ANL/EES-TM-349

DETERMINANTS OF EFFECTIVENESS OF INTERNATIONAL COLLABORATIVE RESEARCH AND DEVELOPMENT: PROJECT STATUS REPORT

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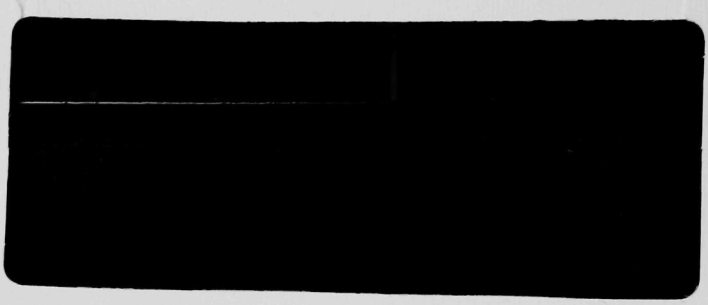

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by

Carole B. Szpunar, George E. Dials, Jerry L. Gillette,
and William A. Buehring

Energy and Environmental Systems Division
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ABSTRACT

At the request of the U.S. Department of Energy, Office of the Assistant Secretary for Fossil Energy (DOE/FE), Argonne National Laboratory developed a method to help DOE/FE decision makers assess the desirability of participation in specific international collaborative research and development (R&D) activities. Based on a review of 71 completed, existing, and planned R&D agreements, followed by structured interviews and preference assessments with individuals experienced in international coal research activities, six attributes for measuring the effectiveness of such agreements were chosen: (1) probability of achieving agreement-specific objectives, (2) U.S. balance-of-trade implications, (3) joint commitment of the R&D partners, (4) distribution of anticipated benefits from the R&D, (5) professional challenge and worthiness of the R&D, and (6) level of industrial participation. Based on decision-analysis principles, utility functions were then developed reflecting the preferences of the experts with regard to the attributes. These attributes and utility functions comprise the basic methodology tools. The methodology was then used to rank 22 completed agreements, as well as 23 proposed R&D topics, in order of their highest desirability for DOE/FE participation. The proposed topics were selected from a list of over 100, involving 21 developing countries, identified as having potential for DOE/FE collaboration.

1 INTRODUCTION

1.1 SCOPE OF WORK

This report describes the steps involved in developing a decision-analysis methodology as a tool for evaluating and prioritizing collaborative international research and development (R&D) activities by the U.S. Department of Energy, Office of the Assistant Secretary for Fossil Energy (DOE/FE). It is intended primarily as a status

report on a larger DOE/FE project being conducted by Argonne National Laboratory (ANL). The project has three primary objectives:

1. Identify and define measures of effectiveness of DOE/FE international collaborative R&D activities,

2. Develop a method to help DOE/FE decision makers assess the desirability of DOE/FE participation in collaborative R&D proposals, and

3. Apply that method to evaluate and prioritize proposed initiatives, with particular emphasis placed on collaborative R&D proposals with developing countries.

International activities are an important element of the overall R&D program of DOE/FE. In December 1985, the International Research and Development Panel of the Energy Research Advisory Board (ERAB) issued a report[1] that unequivocally supported strong, balanced, international R&D collaboration involving DOE. The panel developed four general criteria to assess the viability of proposed collaborative ventures:

1. Consonance of goals and objectives among the partners,

2. Potential for mutual benefits acceptable to all partners,

3. Contribution to U.S. energy security, and

4. Sustainability of program technical quality and funding throughout the collaborative period.

In April 1987, the Assistant Secretary for Fossil Energy stated in a decision memorandum that DOE/FE should continue to pursue international collaborative R&D, but with emphasis on those programs that appear to be the most beneficial to the United States. To assure compliance with that directive, the Assistant Secretary called for the development of specific criteria to evaluate agreements under consideration. This task was an important rationale of the ANL project.

The Assistant Secretary also defined two key considerations at the outset to guide the assessment of benefits to the United States from proposed agreements -- the potential impact of such agreements on (1) U.S. industry competitiveness and (2) the *quid pro quo*, a term that refers to the balance between the value received by the United States with the value given (i.e., outlay of resources). The value received can consist of both direct and indirect benefits and can apply to either the public or private sector.

As work on the project progressed, the scope expanded to cover several additional but related tasks. For instance, it became apparent that, in order to identify elements of international R&D agreements that could be used to measure their success (or likelihood of success), it would be useful to understand the problems or issues facing

the designers, negotiators, and/or implementers of such agreements. Exploration of this topic led to the conclusion that these issues fall into two categories: motivational and organizational. Motivational issues deal with the national objectives, financial considerations, and technical considerations of each party to the agreement. Organizational issues deal with the management structure in each country and the physical impediments to achieving the agreement's objectives.

Another important task was to test and demonstrate the efficacy of the methodology once it had been developed. This was done by using it to rank the desirability of 22 completed (i.e., closed) agreements. These agreements had been identified during the first phase of the project, when a large number of agreements were studied to help identify measurable elements of effectiveness.

The methodology was also applied to an evaluation of new international R&D possibilities. To accomplish this task, the ANL project team identified over 100 potential research topics involving 21 developing countries. The energy and technological needs of these nations were matched, in a broad and preliminary fashion, with possible U.S. strengths, reflecting the ERAB panel's criteria for proposed collaborative ventures described above. Of these topics, 23 were selected for the methodology application. Country profiles incorporating the entire list of research topics are included among the appendices to this report. Follow-on activities will include working with DOE staff and representatives of those countries to develop more-definitive R&D proposals from that list.

The usefulness of the methodology depends on the needs of DOE/FE. Simply using it as one tool in evaluating a proposed agreement, even if exogenous factors lead to a different decision from that suggested by the methodology outcome, can be of benefit by clarifying important considerations and agreement characteristics. The experience to date of DOE/FE staff members and outside experts indicates that the methodology can aid in evaluations of international collaborative R&D proposals.

1.2 METHODOLOGY OVERVIEW

The methodology developed is based on decision analysis, which comprises both a formal approach to decision making and a set of specific techniques. Decision analysis is a systematic and logical set of procedures for analyzing complex, multiple-objective decision problems. The approach is to divide a problem, characteristically one with multiple objectives, as would be the case with DOE funding decisions, into small, understandable parts and to analyze each part separately. The specific techniques are based on multiattribute utility theory, described by Keeney and Raiffa.[2]

In general, the decision-analysis approach can be divided into the following steps:

1. Identifying alternatives,

2. Defining decision objectives and, based on them, measurable attributes of the alternatives,

3. Determining how the alternatives perform with respect to the attributes identified in step 2,

4. Quantifying the preferences of the decision maker(s), and

5. Evaluating and comparing alternatives based on the outcomes of steps 3 and 4.

For this project, the alternatives to be evaluated (step 1) would consist of a set of proposed international collaborative agreements, and the basic decision would be whether to fund any of these agreements and, if so, which one(s). Accordingly, step 2 involves specifying a comprehensive set of objectives that reflects concerns relevant to the funding decision. Attributes are measures that provide a quantitative basis for specifying how well objectives are met. A numerical scale must then be established for each of the attributes.

As an example, one objective in the DOE funding decision might be to maximize the commercial applicability of R&D results. The associated attribute might therefore be defined as "the expected time frame for commercial applicability" and the attribute scale might consist of three numerical values, where 1 equals near-term, 2 equals medium-term, and 3 equals long-term commercial applicability. This type of scale is a *constructed* scale, made by associating a description of events or conditions with a discrete numerical index. Only the defined points on such scales have meaning. Another type of scale is a *natural* scale. For example, for the objective of minimizing sulfur dioxide (SO_2) emissions, the associated attribute would be the "level of SO_2 emissions." In this case, a natural scale would be used, e.g., the tons of SO_2 emitted. This scale would be continuous, the values on it ranging from some minimum value to a maximum value corresponding to the air quality standard for SO_2.

Step 3 involves a technical assessment to determine the possible outcome levels, in terms of the attribute measurement scales, for each agreement. Uncertainties must be quantified when outcome levels are not known exactly. For example, one agreement might be considered likely to produce commercially applicable results in the near term, compared to the long term for another agreement. In terms of the constructed scale given above, the likely outcomes of these two agreements would be quantified as levels 1 and 3, respectively.

Step 4, quantification of decision-maker preferences, involves assessing the decision maker's degree of satisfaction with each attribute (referred as a single-attribute utility function) and integrating the resulting set of utility functions (i.e., one for each attribute) into a single, multiattribute utility function. This step is performed abstractly, without reference to particular alternatives; however, the utility function that results can subsequently be used to predict the decision maker's expected degree of satisfaction with any set of alternatives. This, in fact, is what occurs in step 5, which brings together the results of the previous steps. For each alternative, the multiattribute utility function is run with the attribute levels determined in step 3. The result is an expected utility, represented by a score ranging from 0 to 1000. The best agreement is the one with the highest utility score. The agreements can be listed in descending order by their utility scores, which would be in effect a ranked list.

Two caveats should be noted. First, it is impossible to "verify" that the ranked list of agreements produced by the methodology is "correct." The best one can say is that, according to the technical and subjective assessments incorporated in the approach, the top-ranked proposal is considered to be more desirable for DOE/FE participation than the second-ranked proposal. One cannot extrapolate from this to say, however, that the top-ranked proposal should be funded (it could just be the top-ranked of a very poor set).

