work elements placed in the top third of the ratings.
5. The Direct Heating and Conversion System work elements had the lowest group scores. Most of these work elements fell in the bottom third and no work elements appeared in the top third of the ratings.

6. On the average the largest percentage of the Work Element Rating score was due to the FOM_n term for Chemical Processes (71%), Closed-Cycle Power Systems (65%), and Materials (68%), as opposed to the PBA_n term. Thus, the high ranking of these projects was a result of the large influence of benefit/cost ratios. Alternatively, the Direct Heating and Conversion rating scores were much more heavily influenced by the PBA_n factor; on the average, 83% of its WER score was due to influence of the $0.15 \times PBA_n$ term.
7. The appraisal criteria and work element data requirements were misinterpreted by some project managers. The particular definitions chosen for some of the variables and data items may have lead to nonstandard entries on the data forms for some work elements.
8. The compressed appraisal time schedule did not permit sufficient opportunity for thorough collection and verification of work element data. Moreover, during the appraisal, it became apparent that the results were highly dependent upon accurate input data.
9. The standardized energy consumption and efficiency data from the Reference Energy System were not available at the disaggregated level necessary for direct application to the range of ECUT work elements (Brookhaven National Laboratory 1979). Also, the particular technologies assumed to be present for the forecasted years 1990 and 2000 energy use were not completely documented.
10. Some overlapping in the definition of appropriate work elements and their areas of research occurred. For instance, "separation" research and "feedstock preparation" appeared in both the physical and chemical project areas.
11. The appraisal review panel had some difficulty in considering all the detailed work element data during its limited review period.

RECOMMENDATIONS

As a result of the experience in the 1981 appraisal, several recommendations to improve future appraisal efforts have been developed:

1. The ECUT program planning activities should include a formal, systematic research appraisal as part of the annual work element review and budgeting process.
2. Improvements in the clarity and completeness of the definitions for the appraisal criteria and data should be made to insure common interpretation of analysis and data requirements. Particular attention is necessary for the market penetration variables and the nonenergy benefits assessments.
3. The appraisal process schedule should allow more time for collection and review of work element data. Closer coordination between the ECUT planning staff and the project managers during data collection should help clarify the data needs and allow verification of performance claims.
4. The appraisal data should be reviewed by the planning staff prior to the appraisal review session to identify areas for detailed focus early in the appraisal process.
5. A more explicit process to clearly document and relate the ECUT Division objectives to the steps of the appraisal process should be completed prior to

selection of the fuel savings weights and time frames. These weights should be reviewed and updated to incorporate the most current DOE policy and fiscal guidance.

6. A careful review of the work element R&D description and market applications affected by the research should be completed prior to detailed data collection to avoid overlap in research areas covered or in energy savings claimed. Also, the work element R&D costs should be reviewed for consistency with the energy savings benefits claimed.
7. The data review process by the appraisal panel should be revised so that a detailed review is completed only for data subject to significant question.
8. Alternative methods to compute numerical work element ratings using the appraisal data should be investigated to assess their attractiveness for future appraisal sessions.
9. A sensitivity analysis to identify and describe the appraisal calculation parameters that have the most influence on the WER rating results should be conducted.

A review of these recommendations is being conducted as part of the planning process for the 1982 ECUT Work Element Appraisal. In addition, the process of appraising ECUT R&D is undergoing continual evaluation in a search for methods of analysis most appropriate to exploratory applied technology research. For example, sensitivity analyses of the 1981 appraisal are being conducted to study the following issues:

- analysis of the accuracy requirements for appraisal input data
- identification of those appraisal calculation parameters that are most sensitive to changes in the input data
- determination of whether the major assumptions in the current appraisal calculation have a significant effect on the results when compared with other assumptions.

Also, investigations for better ways to measure the benefits of federal R&D expenditures for technology development are planned. The ECUT Appraisal Review Panel considers these activities as important steps in providing effective planning methods that will help to meet the long-range ECUT and national energy objectives.

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APPENDIX I

ECUT CANDIDATE WORK ELEMENT DESCRIPTIONS

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ECUT CANDIDATE WORK ELEMENT DESCRIPTIONS

ENGINE COMBUSTION TECHNOLOGY

Otto-Cycle Engines

This work element uses laser-based measurement and multidimensional computer analysis of the dynamic chemical and physical forces acting in cylinder combustion to support the development of new technologies that can improve the efficiency, emissions, and fuel flexibility of gasoline-fueled automobile and truck engines. Engine designs under study include Direct Homogeneous Charge (DHC) and Direct Injection Stratified Charge (DISC).