Second, the ranking produced does not imply that DOE/FE should fund the proposals in the order specified. Several critical dynamic factors, such as budget constraints and current political considerations, are excluded from the procedure. If the top-ranked proposal exceeds the budget, the second-ranked one would be the next most appropriate.

For this project, a total of six attributes were eventually developed, each with either a constructed or a natural numerical scale. Also, utility functions were developed not for one decision maker, but for 11 persons, including current or former DOE decision makers, technical experts, and other knowledgeable persons whose preferences might be representative of those involved in the decision-making process at some time. Hence, as discussed in Secs. 4 and 5, an additional step is incorporated into the methodology to average the 11 sets of utilities to arrive at a single basis for ranking agreements.

The information obtained from all 11 utility functions is valuable in assessing agreements, particularly proposed agreements, for several reasons. First, it captures the concerns of each expert without unduly emphasizing the views of any one. Second, consistency among the rankings shows a "consensus" and reinforces the appropriateness of the final ranking, which is obtained by an averaging procedure. For example, an agreement that is consistently near the top of the 11 separately ranked lists would likely be a desirable agreement. Third, inconsistency among the rankings, especially if some are quite low, could suggest some deficiencies in the agreement and lead to a reexamination or redesign of certain aspects of that agreement. Finally, the spread between the highest and lowest rankings can help demonstrate the degree of likely diversity in opinion about each proposal in question.

Nevertheless, while 11 separate utility functions provide important and useful information about a group of agreements, they can also sometimes make evaluation difficult for those individuals who must make ultimate choices among agreements and who are looking for "one answer" to guide them in making these choices. It was for this reason that the procedure was developed to average the 11 sets of utilities, then order the average utility scores to arrive at an overall ranking. This procedure offers the "one answer" solution while incorporating each knowledgeable point of view.

1.3 ORGANIZATION OF THIS REPORT

Sections 2 and 3 describe the chronology of steps involved in developing the methodology tools. Two applications are then presented in Sec. 4. Section 5 discusses the theoretical guidelines developed for designing agreements, and Sec. 6 summarizes work that is continuing or is planned. The methodology development is described by Buehring et al. in Argonne National Laboratory Report ANL/EES-TM-348.

2 IDENTIFICATION OF OBJECTIVES AND ATTRIBUTES

Two key steps in the methodology development were to (1) identify measurable attributes that can be used to evaluate the desirability of participation in a collaborative R&D agreement and (2) derive a set of utility functions reflecting a diversity of knowledgeable opinion regarding these attributes. Work on these tasks progressed in an iterative fashion. This section outlines the chronology of the work performed up to and including the development of a final list of attributes and assignment of scaling constants to them. Section 3 explains the development of a final set of 11 multiattribute utility functions.

2.1 OVERALL METHODOLOGY OBJECTIVE

The overall objective of the methodology was not well defined at the early stages of the study. It was clear that the methodology should account for the perceived likelihood of an agreement's "success," but the project team could not specify an overall objective in terms that would meet the requirements of a formal decision-analysis approach before reviewing closed agreements and holding discussions with individuals who had extensive experience with international agreements.

2.2 INITIAL SET OF POTENTIAL ATTRIBUTES

The first step in developing the methodology was to define an initial set of measures (potential attributes) for international R&D agreements. This was accomplished through examination of 71 completed, existing, and planned international collaborative R&D agreements related to fossil energy and through discussions with experts having expertise in either international agreements or decision-analysis techniques. The agreements reviewed were drawn from the September 1986 edition of *Fossil Energy International Program Activities*[3] and consisted of 43 active, 11 planned, and 17 closed agreements. The documentation used included:

1. Historical documents and correspondence relating to specific projects or general R&D programs,
2. Congressional testimony related to each type of agreement,
3. Memoranda of understanding (MOUs) and correspondence regarding the proposed agreements,
4. Studies on international energy cooperation,
5. DOE/FE project files,
6. Pittsburgh Energy Technology Center project files, and
7. General-periodical information on major collaborative efforts.

Limited discussions were conducted to fill in the information gaps. Those contacted included DOE/FE project coordinators, project team members from the Bartlesville and Pittsburgh Energy Technology Centers and the Laramie Energy Research Center, and others knowledgeable of specific projects, e.g., ANL researchers involved in the Grimethorpe fluidized bed combustor (FBC) project sponsored by the International Energy Agency (IEA). Opinions on the merit and pitfalls of specific projects were gathered.

Primary and secondary objectives for all agreements were determined, as well as the extent to which these objectives were achieved. Other information relating to the agreements was also gathered to assist in a later project phase (not discussed in this report) aimed at identifying research areas for future collaborative agreements. Focus was on the *quid pro quo* aspects of each agreement.

At this stage, the review included general MOUs as well as existing and closed agreements, and multilateral as well as bilateral agreements. A number of constraints, were soon adopted, however.

First, it was decided to limit consideration primarily to bilateral agreements, i.e., agreements between two countries as partners. One reason was that multilateral agreements such as those sponsored by the IEA, although important, comprised only a small number of the 71 fossil energy agreements examined (5 of the 43 active, 2 of the 11 planned, and 3 of the 17 closed agreements).

Second, it was decided that an MOU could not be assessed in the same way as an implementing agreement. An MOU is usually a first step in the negotiating process; it is a promise to collaborate in a certain research area on a set of topics with the details to be worked out subsequently. Hence, MOUs were reviewed for content and potentially measurable characteristics, but no attempt was made in later stages of the project to subject them to a more rigorous ranking process based on merit, since no supportive details usually exist.

The purpose at this stage of the project was to generate a list of potential measures that would cover a wide range of desirable objectives for international agreements. This initial set was expected to be shortened by eliminating those measures that, upon further reflection, seemed less important in defining elements of a desirable collaborative agreement. The 28 potential attributes identified for this initial list are summarized in Table 2.1.

This initial set of attributes was then used to evaluate several collaborative agreements that had been completed. That is, each agreement was characterized by selecting the level on each attribute scale that best described the agreement. A total, therefore, of 28 numerical values for each agreement were recorded.

2.3 REFINEMENT OF THE METHODOLOGY OBJECTIVE AND ATTRIBUTES

Having gained the experience of evaluating collaborative agreements with respect to the initial set of potential attributes, the project team returned to the

TABLE 2.1 Initial Set of Potential Attributes for Evaluating International R&D Agreements[a]

Category of Objectives	Attribute	Type of Scale[b]
Management and structural	Project duration	N
	Number of participants	N
	R&D location	C
	Management structure (e.g., joint venture)	C
	Party initiating the agreement	C
Financial	Funding levels	N
	Industrial funding	N
	Assurance of continued funding	C
	DOE payback	N
	Transfer of funds between countries	C
Technical	Agreement scope	C
	Agreement focus	C
	Nature of agreement objectives	C
	Expertise exchange between countries	C
	Distribution of benefits	C
	Time frame of issues	C
	Interest level (by U.S. government and industry)	C
	Need for unique facilities	C
	Impact of R&D results on decision making	C
	Possibility for increasing effort during the project	C
	Impact on U.S. balance of trade	C
	Impact on U.S. industry	C
	Impact on world stability	C
	Time spent on technical visits	N
Other	Existence of cultural or language impediments to achievement of agreement objectives	C
	Geographic location of the countries involved	C
	Industrialization level of the major non-U.S. participant	N
	Nature of relations between the U.S. and other participating governments	C

[a]See App. A for a more complete explanation of the attributes and their corresponding scales.

[b]C = constructed, N = natural.

question of what the overall objective of the methodology should be and how it could best be measured. The following statement was constructed:

> The overall methodology objective is to rank proposed international collaborative implementing agreements in order of highest *desirability* for potential DOE/FE participation.

Desirability is based on such objectives as achieving the specific aims of an agreement, assuring a fair distribution of benefits, and assuring the technical worthiness of the R&D activity performed.

However, the project team also realized by this point that some important dynamic factors affecting the decision-making process had to be exogenous to the methodology. Such factors include budgetary, political, and geographical (i.e., strategic) considerations. For example, if budgetary constraints are severe, it might not be possible to strictly adhere to the ranking produced by the methodology. As an example, if the top-ranked proposal by itself exceeded the budget, and the second-ranked proposal did not, then the latter would likely become the first priority for funding. Political and geographical considerations are also best considered outside the methodology because they can change rapidly and can strongly affect the appropriateness of a final recommendation regarding a proposed agreement.

Another possible exogenous factor is the consonance of objectives between the agreement partners. The project team felt that it might be difficult for a reviewer of a proposed agreement to quantify this factor and that it should be left for the decision maker(s) at the time of the funding decision.

Hence, the desirability ranking provided by the methodology is merely one input to the final funding decision, which must also take into account a variety of exogenous circumstances. To make this limitation clear to the experts interviewed in the next project phase, as well as to methodology users, the project team constructed the following summary statement regarding the methodology's assumptions:

> Other important exogenous and/or dynamic factors, such as budget constraints, current political considerations, and consonance of goals and objectives between the interacting parties, must be evaluated and incorporated at the time of funding decisions.

Subsequently, the project team refined the attributes into a more manageable set. One consideration guiding this process was the need to conduct utility assessments of the attributes through interviews with key individuals. Such a process can be time-consuming, especially if a large number of attributes of minimal importance are included in the list. Therefore, every attempt was made to reduce the set to a minimum size.