Diesel Engines

Laser-measurement techniques and computer analysis will be used to examine the combustion dynamics inside diesel engines. By analyzing internal temperatures, pressures, and turbulences, the efficiency and emissions characteristics of diesel-powered automobile and truck engines will be enhanced.

CLOSED-CYCLE POWER SYSTEMS

Stirling Cycle Technology

The focus of this work element is on specific deficiencies in stirling engine technology. The research work will seek to improve the design of air preheaters and the heat transport system from combustion gas to engine working fluid, seals and piston rings. Work will also be directed toward improved designs that require less materials at a lower cost.

Closed-Cycle Brayton Technology

The objective of this work element is to improve the economics and market potential of closed-cycle brayton engines by upgrading design, materials, and systematic heat transport components so that the technology can perform with greater efficiency at higher temperatures.

Rankine Cycle Technology

This research will investigate the desirability of candidate organic fluids, gather information on the reliability and the appropriateness of the technology to various applications, and implement improved heat transfer mechanisms in the corrosive exhaust environment.

Advanced Closed-Cycle Technology

Research in this work element will examine in the stirling and brayton technologies the characteristics of physical process and chemical/fluid variations that might have advantages in specific industrial, transportation, and urban waste applications.

DIRECT HEATING AND CONVERSION

Data and Design Methods Development for Alternate Fuels in Furnaces and Boilers

By assembling a data base on the chemical and physical characteristics and the combustion properties of candidate fuel alternatives to petroleum, this work element will provide practical experience in burning liquids and gases derived from nonpetroleum sources. In addition, it will also provide appropriate boiler and furnace design parameters to establish fuel flexibility and environmental integrity.

Advanced Concepts for Using Dirty Fuels in Furnaces and Boilers

This research will investigate advanced concepts to create clean, compact, reliable, and low-maintenance industrial furnace and boiler systems. It will also investigate modifications to existing combustion concepts, such as grate burners, fluid bed, entrained flow, and molten salt, to take advantage of the physical and chemical characteristics of marginal fuels.

Retrofit and Fuel Flexibility in Furnaces and Boiler Systems

The total combustion system fuel supply, storage, preparation, injection heat transfer, cleanup, and exhaust will be considered in this research, along with instrumentation and control systems. These areas will be studied to design low-cost retrofit systems that will enable industrial boilers and furnaces to operate over a wide variety of fuel input conditions.

Direct Thermal to Electric Conversions in Furnaces and Boiler Systems

The objective of this work element is to capitalize on the potential that exists in high temperature environments in furnaces using alternate fuels to convert thermal energy directly to electricity. The focus will be on examining thermionics and thermoelectrics to increase the operational temperature and environmental range in which the alkali metal thermoelectric converter (AMTEC) can be effective. This work is intended to provide flexibility in the mix of electrical power and process heat requirements over an entire range of operational needs.

PHYSICAL PROCESSES

Heat Transfer

This work element will improve heat exchanger efficiency by reducing losses due to thermodynamic irreversibilities. It will also obtain operating data and design information on the fouling and corrosion characteristics of different surface materials. It will improve cost effectiveness by identifying core densities with margins of safety and reliability appropriate to the application.

Feedstock Preparation

This research will identify opportunities to improve energy use in the initial stages of the ore beneficiation process, including crushing and grinding of mineral feedstocks in the primary metals industries.

Industrial Waste

The purpose of this work element is to identify deficiencies in the technology base associated with transportation, classification, and reclamation of energy and materials from industrial waste streams, and to reduce the amounts of capital and energy required to recapture these resources.

Sensor Technology

The objective of this work element is to promote and develop the use of sensor and control systems in manufacturing processes, especially in mature industries with aging capital stocks like primary metals. Sensor technology will be used for early detection of flaws and reduction of defects by better measurement and process speed control. These improvements will result in less energy use, reduced costs, improved system reliability, and better product quality.

Separation

This research will develop less energy-intensive operations like liquid-liquid extraction and membrane separation as alternatives to distillation and evaporation processes. It will also improve efficiencies of distillation and separation where no opportunities for alternatives exist by introducing compression and condensation stages into the process cycle and by developing improved models of the steady-state and transient performances of the process.

CHEMICAL PROCESSES

Electrowinning and Electrodeposition

Through modern instrumentation and techniques for improved diagnostics and process control, this research will develop a technology base to increase processing rates in metallurgical reactors by determining mechanisms and flow rates for chemical processes in electrolytic cells. In addition, this work will identify approaches necessary to develop salts that melt at lower temperatures than currently used materials.

Separation Processes

The work in this element will concentrate on supercritical fluid extraction, membrane applications (including hollow fibers), physical absorption as an alternative to liquefaction or chemical reaction, and flotation technology, including use of surfactants in ore and biochemical separation processes. Studies of these technologies will be done to validate advanced concepts for operation of energy-intensive processes.