The modified set is presented in App. B and consists of nine attributes:

1. Maximizing the probability of achieving agreement-specific objectives,

2. Extent of industrial participation in the agreement,

3. Relative amounts of money contributed by the United States and its foreign partners,

4. Location where project funds are spent,

5. Benefits to each partner,

6. Quality of research,

7. Commercial applicability of the results,

8. Benefits to U.S. industry, and

9. Degree to which DOE/FE can recoup its investment if the objectives of the agreement are achieved.

The first attribute was comprised of seven separate measures, reflecting additional attributes from the initial list that encompassed various financial, technical, and structural considerations that would affect the probability of meeting the specific objectives of an agreement. It was planned that the values assessed for these measures during an agreement evaluation would be combined into a single value for this attribute.

2.4 INITIAL INTERVIEWS

The refined set of attributes was sent to eight experts for their consideration in preparation for the utility assessment interviews. The eight experts involved were selected because of their knowledge and experience in international coal research activities and/or a detailed involvement in this project. Many were current or former DOE personnel. The specific purpose of these interviews was to ascertain the viewpoint of each expert with regard to (1) the relative importance of each attribute and (2) the relative importance of each level on the scale for each attribute. The latter set of information comprises the single-attribute utility functions for each expert. The former set of information results in numerical weights, or scaling constants, assigned to the attributes. When the single-attribute utility functions are weighted according to these weights and combined, the result is a multiattribute utility function for each expert.

As these interviews were being conducted, it became apparent that further thinking was needed with regard to several of the attributes as well as some of the attribute scales. For example, several experts were troubled by the concept of industrial participation underlying attribute 2. They pointed out that some agreements were designed with industrial participation as an essential or important component, while in other agreements, typically those oriented toward basic or academic research (rather than applied research), industrial participation was neither intended nor even desired. These experts felt that collaborative agreements should be divided into two categories -- industrially oriented agreements and agreements with a basic-research focus.

Some experts took issue with some of the constructed scales. They felt that some of the less desirable points on these scales were in effect screening criteria and should be avoided in any international collaborative agreement. Therefore, they had difficulty when asked to make a tradeoff of these levels with higher levels of the same attribute or with levels of other attributes. In order to develop utility functions for these experts, it became necessary to eliminate these unacceptable levels so that appropriate tradeoffs could be made.

Finally, some of the attributes were considered to be much more important than others, and some were considered to be not important at all. The project team decided that the latter category of attributes could be omitted without affecting the evaluations of any existing or proposed international collaborative agreements.

Hence, the project team decided to pare the modified list even further, eliminating those attributes deemed by most, at this stage, as being relatively unimportant or impossible to value. It was also decided to develop utility functions only for evaluations of projects in which industry participation is deemed to be important or necessary. Collaborative projects of the basic-research type were set aside for the moment. The reason is that different utility functions would be needed for that type of project, because different importance would be attached to the attributes depending on the type of proposal. Work is planned to design such utility functions for academic or basic-research projects.

2.5 FINAL SET OF ATTRIBUTES

Because of the feedback from the interviews discussed above, it was decided to discard the eight utility functions that resulted from those interviews, rework the attributes, and then conduct a new round of interviews.

The revised set consists of only six attributes and is presented in Table 2.2 along with the corresponding scales. These attributes cover (1) the probability of meeting the agreement-specific objectives, (2) balance-of-trade implications, (3) the distribution of benefits among the partners to the agreement, (4) the level of commitment by each partner, (5) the professional worthiness of the research to be done, and (6) the degree of industrial participation in an agreement. The last attribute would be considered in evaluations of either industrially oriented or research-oriented agreements. However, as discussed above, separate utility functions would be needed, with different weights assigned to each attribute, depending on the type of agreement being evaluated.

The results of the second round of interviews, which were based on this final attribute set, are discussed in Sec. 3.

TABLE 2.2 Final Set of Attributes for Evaluating International Collaborative R&D Agreements

	Attribute	Full Description	Numerical Levels[a]
1	Probability of meeting agreement-specific objectives	What is the probability of success in achieving agreement-specific objectives?	
	Resources	What is the likelihood that resources have been allocated properly and sufficiently to achieve agreement-specific objectives with respect to (1) project duration, (2) project funding, (3) assurance of funding throughout the project at the agreed-upon rate, (4) technical communications and personnel exchanges (excluding administrative functions), and (5) quality of researchers?	1 = Unlikely to be sufficient (0-20%) 2 = Barely adequate, if no project difficulties are encountered (21-40%) 3 = Adequate, but may require adjustment (41-60%) 4 = Adequate (61-80%) 5 = Assuredly adequate (81-100%)
	Structure	What is the likelihood that the management structure can accommodate (1) critical, but routine day-to-day operations and (2) political, cultural, language, and/or other impediments to achievement of agreement-specific objectives?	1 = Complex and/or possibly unwieldy (0-20%) 2 = Complex, but manageable (21-40%) 3 = Adequate, but may require adjustment (41-60%) 4 = Appropriate for general situations (61-80%) 5 = Strong and workable, with procedures already in place to handle possible difficulties (81-100%)
	Technical difficulty	What is the likelihood that the technical difficulty or risk will impede achievement of agreement-specific objectives?	1 = Little (0-25%) 2 = Modest (26-50%) 3 = High, but with procedures in place to manage risk (51-75%) 4 = Significant (76-100%)
2	Balance-of-trade effects[b]	If the agreement-specific objectives are met, what is the anticipated impact on the U.S. balance of trade?	1 = Modest, relative to other agreements 2 = Moderate, typical of many agreements 3 = Large, relative to most agreements 4 = Very large, relative to most agreements
3	Joint commitment	What is the level of joint commitment exhibited by the partners?	1 = Somewhat weak, e.g., partners' objectives overlap only modestly 2 = Moderate, e.g., interests are unbalanced among partners 3 = Essentially equal and of strong importance to partners 4 = Of national priority for partners, e.g., interest exhibited at the ministerial level
4	Distribution of benefits[c]	If agreement-specific objectives are met, what is the anticipated distribution of benefits, in terms of being commensurate with the costs expended by each partner?	1 = Somewhat one-sided, in favor of the foreign partner(s), but still acceptable to the United States 2 = Fair, with (1) technical benefits to all, (2) technical benefits to the foreign partner(s) and financial benefits to the U.S., (3) technical benefits to the foreign partner(s) and political relations with the U.S. significantly enhanced, or (4) some combination of the preceding possibilities. 3 = More advantageous to the U.S., but not to the degree of being threatening and/or disruptive to relationships with the foreign partner(s)

TABLE 2.2 (Cont'd)

Attribute	Full Description	Numerical Levels[a]
5 Research challenge	What is the professional challenge and worthiness of the research?	1 = Routine, of little technical challenge 2 = Routine, but with extensive technical training for one partner in order to develop its capabilities for future collaboration 3 = Modest, and including development and adaptation of procedures to meet agreement-specific objectives 4 = Challenging, with potential for significant findings 5 = At the "cutting-edge" of research, with significant challenge and/or potential for important findings
6 Industrial participation[d]	What is the anticipated level of industrial participation?	1 = Participation or interest present, but little or no industrial funding (could include manpower contributions and payment of incidental costs, e.g., for travel) 2 = Significant industrial funding, but not exceeding 50% for any partner 3 = Significant industrial funding, exceeding 50% for at least one foreign partner 4 = Significant industrial funding exceeding 50% for the U.S., but not for each non-U.S. partner 5 = Industrial funding greater than 50% for each partner

[a]The percentages given for each numerical level for Attribute 1 quantify the probability of meeting the agreement-specific objectives associated with each of the qualitative-level descriptions. For example, a range of 61-80% for meeting agreement-specific objectives has been selected to be representative of adequate resources.

[b]In evaluating the levels for this attribute, the reviewer should consider such factors as (1) the difficulty of and time needed for actions after the project before the balance-of-trade benefits can be realized, and the corresponding likelihood that U.S. industry can and will pursue the indicated commercial targets, (2) the current and future size of the pertinent market, likely U.S. share, and nature and dollar value of the resulting U.S. exports (e.g., hardware, services only, license fees only), and (3) the presence or lack of competitive forces or other factors that could limit the U.S. ability to exploit the technical benefits and proprietary rights acquired as a result of the project.

[c]Fairness does not require benefits to be distributed equally or to be identical. For example, if the partners' investment shares are 60/40, a fair distribution of benefits would also be 60/40. Also, one partner may seek internal use of the technology, and the other export markets. In this case, fairness would relate to the relative value to be obtained from these benefits. Another fairness consideration relates to the differences in timing as to when each county can make use of the R&D results.

[d]In evaluating the importance of this attribute, the reviewer should consider such factors as (1) the desirability of project control by industry, as measured by its funding contribution, (2) the degree to which industrial interest is reflected by funding at the R&D stage, (3) the degree to which industrial influence on management decisions by each partner (achieved by industrial funding in excess of 50% in a government/industry partnership) is desirable to enforce commercial thinking during the R&D stage and thus facilitate commercial use of the results, and (4) the relative advantages of intergovernmental partnerships supported by industry, versus interindustrial partnerships supported by governments. The industrial classification would include such organizations as the Tennessee Valley Authority, which is staffed by government employees.

3 UTILITY ASSESSMENTS

The second and final round of interviews involved 11 individuals. Six had participated in the initial round, but two of the others were not available for round 2. Five new experts were added to broaden the spectrum of views on which to base the utility functions for the methodology. Altogether, the two rounds of interviews involved five DOE/FE personnel (including a Deputy Assistant Secretary and a member of the Assistant Secretary's staff), two former DOE/FE Deputy Assistant Secretaries, three ANL personnel, two consultants knowledgeable in international coal activities and/or government-to-government agreements, and a former IEA Research Director.

Emphasis in the interviews was placed on the industrial category of proposed agreements. However, data were also collected on how the experts would change their preferences if the proposed agreements were to be considered from a research focus instead.

The purpose of these interviews was to develop utility functions reflecting each expert's preferences with regard to the six attributes on the final list (Table 2.2). Three steps were involved:

1. Specifying attribute weights,
2. Assessing single-attribute utility functions, and
3. Constructing multiattribute utility functions from the functions developed in step 2.

These steps are described in Secs. 3.1 and 3.2.

Together with the attributes and associated scales described in Table 2.2, the 11 utility functions discussed in this section complete the methodology tools developed. How to use these tools in evaluating a group of agreements is illustrated in Sec. 4.

3.1 ATTRIBUTE WEIGHTS

Each expert was asked to consider what tradeoffs among the attributes (if not all could be equally achieved at an optimal level, for instance) he or she would find acceptable. This judgment of the relative importance of the attributes was to be reflected in numerical weights assigned to each. Table 3.1 summarizes the results. The weights assigned by the 11 experts to each attribute varied widely, as indicated by their standard deviation, which is of the same order of magnitude as their average. However, each attribute was rated as first or second in importance by at least one of the 11 experts, which demonstrates that all six attributes represent important considerations in the funding decision. This finding verified the project team's expectation that all six attributes would be found important, because they were the ones retained or derived from the larger set used in the initial round of interviews. Another important finding is that none of the experts rated any attribute as high as 0.5 (although expert 9 came close

TABLE 3.1 Weights Assigned to the Final List of Attributes[a]

Expert	Probability of Achieving Agreement-Specific Objectives	Balance of Trade	Joint Commitment	Distribution of Benefits	Research Merit	Industry Participation
1	0.39	0.28	0.07	0.08	0.03	0.15
2	0.31	0.36	0.09	0.15	0.05	0.04
3	0.21	0.29	0.13	0.15	0.06	0.16
4	0.14	0.13	0.27	0.08	0.01	0.37
5	0.46	0.09	0.20	0.05	0.05	0.15
6	0.29	0.13	0.08	0.16	0.23	0.11
7	0.26	0.10	0.23	0.13	0.21	0.07
8	0.20	0.15	0.16	0.18	0.16	0.15
9	0.49	0.13	0.14	0.09	0.09	0.06
10	0.22	0.40	0.09	0.11	0.08	0.10
11	0.21	0.01	0.36	0.42	<0.01[a]	<0.01[a]
Average	0.29	0.19	0.16	0.15	0.09	0.12
Standard deviation	±0.11	±0.12	±0.09	±0.10	±0.07	±0.09

[a]The weights assigned by each expert add to 1.00. In the case of expert 11, the weights assigned to research merit and industry participation are too negligible to affect the total.

for attribute 1); thus, none of the 11 utility functions eventually developed is dominated by only one attribute.

Attribute 1 -- the probability of achieving agreement-specific objectives -- consists of three components (explained in Table 2.2). The weights for these components are presented in Table 3.2. In general, resources and management structure were valued more highly than the technical difficulty component. However, as was the case for the six attributes overall, all three components were considered important.

3.2 SINGLE-ATTRIBUTE AND MULTIATTRIBUTE UTILITY FUNCTIONS

Each expert was then asked to consider, for each attribute with a constructed scale (i.e., all attributes except the first), the relative importance of each level on that scale. To quantify this judgment, each expert was asked to arrange the levels, one attribute at a time, in order of preference and to rank each level on a scale from 0 to 100. This assessment produced six single-attribute utility functions for each of 11 experts. Such results amount to a large data set that does not readily lend itself to a

TABLE 3.2 Weights Assigned to the Three Components of Attribute 1[a]

Expert	Resources	Management Structure	Technical Difficulty
1	0.35	0.20	0.45
2	0.45	0.25	0.30
3	0.40	0.50	0.10
4	0.30	0.60	0.10
5	0.40	0.40	0.20
6	0.40	0.40	0.20
7	0.30	0.50	0.20
8	0.40	0.40	0.20
9	0.60	0.15	0.25
10	0.60	0.25	0.15
11	0.40	0.50	0.10
Average	0.42	0.38	0.20

[a]Attribute 1 is the probability of achieving agreement-specific objectives. The weights assigned by each expert add to 1.00.

summary tabular display. However, some general statements about the resulting utility functions can be made.

In general, there was reasonable agreement among the experts with respect to the desired levels of achievement for each attribute, though some experts had strong preferences with respect to certain scales. Attribute 6 (industrial participation) provides an example of some of the differences in opinion. One of the experts rated level 2 (see Table 2.2 for a definition of the levels) as being the most desirable level of achievement, and rated level 3 almost as highly. Levels 4 and 5 were rated next in desirability, but only as 40% and 35% as desirable, respectively, relative to level 2. On the other hand, another expert, one with a strong industrial background, rated level 5 as the most desirable. Level 2 was only the fourth most desirable and was rated as 30% as desirable as level 5 -- almost an exact reverse of the rating by the first expert. This difference was much greater than was typical of the differences among the experts. The diversity exhibited in these single-attribute utility functions helps illustrate the usefulness of the decision-analysis approach in accommodating different perspectives relating to a decision problem.

On the basis of the attribute weights developed earlier (see Sec. 3.1), the six single-attribute utility functions for each expert were combined to arrive at a multiattribute utility function for each expert. Since 11 experts were involved, 11 multiattribute utility functions were developed, each reflecting a different perspective

on how to rate the desirability of various collaborative R&D proposals for DOE/FE involvement.

An important question considered by the project team was whether all 11 multiattribute utility functions are needed. Partly for the purpose of examining this question, a trial run of the methodology was conducted, using a set of closed agreements. However, the functions proved to be sufficiently different (as discussed in Sec. 4) that it did not seem desirable to discard any one of them. Hence, it is recommended that all 11 be used in applications of the methodology.

4 APPLICATIONS

This section presents two applications of the methodology: one involving a set of 22 closed agreements, the other involving a set of 23 proposed R&D topics. These applications are discussed in Secs. 4.1 and 4.2, respectively.

4.1 CLOSED AGREEMENTS

A detailed review of 22 closed agreements and completed annexes to active agreements was conducted in the first project phase to assist in establishing the objectives and attributes needed for the methodology. After the methodology tools were developed -- i.e., the attributes, their weights, and the multiattribute utility functions -- the team decided to reexamine the 22 agreements as a trial run of the methodology. The outcome was a hypothetical rank-ordering of the agreements in terms of their desirability for DOE participation. This section describes the steps involved in this application. The 22 agreements are identified in Table 4.1.

4.1.1 Assessment Relative to the Attribute Scales

Each of the 22 closed agreements was rated by the project team with respect to the final list of attributes presented in Table 2.2. For each agreement, a value was assigned from each attribute scale shown in Table 2.2 showing the level to which that attribute was actually achieved, in the technical judgment of the reviewers. The resulting attribute levels for the 22 agreements are shown in Table 4.2. For example, for agreement 1, the team felt that the assignment of resources to achieve the specific objectives of the agreement had been adequate (level 4), that the management structure had been appropriate (level 4), and that the technical difficulties or risks had been modest (level 2). As another example, for all but two agreements, the level of industrial participation was rated as 1, indicating the existence of some industrial participation or interest, but little or no industrial funding.

In this application, the project team acted as one body in setting a single set of attribute levels for each agreement. In future applications of the methodology, the attribute levels could be set by more than one DOE/FE technical staff person. It is believed that the attribute definitions and scales have been set in such a way that a serious review of the same proposed agreement by two or more knowledgeable persons will result in similar assignments of the attribute levels. Some differences, however, will undoubtedly remain even after a discussion of the reasons for each reviewer's estimates. For example, one reviewer might rate a proposed agreement at level 2 for a particular attribute, and another reviewer might rate it at level 3. In such a case, the input attribute level could be specified using a probability distribution, e.g., a 0.50 probability of the outcome being level 2 and a 0.50 probability of it being level 3. A strength of the recommended approach is the ease in which a technically valid procedure for handling uncertainty is incorporated into the estimates of attribute levels.

TABLE 4.1 Closed Agreements Used for the Trial Application of the Methodology

Agreement	Topic or Activity	Non-U.S. Partner
1	Characterization of heavy crude oil (information exchange)	Venezuela
2	Ground subsidence due to fluid withdrawal (modeling)	Venezuela
3	Training of petroleum engineers	Venezuela
4	Coal-water mixtures (information exchange)	IEA
5	Mobil Co. process for converting methanol to gasoline or olefins	FRG[a]
6	Coal uses (information exchange)	Australia
7	Feasibility studies on atmospheric FBCs and surface gasification	Brazil
8	Oil-fluid dynamics and chemical-process modeling (personnel exchange)	Mexico
9	Coal mining and preparation	FRG
10	Hydrogenation technology (information exchange)	FRG
11	Training workshops on fossil energy	India
12	SRC[b] II Phase Zero	Japan
13	Magnetohydrodynamics (information exchange)	Netherlands
14	Magnetohydrodynamics (personnel exchange)	Netherlands
15	Coal-mining research	Poland
16	Coal uses (information exchange)	Poland
16	Oil products (information exchange)	Venezuela
17	Application of oil-field techniques	Venezuela
18	Application of oil-saturation methods	Venezuela
20	Coal mining (information exchange)	IEA
21	Coal-oil and coal-liquid mixtures (information exchange)	IEA
22	Building and testing of a pressurized FBC (Grimethorpe project)	IEA

[a]Federal Republic of Germany.