Biological Processes Development

This work element will develop an understanding of microbial processes for their adaptation to the manufacture of chemical commodities and for production of alternative feedstock chemicals. It will concentrate on recombinant DNA, and on engineering aspects of immobilized biocatalyst reactors so these technologies can be scaled up to a level suitable for commercialization in the industrial sector.

Chemical Feedstocks from Biomass and Waste

This work element will seek better use of cellulose by developing and optimizing the enzymatic process of obtaining fermentable sugars through identification and characterization of the best enzyme sources, investigation of immobilized enzyme systems, and development of a continuous process concept. With ultrasensitive instrumentation it

will also seek to optimize anaerobic digestion performance by monitoring the gases, particularly methane, generated in the head of the reactor.

Industrial Organic Chemicals, Plastics and Synthetics

This work element will provide a means to generate more efficient, cleaner reactions under milder conditions through the development of both new catalysts for syngas and olefin conversion and oxidation, and novel electrochemical and photoelectrochemical processes for the reduction of CO and CO₂.

Nitrogen Fixation

To improve the activity and selectivity of catalysts, this work element will utilize recent advances in understanding how catalyst systems function to produce higher yields and improved efficiencies of steam reformers for H₂ and ammonia manufacture.

MATERIALS

Materials for High-Temperature Waste Heat Recuperators

This work element will develop advanced ceramic and metal coating materials concepts for high-temperature heat exchangers for use in various exhaust stream environments to deliver preheated combustion air at 870°C.

Materials for Buildings Heat Exchangers

This work element will seek to develop low-cost fabrication techniques for heat exchangers to be used primarily in the residential and commercial sector. This will be done through identification of candidate materials, testing for thermal conductivity, structure integrity and life in the actual operating environment, and measurement of permeabilities to moisture and gaseous pollutants.

Materials for Buildings Insulation

The objective of this work element is to conduct research on materials degradation due to aging and seasonal cycling and to identify superior alternatives to foam and fibrous insulation materials in wide use today.

Materials for the Light-Duty Adiabatic Diesel and for Advanced-Heat Engines for Ground Transportation

This work element will conduct design studies of conceptual adiabatic diesel engines, and then candidate materials concepts will be selected and tested under laboratory conditions. Surviving materials will then be tested in real engines. The work element will also develop advanced structural ceramics and metals and seal materials for use in advanced turbine and stirling engines to achieve a 5% increase in fuel economy over modern spark ignition engines.

Advanced Electrodes for Aluminium Reduction Cells

This work element will develop titanium-diboride cathodes that can withstand cracking and corrosion problems in a Hall aluminum reduction cell environment.

Tribological Applications to Ground Transportation

Concentrating on piston rings, skirts, traction drives, and bearings, this work element will develop advanced materials and lubricants that could improve fuel economy in the ground transportation sector by 25%.

Recycle of Plastics

Through research work on compatibilizers, separations, and utilization of polymer mixtures, this work element will advance the technology for plastics recycle. A potential saving of 31% of the fossil fuel energy annually required to produce plastics will result.

Light-Weight Materials for Ground Transportation

This work element seeks to improve vehicle fuel economy by developing light-weight structural materials like magnesium and composite polymer ceramics.

APPENDIX II

WORK ELEMENT APPLICATIONS SUMMARY

APPENDIX II

WORK ELEMENT APPLICATION SUMMARY

	Trans- port: Auto	Trans- port: Other	R/C: Space Cond	R/C: Misc Elec	R/C: Misc Thermal	Ind: Elec Drive	Ind: Basic Metals	Ind: Petro- chem	Ind: Process Heat	Utilities
1. Engine Combustion Technology										
1. Otto Cycle Engines	•		•							
2. Diesel Engines	•	•								
2. Closed Cycle Power Systems										
1. Stirling Cycle Technology	•	•	•	•		•			•	•
2. Closed Cycle Brayton Technology		•	•	•		•			•	•
3. Rankine Cycle Technology		•	•			•			•	•
4. Advanced Closed Cycle Technology		•	•			•			•	•
3. Direct Heating and Conversion										
1. Data & Design Methods Development for Alternate Fuels in Furnaces & Boilers			•		•				•	•
2. Advanced Concepts for Using Dirty Fuels in Furnaces and Boilers			•		•				•	•
3. Retrofit and Fuel Flexibility in Furnace and Boiler Systems			•		•				•	•
4. Direct Thermal-to-Electric Conversions in Furnaces and Boiler Systems			•		•				•	•
4. Physical Processes										
1. Heat Transfer	•	•	•	•			•	•		•
2. Feedstock Preparation							•			
3. Industrial Waste							•	•		
4. Sensors	•	•	•	•	•		•	•	•	•
5. Separation								•	•	
5. Chemical Processes										
1. Electrowinning and Electrodeposition							•		•	
2. Separation Processes								•	•	
3. Biological Processes Development								•		
4. Chemical Feedstocks from Biomass Waste								•		
5. Industrial Organic Chemicals, Plastics and Synthetics								•	•	
6. Nitrogen Fixation									•	
6. Materials										
1. Materials for High Temperature Waste Heat Recuperators							•			•
2. Materials for Buildings Heat Exchangers			•							
3. Buildings Insulation			•							
4. Materials for the Light Duty Adiabatic Diesel and for Advanced Heat Engines for Ground Transportation	•	•								
5. Advanced Electrodes for Aluminum Reduction Cells							•			
6. Tribological Applications to Ground Transportation	•	•								
7. Recycle of Plastics								•		
8. Lightweight Materials for Ground Transportation	•	•								