[b]Solvent-refined coal.

TABLE 4.2 Attribute Levels for the Closed Agreements[a]

Agreement	Probability of Achieving Agreement-Specific Objectives: Resources	Management Structure	Technical Difficulty	Balance of Trade	Joint Commitment	Distribution of Benefits	Research Challenge	Industry Participation
1	4	4	2	2	2	2	3	1
2	5	4	2	2	2	2	3	1
3	4	4	1	1	1	1	1	1
4	4	5	2	2	2	2	3	1
5	4	4	3	2	3	2	4	2
6	1	3	1	1	1	1	1	1
7	1	3	2	1	1	2	1	1
8	5	4	1	2	2	2	2	1
9	3	4	2	1	2	2	3	1
10	2	3	1	1	2	2	1	1
11	4	4	2	2	2	1	2	1
12	3	3	1	1	1	1	3	1
13	4	4	1	1	3	2	1	1
14	4	4	2	1	3	2	4	1
15	3	4	2	1	2	1	3	1
16	3	3	1	1	2	1	1	1
17	4	4	2	2	2	2	2	1
18	3	3	1	2	2	2	1	1
19	4	4	1	1	2	1	1	1
20	3	3	1	1	2	2	1	1
21	3	3	1	1	2	2	1	1
22	5	5	3	2	4	2	4	2

[a]The attribute levels are defined in Table 4.2, and the closed agreements are defined in Table 4.1.

Estimating the probability of achieving agreement-specific objectives (attribute 1) involved a separate evaluation for each of the three components of this attribute (resources, management structure, and technical difficulty). As shown earlier in Table 3.2, different weights were assigned to these components during the interview phase of the project. These weights were used to combine the separate probabilities estimated for the three components into a single, overall probability for attribute 1. This calculation assumed a linear single-attribute utility function for each of the three components of attribute 1. That is, a level 3 for component 1 (resources) translates into a utility of 0.5 on that scale (the midpoint of the range is level 3, as shown in Table 2.2). This step was performed for each of the 11 utility functions.

Utility functions for experts who attached greater importance to management structure (component 2) generally produced different overall results for attribute 1 than utility functions for experts who attached greater importance to resources (component 1). This outcome is reasonable because the methodology is primarily intended for applications to proposed agreements, where the probability of achieving agreement-specific objectives is not known and can be presumed to be a function of the three components listed.

Although the weights assigned to the three components differed, the estimated probabilities of achieving agreement-specific objectives for the 22 closed agreements displayed only small differences in most cases. This result is shown in Table 4.3. This would not be the case if more agreements had high ratings on resources but low ratings on management structure, or vice versa. Therefore, more diversity in the levels for attribute 1 may be evident when a typical set of proposed agreements is evaluated.

During the interview phase of the project, three experts (5, 6, and 8) had assigned the same weights (0.40, 0.40, and 0.20) to the three components of attribute 1 (see Table 3.2) and, therefore, their utility functions yielded the same probabilities, as shown in Table 4.3. Individuals 3 and 11 also assigned identical weights (0.40, 0.50, and 0.10).

TABLE 4.3 Probability of Achieving Agreement-Specific Objectives for the Closed Agreements: Results for Attribute 1

Agreement	Probability Produced by Each Utility Function (%)											Avg. Probability (%)	Rank by Avg.
	1	2	3	4	5	6	7	8	9	10	11		
1	71	72	74	74	73	73	73	73	73	74	74	73	9.5
2	80	84	84	82	83	83	81	83	88	89	84	84	4
3	86	82	78	78	80	80	80	80	81	79	78	80	6
4	85	90	97	97	93	93	93	93	92	95	97	93	1
5	56	62	71	71	67	67	67	67	65	69	71	67	12
6	55	42	35	40	40	40	45	40	32	28	35	39	21
7	40	32	32	37	33	33	38	33	24	22	32	32	22
8	95	94	88	85	90	90	88	90	96	94	88	91	2
9	62	61	64	67	63	63	66	63	58	59	64	63	13.5
10	64	54	45	48	50	50	52	50	48	42	45	50	20
11	71	72	74	74	73	73	73	73	73	74	74	73	9.5
12	72	65	55	55	60	60	60	60	62	58	55	60	17
13	86	82	78	78	80	80	80	80	81	79	78	80	6
14	71	72	74	74	73	73	73	73	73	74	74	73	9.5
15	62	61	64	67	63	63	66	63	58	59	64	63	13.5
16	72	65	55	55	60	60	60	60	62	58	55	60	17
17	71	72	74	74	73	73	73	73	73	74	74	73	9.5
18	72	65	55	55	60	60	60	60	62	58	55	60	17
19	86	82	78	78	80	80	80	80	81	79	78	80	6
20	72	65	55	55	60	60	60	60	62	58	55	60	17
21	72	65	55	55	60	60	60	60	62	58	55	60	17
22	70	80	93	93	87	87	87	87	83	90	93	86	3

The diversity among the 11 utility functions regarding attribute 1 led to some differences in the results for the 22 agreements, as shown in Table 4.3. For example, the probability of achieving agreement-specific objectives (attribute 1) was estimated to be between 56% and 71% for agreement 5 and between 70% and 93% for agreement 22. These results occurred primarily because these two agreements were considered the two most technically difficult of the set (level 3 of attribute 3 in Table 4.2). The technical difficulty component was weighted as much as 45% in importance and as low as 10% (Table 3.2). Therefore, agreements that were considered more technically difficult were generally estimated to have a lower probability of achieving their objectives than some others.

Also shown in Table 4.3 is the ranking of the 22 closed agreements that would result if the average of the 11 scores for attribute 1 alone is used as the basis for ranking. This ranking can be compared with that obtained by using the scores for all six attributes (see Sec. 4.2). As will be discussed in Sec. 4.2, the two approaches produce quite different results. This demonstrates that the probability of achieving agreement-specific objectives is not a sufficient criterion by itself for evaluating agreement proposals.

4.1.2 Utility Function Results

The next step was to insert the attribute levels from Table 4.2 into the 11 utility functions to calculate the expected utility that each decision maker would have for each agreement. This calculation of expected utility involves many mathematical operations and data-handling procedures. To automate the process for this project, which involved a large number of alternatives to be evaluated (i.e., 22 agreements), the project team modified some ANL software being developed for other projects. That software, known as the Interactive Decision Evaluation and Analysis system, enabled these calculations to proceed quickly and accurately.

Expected utilities were determined for all 22 agreements for each of the 11 utility functions. Utility is generally scaled from 0 to 1 and is expressed as a decimal fraction, e.g., 0.45. These utility scores were multiplied by a factor of 1000 and are listed in Table 4.4. Also shown are the averages of the 11 expected utilities for each agreement and, in the last column, the rankings assigned to the agreements on the basis of these average values.

The 11 sets of utility scores in Table 4.4 can be used to arrange 11 separately ranked lists of the agreements, as shown in Table 4.5. (For reference, the ranks shown in the last column in Table 4.4 are repeated in Table 4.5.) The results indicate a general consistency among the utility functions. For example, in all cases, agreement 22 is the most desirable and agreement 6 the least desirable. Agreement 5 was rated as no lower than fifth and no higher than second in all 11 cases.

However, the rankings listed in Table 4.5 also demonstrate differences, based on the individual preferences underlying the utility functions. For example, agreement 13 was ranked as second highest by utility function 11 and as 11th highest by utility function 10. These differences can be explained by examining the preferences underlying the

TABLE 4.4 Expected Utilities and Final Ranking for the Closed Agreements

Agreement[a]	Expected Utilities Produced by Each Utility Function											Avg.	Rank by Avg.
	1	2	3	4	5	6	7	8	9	10	11		
22	665	664	596	856	795	660	849	871	678	604	894	739	1
5	622	600	536	829	698	588	759	806	576	528	765	664	2
14	472	407	408	459	545	535	652	735	532	319	761	529	3
2	488	570	410	245	451	498	454	700	535	475	577	491	4
4	479	554	414	250	451	498	466	700	477	457	584	484	5
8	516	591	420	247	467	450	448	579	534	458	586	481	6
13	474	401	357	449	529	375	457	573	486	268	766	467	7
1	466	535	395	240	407	482	437	694	459	445	554	465	8
17	461	523	401	239	395	426	416	570	412	419	554	438	9
18	455	488	331	221	322	356	365	534	346	371	525	392	10
9	400	321	279	214	340	433	344	657	327	257	530	373	11
20	413	306	230	201	296	324	289	504	279	211	518	325	12.5
21	413	306	230	201	296	324	289	504	279	211	518	325	12.5
11	381	383	309	164	351	343	319	392	338	353	135	315	14
10	390	277	214	193	259	304	273	494	222	185	510	302	15
15	320	182	188	139	297	350	247	479	253	191	111	251	16
16	367	218	175	146	334	276	236	341	290	185	134	246	17.5
19	367	218	175	146	334	276	236	341	290	185	134	246	17.5
7	289	204	177	155	165	240	189	419	153	118	430	231	19
12	313	160	159	102	242	319	177	423	269	154	29	213	20
3	335	188	162	119	294	252	179	289	290	150	63	211	21
6	252	83	92	84	141	173	104	250	100	59	13	123	22

[a]Listed in order of their final ranking (see the last column).

utility functions and the characteristics of the specific agreement. In this instance, expert 11 placed strong emphasis on joint commitment (attribute 3) and distribution of benefits (attribute 4), whereas expert 10 did not (Table 3.1). At the same time, agreement 13 was characterized as having a particularly strong joint commitment and a fair distribution of benefits.

The agreement rankings based on averaging expected utility for all utility functions (see the last column in Tables 4.4 and 4.5) is the best way to incorporate the diversity of preferences demonstrated among the 11 experts. An alternative would be to pick the single utility function whose results most closely approximate the order that results from the average of the rankings. However, using one person's utility function to represent such a diverse group is likely to be a poor approximation in most cases, and, intuitively, it may not be very satisfying to allow one individual to represent the group.

A comparison of the final ranking in Table 4.5 and that in Table 4.3, which was based solely on the utility scores for attribute 1 (the probability of achieving agreement-specific objectives), shows the importance of attributes 2-6 in this methodology. A high probability of achieving agreement-specific objectives does not by itself necessarily imply a high desirability for DOE/FE participation. For example, agreement 3 was

TABLE 4.5 Individual Utility Function Rankings of the Closed Agreements[a]

Agreement	Utility Function											Final Ranking[b]
	1	2	3	4	5	6	7	8	9	10	11	
1	8	6	8	8.5	8	6	8	6	8	6	8.5	8
2	5	5	5	7	7	5	6	5	4	4	7	4
3	17	17	18	20	14	19	18.5	21	13	20	20	21
4	4	3	3	5	5	4	4	4	2	3	5	5
5	2	4	2	2	2	2	2	2	5	2	3.5	2
6	22	22	22	22	22	22	22	22	22	22	22	22
7	21	18	19	16.5	21	21	20.5	17	21	21	15	19
8	3	2	4	6	6	7	7	8	3	5	6	6
9	13	12	12	11	12	8	11	7	13	12	10	11
10	14	15	15	14	19	17	15	14	19	17	14	15
11	15	11	11	15	10	13	12	18	10	9	17	14
12	19.5	21	20	21	20	16	20.5	16	17	18	21	20
13	6	9	9	4	4	10	5	9	7	11	2	7
14	7	10	6	3	3	3	3	3	6	10	3.5	3
15	19.5	19	16	18	15	12	16	15	18	16	18	16
16	18	20	21	19	18	20	18.5	20	20	19	19	17.5
17	9	7	7	8.5	9	9	9	10	9	7	8.5	9
18	10	8	10	10	13	11	10	11	11	8	11	10
19	16	16	17	16.5	11	18	17	19	13	15	16	17.5
20	11.5	13.5	13.5	12.5	16.5	14.5	13.5	12.5	15.5	13.5	12.5	12.5
21	11.5	13.5	13.5	12.5	16.5	14.5	13.5	12.5	15.5	13.5	12.5	12.5
22	1	1	1	1	1	1	1	1	1	1	1	1

[a]Based on the utility scores in Table 4.4.

[b]From the last column of Table 4.4.

ranked sixth highest in terms of the probability of achieving its objectives, but was ranked 21st out of 22 in the ultimate ranking based on all six attributes. Agreement 5 was ranked in the middle (12th) in terms of attribute 1 but emerged as second highest in the ultimate ranking.

Figure 4.1 shows the expected-utility results from Table 4.4 in the form of a bar graph. The ends of bars represent the lowest and highest expected utilities produced by the 11 utility functions for the agreements. The average of the 11 values for each agreement is also indicated. The location of the average within each range gives a rough indication of the distribution of the expected utilities. For example, the average expected utility for agreement 8 is 481, which is greater than the midpoint of the range of expected utilities (247 to 591) across the 11 utility functions. In fact, 10 of the individual expected utilities are greater than the midpoint.

The application described in this section may be useful as a rough guide to applying the methodology to evaluations of existing or proposed agreements. Some differences may occur, as noted in Sec. 5, because of the inherent differences between

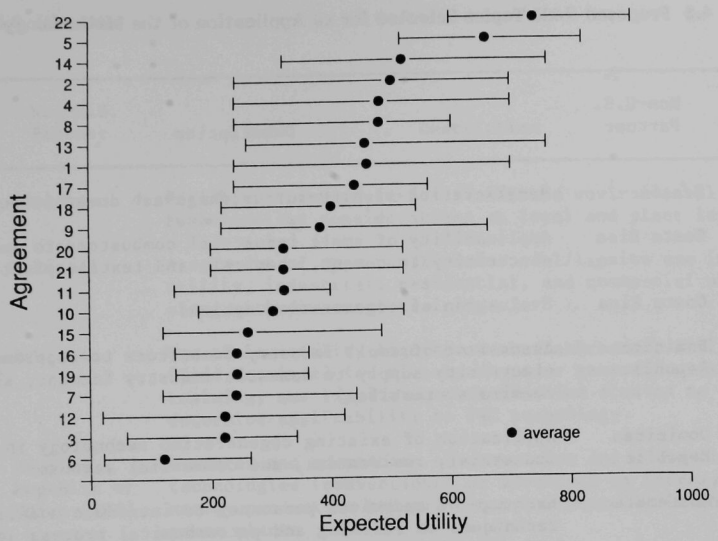

FIGURE 4.1 Range of Expected Utilities for the Closed Agreements (based on Table 4.4)

closed agreements, where outcomes are already known, and proposed agreements, where outcomes must be estimated. The methodology can be modified to include a different set of experts, a different averaging procedure to obtain the ultimate ranking, or a modified set of attributes. A computer program is being developed to assist DOE/FE personnel in making these or other changes themselves if needed.

4.2 PROPOSED TOPICS

The next task was to test the methodology on potential international collaborative R&D initiatives. The topics used are identified in Table 4.6.

4.2.1 Identification of Possible Topics

To develop a list of topics for this application, it was necessary first to identify countries where significant potential might exist for collaborative R&D agreements with DOE/FE, and then to identify technological areas in which agreements might be mutually beneficial. Information was obtained from literature searches, discussions with appropriate U.S. and foreign personnel, examination of regional development plans, and other sources.

TABLE 4.6 Proposed R&D Topics Selected for an Application of the Methodology

Topic	Non-U.S. Partner	Description
1	Brazil	Beneficiation of high-sulfur, high-ash domestic coal
2	Costa Rica	Applicability of small industrial combustors to supply electricity to cement, chemical, and textile plants
3	Costa Rica	Evaluation of cogeneration options
4	Dominican Republic	Assessment of small industry combustors to supplement electricity supply to domestic industry (cement, sugar, chemicals, textiles)
5	Dominican Republic	Application of existing cogeneration technology in the industrial, residential, and commercial sectors
6	Guatemala	Exchange of technical personnel to introduce modeling techniques on refining and petrochemical process design and operations
7	Honduras	Use of coal as an oil substitute in small industrial boilers (in the cement, textile, and tile- and brick-making industries)
8	India	Characterization studies of low-quality coals from western India
9	India	Beneficiation studies on low-quality coals from western India
10	India	Feasibility studies on cogeneration
11	India	Feasibility studies on small coal plants
12	Indonesia	Transfer and adaptation of conversion and combustion technologies (conventional or advanced) to increase energy production and efficiency, especially in thermal power plants
13	Indonesia	Basic coal science and coal characterization
14	Jordan	Study of coal-water mixtures and pulverized coal injection to permit retrofitting of oil-burning units in industry and power-generating facilities
15	South Korea	Pressurized fluidized bed coal combustors (FBCs)

TABLE 4.6 (Cont'd)

Topic	Non-U.S. Partner	Description
16	Morocco	Feasibility study of FBCs to address environmental and fuel-handling considerations at local and plant levels
17	Pakistan	Assessment of opportunities for coal/lignite use in the utility, industrial, residential, and commercial sectors along with personnel training
18	Pakistan	Use of low-quality lignite at the Lakhra coal field (Sind Province) for mine-mouth power generation; staff training, and lignite characterization studies to determine applicability to FBC technology
19	Peoples Republic of China (PRC)	Transfer and adaptation of conversion and combustion technologies (conventional or advanced) to increase energy production and efficiency, especially in thermal power plants
20	PRC	Coal-water mixture studies to mitigate transport bottlenecks
21	PRC	Assessment of environmental problems, with focus on industrial pollution (especially SO_2 and particulates) in order to propose strategies for abatement
22	Thailand	Use of high-quality lignite from Lamphun for the cement, fertilizer, and petrochemical sectors
23	Thailand	Separation procedures to increase extraction quantities of liquefied petroleum gas

The following criteria were used for screening countries: (1) dependence on oil imports, (2) existence of strong domestic fossil energy programs, (3) existence of large indigenous fossil energy reserves (oil, gas, oil shale, or coal/lignite), and (4) potential for acquiring development funds from other agencies (e.g., the U.S. Agency for International Development, the World Bank, the United Nations Development Program, and/or other international agencies). Based on these criteria, 21 countries were selected for further consideration.