GLOSSARY

For purposes of this report, several terms have been specifically defined to describe the appraisal analysis.

Adjusted Energy Savings (AES) - The reduction in weighted primary energy use attributable to ECUT research work for a particular end-use technology application. AES is obtained by first determining the fuel savings due to ECUT research by fuel type. Each fuel use value is then multiplied by a weighting factor whose magnitude indicates the relative importance of savings for each particular fuel type. The fuel type results are then summed to compute the total AES.

Average Efficiency of Service - The average energy service output (in quads) divided by the average fuel input (in quads) for a technology application or process, in an end-use sector.

Basic Funding Level - The FY 1981 work element funding level plus a modest increase for inflation effects (no new research activities).

Energy Fuel Requirement - The amount of primary fuel needed by a system, process, or device to satisfy a specified Energy Service Demand.

Energy Service Demand - The amount of delivered energy, measured in quads, projected to be used in a target year (either 1990 or 2000) in an end-use sector where an ECUT work element would be applied.

Enhanced Funding Level - The funding level needed to accelerate the schedule, expand the scope, or reduce risk of failure to meet the objective for a research activity.

Figure of Merit (FOM) - A benefit/cost calculation, derived by dividing the Adjusted Energy Savings of a work element by its R&D cost in thousands of dollars.

Fuel-Mix Weighting Factor - A number that reflects the sum of all individual fuel proportions in a given Work Element Application in a given target year, weighted by the Fuel-Savings Weighting Factors. The number is computed by multiplying each fuel proportion times its corresponding Fuel Weighting Factor and adding the results.

Market Penetration Fraction - The percentage of a Work Element Application market that would be captured in a particular year by the technology advance resulting from the R&D efforts in a work element. The total market size is defined by its Energy Service Demand.

Minimum Funding Level - The smallest funding amount needed to meet current contracted obligations and keep key staff on the research activity.

Primary Energy Consumption Proportion - the fraction (or percent) of Energy Service Demand that would be met by the use of a particular primary fuel type. A breakdown of fuel types used in this appraisal is given below:

1. petroleum	4. electricity
2. gas	5. synfuel
3. coal	6. other

Program - The entire group of project research and development activities in the ECUT Division.

Program Elements - The two broad areas of research and development funded by the ECUT program in the Energy Conversion Technologies and Energy Utilization Technologies areas.

Projects - The six areas of technology research funded by the ECUT Program. In this document, the areas are Engine Combustion Technology, Closed-Cycle Power Systems, Direct Heating and Conversion Systems, Physical Processes, Chemical Processes, and Materials.

Project Evaluation - A formal review of the ongoing work elements in an ECUT project for the purpose of management control and progress review.

Public Benefits Assessment (PBA) Score - A number between zero and one that reflects the degree to which a work element will contribute to the general economic, social, environmental, and institutional welfare.

Work Elements - Categories of closely related research work that are within each ECUT project and that refer to particular technology areas. Work elements are defined specifically enough to allow estimation of the energy conservation potential of the research activities.

Work Element Application - A work element subdivision that defines a single specific energy-using system, process, or end-use sector.

Work Element Appraisal - The process of systematically and objectively analyzing the future energy and fuel savings, public benefits, and research dollar costs associated with the R&D efforts of the proposed ECUT work elements. The quantitative results are used to produce a rank ordering of work elements that are used as an input to ECUT program budgeting.

Work Element Rating (WER) Score - A number that is the final result of the application of the appraisal calculations to each work element. The number is comprised of the Figure of Merit (normalized) plus 0.15 times the Public Benefits Assessment Score (normalized).

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