The following information was then obtained about each country selected: (1) its electrical and industrial demand requirements, (2) its ability to develop indigenous fossil fuel resources, (3) its infrastructure conditions, including transportation constraints, (4) pollution abatement concerns, and (5) political hurdles, e.g., import tariffs and energy price subsidies.

In identifying possible collaborative R&D opportunities with these countries, the project team gave careful consideration to the concept of *quid pro quo*. It was thought that a *quid pro quo* could be achieved (i.e., with equitable benefits for both countries) in such areas of (1) technology transfer, (2) technical support and training, (3) resource development and exports, (4) balance-of-trade adjustments, and (5) energy security issues. The following topic areas were identified:

1. Beneficiation of indigenous resources,
2. Conversion and combustion technologies, including both conventional and clean coal technologies,
3. Energy planning, including methodology development and personnel training,
4. Coal-water mixtures,
5. Gas pricing, and
6. Environmental assessment.

Based on the country and technology profiles, cursory proposals for new DOE/FE initiatives were identified. In all, 109 R&D topics were identified as possibilities for collaborative projects. Profiles of the 21 countries, in which their technology needs are matched with areas of DOE/FE expertise, are presented in App. C. For the application presented in this report, the project team trimmed the list to 23 specific research opportunities in 17 countries. These topics are identified in Table 4.6.

4.2.2 Topic Rankings

Since the methodology was derived from agreements with developed countries, the project team made the assumption that the methodology could also provide applicable insight for proposed agreements with developing countries. The steps involved in applying the methodology were the same as those described in Sec. 4.1 for the closed agreements.

First, preliminary estimates of attribute levels for each proposed R&D topic were assessed and are listed in Table 4.7. Next, the levels assigned in Table 4.7 to the three components of attribute 1 (the probability of achieving agreement-specific objectives) were inserted into the 11 single-attribute utility functions for that attribute to estimate the overall probability of achievement for each topic. The results are displayed in Table 4.8. Topic 15 was estimated on average to have the highest probability (82%) of achieving its objectives. The next highest probability estimate was 65%, for topics 10 and 11. In general, the probability results show reasonable agreement among the 11 utility functions. However, for several topics, the difference between the highest and lowest probabilities was 20% or more. Table 5.3 also shows the average of the 11 probability values calculated for each agreement, and the order of desirability if this attribute alone were used as the basis for ranking the topics.

TABLE 4.7 Attribute Levels for the Proposed Topics[a]

Topic	Probability of Achieving Agreement-Specific Objectives: Resources	Management Structure	Technical Difficulty	Balance of Trade	Joint Commitment	Distribution of Benefits	Research Challenge	Industry Participation
1	3	4	3	3	3	2	4	1
2	3	3	1	1	2	2	1	2
3	3	3	1	1	2	2	1	2
4	3	2	1	1	2	2	1	2
5	3	2	1	1	2	2	1	2
6	2	2	1	1	3	2	2	1
7	3	3	1	1	2	2	1	1
8	2	4	1	1	3	2	1	1
9	2	4	2	2	3	2	3	1
10	3	4	1	1	2	2	1	2
11	3	4	1	2	2	2	1	2
12	2	2	1	3	3	2	3	2
13	2	2	1	2	2	2	1	1
14	4	3	3	2	2	1	3	2
15	5	4	1	3	3	2	3	2
16	2	3	2	2	3	2	3	1
17	3	2	1	2	2	2	2	1
18	3	2	3	3	3	2	4	2
19	4	2	2	3	3	1	2	1
20	3	2	2	2	2	2	3	1
21	2	1	3	1	2	1	3	1
22	3	2	2	2	2	1	2	1
23	4	2	2	2	2	1	2	1

[a]See Table 2.2 for definitions of these levels.

The probabilities shown in Table 4.8 and the attribute levels shown in Table 4.7 for the remaining attributes were then inserted into the 11 multiattribute utility functions and used to calculate expected-utility scores for each topic. These scores are presented in Table 4.9. Comparison of these scores with those in Table 4.4 for the closed agreements reveals some differences in the character of the results. For example, utility function 1 produced one of the lowest levels of satisfaction among the closed agreements (677) but one of the largest among the proposed topics (911). Utility function 11 produced the largest level of satisfaction among the closed agreements (941) and has only the sixth largest among the proposed R&D topics (806). These differences in the raw utility scores demonstrate the differences in preferences expressed by the 11 experts and the differences in the character of the data available on the two sets of alternatives evaluated.

Figure 4.2 shows the expected-utility information from Table 4.9 in the form of a bar graph. It is similar to Fig. 4.1 for the 22 closed agreements and indicates the ranges and averages of the expected utilities across all 11 utility functions.

TABLE 4.8 Probability of Achieving Agreement-Specific Objectives for the Proposed Topics: Results for Attribute 1

Topic	Probability by Utility Function (%)											Avg. Probability (%)	Rank by Avg.
	1	2	3	4	5	6	7	8	9	10	11		
1	48	51	59	61	56	56	58	56	50	53	59	55	9
2	67	61	54	54	58	58	58	58	59	56	54	58	5
3	67	61	54	54	58	58	58	58	59	56	54	58	5
4	63	56	44	42	50	50	48	50	56	51	44	50	14
5	63	56	44	42	50	50	48	50	56	51	44	50	14
6	56	47	36	36	42	42	42	42	44	39	36	42	20
7	67	61	54	54	58	58	58	58	59	56	54	58	5
8	64	57	56	60	58	58	62	58	50	49	56	57	7
9	53	50	53	57	52	52	56	52	44	45	53	52	12
10	71	66	64	66	66	66	68	66	62	61	64	65	2.5
11	71	66	64	66	66	66	68	66	62	61	64	65	2.5
12	56	47	36	36	42	42	42	42	44	39	36	42	20
13	56	47	36	36	42	42	42	42	44	39	36	42	20
14	51	55	57	55	56	56	54	56	59	60	57	56	8
15	85	84	80	78	82	82	80	82	86	85	80	82	1
16	49	45	43	45	44	44	46	44	41	40	43	44	18
17	63	56	44	42	50	50	48	50	56	51	44	50	14
18	40	41	39	37	40	40	38	40	44	43	39	40	22
19	59	58	49	45	52	52	48	52	62	59	49	53	10.5
20	52	49	41	39	44	44	42	44	50	47	41	45	16.5
21	29	27	21	19	24	24	22	24	29	26	21	24	23
22	52	49	41	39	44	44	42	44	50	47	41	45	16.5
23	59	58	49	45	52	52	48	52	62	59	49	53	10.5

Table 4.10 summarizes the rankings of the 23 proposed R&D topics that result from the set of utility scores produced by each utility function. The diversity of opinion underlying the utility functions is reflected in the highest and lowest ranks produced for each topic. For example, topic 8 had an overall ranking approximately in the middle of the set, yet the highest rank calculated for it was actually fourth, while the lowest was 20th. The reason is that this proposal is strong on the attributes rated highly by expert 11 and weak on those rated highly by expert 10. Thus, this proposal may warrant additional review, outside the methodology, before a final recommendation regarding it is made. In contrast are topics 15 and 21. Topic 15 was highly rated in all cases, and topic 21 was rated near the bottom of the set by all.

A low ranking does not imply that a proposed R&D topic should not be pursued and funded. These 23 topics were selected manually from the original list of 109 topics

TABLE 4.9 Expected Utilities and Final Ranking for the Proposed Topics

Agreement[a]	Expected Utilities Produced by Each Utility Function											Avg.	Rank by Avg.
	1	2	3	4	5	6	7	8	9	10	11		
15	911	811	711	926	837	587	662	873	747	639	806	774	1
18	780	673	649	888	643	556	717	843	525	559	732	688	2
12	819	677	621	875	639	494	560	830	509	533	730	662	3
1	665	663	659	566	559	569	724	822	540	523	751	640	4
9	444	519	454	455	480	461	528	732	463	408	739	517	5
16	429	506	433	439	445	439	502	720	451	397	728	499	6
11	615	543	384	587	514	406	437	587	373	440	544	494	7
19	597	520	532	460	477	354	415	500	460	427	319	460	8
10	573	360	283	568	488	374	361	557	306	280	537	426	9
8	430	336	326	436	447	341	423	558	357	213	735	418	10
2	560	343	263	555	449	356	333	549	290	269	521	408	11.5
3	560	343	263	555	449	356	333	549	290	269	521	408	11.5
20	414	473	337	203	294	423	369	665	367	395	513	405	13
6	409	318	321	405	394	342	392	560	350	209	716	401	14
17	449	484	348	206	303	381	360	549	350	378	515	393	15
14	479	390	311	502	452	402	344	548	346	416	114	391	15
4	547	327	242	538	412	335	307	539	275	258	510	390	17.5
5	547	327	242	538	412	335	307	539	275	258	510	390	17.5
13	428	446	292	195	251	312	324	511	277	335	509	352	19
7	413	306	230	201	296	324	289	504	279	211	518	325	20
23	354	349	269	136	273	306	265	375	305	330	102	278	21
22	328	322	252	127	238	284	250	363	246	303	94	255	22
21	199	100	98	72	144	237	145	409	143	126	76	159	23

[a]Listed in order of their final ranking (see the last column).

based on factors that were intended to favor the best prospects. Also, to reiterate, the methodology does not account for budgetary limitations, political factors, and other important exogenous considerations that should be included in the final decision on DOE/FE participation.

In sum, the recommended methodology consists of using 11 individual utility functions to calculated expected utilities, and then averaging these to determine a single, overall ranking. Differences among the results produced by each utility function may help identify proposals that are strong in some areas and weak in others. Improvement efforts focused on the weak points could substantially increase ratings for such proposals and promote successful international R&D collaboration.

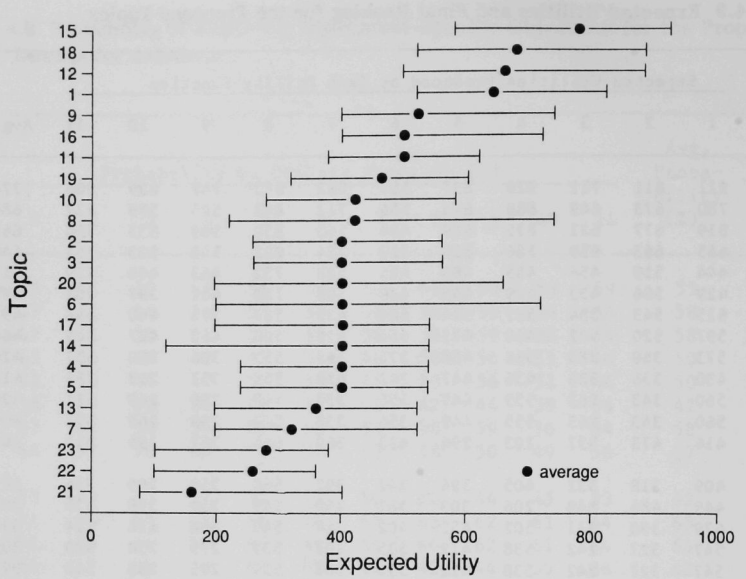

FIGURE 4.2 Range of Expected Utilities for the Proposed Topics (based on Table 4.9)

TABLE 4.10 Individual Utility Function Rankings of the Proposed Topics[a]

Topic	Utility Function											Final Ranking[b]
	1	2	3	4	5	6	7	8	9	10	11	
1	4	4	2	6	4	2	1	4	2	4	2	4
2	8.5	15.5	17.5	7.5	10.5	12.5	15.5	12.5	16.5	16.5	11.5	11.5
3	8.5	15.5	17.5	7.5	10.5	12.5	15.5	12.5	16.5	16.5	11.5	11.5
4	10.5	18.5	20.5	9.5	14.5	17.5	18.5	16.5	20.5	18.5	17.5	17.5
5	10.5	18.5	20.5	9.5	14.5	17.5	18.5	16.5	20.5	18.5	17.5	17.5
6	20	21	12	16	16	15	10	9	12	22	8	14
7	19	22	22	19	18	19	20	19	18	21	13	20
8	15	17	11	15	12	16	8	10	10	20	4	10
9	14	7	6	13	7	5	5	5	5	8	3	5
10	7	13	15	5	6	11	12	11	14	15	10	9
11	5	5	8	4	5	8	7	8	8	5	9	7
12	2	2	4	3	3	4	4	3	4	3	6	3
13	17	11	14	20	21	20	17	18	19	12	16	19
14	12	12	13	11	9	9	14	15	13	7	20	16
15	1	1	1	1	1	1	3	1	1	1	1	1
16	16	8	7	14	13	6	6	6	7	9	7	6
17	13	9	9	17	17	10	13	14	11	11	14	15
18	3	3	3	2	2	3	2	2	3	2	5	2
19	6	6	5	12	8	14	9	20	6	6	19	8
20	18	10	10	18	19	7	11	7	9	10	15	13
21	23	23	23	23	23	23	23	21	23	23	23	23
22	22	20	19	22	22	22	22	23	22	14	22	22
23	21	14	16	21	20	21	21	22	15	13	21	21

[a]A rank of 1 is indicative of the most preferred agreement.

[b]From Table 4.9. The final ranking is based on the average expected utility for each agreement.

5 THEORETICAL GUIDELINES

Before any measures of effectiveness could be identified and defined, it was important to understand the kinds of issues and concerns about collaborative international R&D that the designer, negotiator, or implementer must deal with. Achieving this understanding required the development of a set of informal guidelines.

Two basic sets of issues were addressed:

1. What motivates the partners to collaborate, and why should collaboration occur?

2. Because organization and management can significantly affect mutual ability to achieve the desired outcome of a collaborative effort, project structure is very important. How, therefore, should collaboration be carried out? What is the mechanism most likely to result in an effective effort?

No matter how well organized it is, collaborative R&D with a poorly conceived objective is likely to fragment under stress, simply because the desire to proceed in the face of adversity will not be strong enough. On the other hand, the best-conceived objective may not be attained if the management approach is significantly flawed. On the motivational side, the project team examined specific financial and technical considerations and national objectives. On the organizational side, the project team examined the factors that ensure the participants' continuing commitment, together with the procedures required to reach the agreement-specific objectives (see Fig. 5.1).

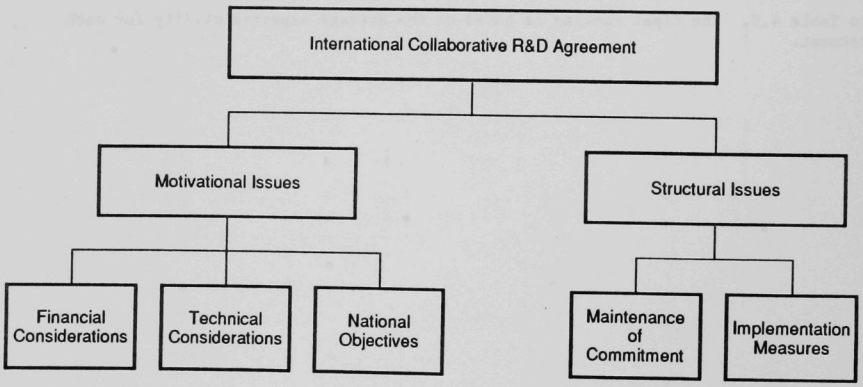

FIGURE 5.1 Issues in an International Collaborative R&D Agreement

Examples of specific questions that the ANL team raised are listed below. These questions are being considered by DOE/FE. Three types of questions are considered. The first set of questions deals with motivation and covers those partnership aspects that motivate the United States and the foreign collaborator:

- Are tasks shared and is information exchanged?
- Are costs shared to eliminate duplication of effort?
- Is a particular technological area developed more cheaply or more quickly because of resource pooling? Is demonstration of a particular technology accelerated?
- Is a wide range of technical and research approaches employed?
- Is scientific and/or engineering competence enhanced?
- Can special technical expertise be acquired?
- Is there a significant payoff? Specifically, is there significant potential to export coal, fossil-fuel technology, commercial expertise, equipment, and/or services?
- Is a test site or special facility offered that otherwise would have been unavailable?
- Is there expansion of a data base on resources and/or their characterization?
- Are experiences and technical information shared outside the project's scope?
- Is cooperation facilitated beyond energy itself?
- Is international cooperation generally enhanced?
- Are additional communication links available to transmit or receive information or perceptions that affect motivation of the other country's decision makers?
- Are broader political objectives served? Are national problems addressed?

The second set of motivational questions deals with the potential disadvantages for both parties:

- Are the opportunity costs too high? Could a better project be carried out with available funds?

- Do development costs exceed the value of, or compensation for, the competitive gains achieved?

- Is the project unwieldy or significantly sensitive to changing requirements? Is the marketability of the technology jeopardized?

- Is control lost to a bureaucracy? Is management cumbersome?

- Do governments seek business opportunities for their own national companies, with nothing offered in return?

- Are foreign marketing covenants and procedures for protecting proprietary information consistent with their U.S. counterparts?

- Is the project vulnerable to withdrawal of funding?

- Might the project take on a life of its own? Will the potential costs be too high to terminate it?

- Is there a potential conflict between energy security and bilateral or multilateral interdependence?

- Is collaboration/cooperation too remote from commercialization to warrant a high level of interest or, conversely, so close as to impede an effective R&D partnership at the government level?

- Is U.S. industry hurt? Is an edge lost to foreign competition?

The last set of questions deals with the organizational support needed for successful project implementation:

- At what level of government or industry is commitment made? How is the commitment made?

- Is the administrative structure institutionalized (rather than comprising only the named individuals)?

- Is industry involved? To what extent? As a funding participant? As a prime contractor or subcontractor? Other?

- Are technology users and producers involved? What commitments have been received from commercial and industrial interests?

- What is the nature of the project?

  - Cooperative? Information exchange only, or with an informal division of labor, or both?

- Collaborative? With joint planning, allocating tasks in advance of actual R&D and avoiding duplication?

- Joint venture? Are joint facilities or enterprises to be employed? Is effort centralized?

- Is there expectation of mutual gain? Is reciprocity expected on equal or complementary capabilities?

- Is technological parity an issue? Or is technology transfer all that is expected?

- Are specific objectives agreed to?

- Are costs overruns likely?

- Does the project have significant technical merit? Do expected results justify financial and technical support?

- Is the project well thought out, with an established work structure, clear and measurable interim milestones, a detailed research strategy, and a predefined statement of expected or desired technical outputs?

- Does the project budget depend on annual government action?

6 CONTINUING EFFORTS

6.1 SUMMARY OF WORK TO DATE

What has been accomplished so far? What results has the project team produced that DOE/FE may begin to implement today?

First, the project team identified a variety of potentially measurable characteristics of international collaborative R&D activities. These characteristics relate to the desirability of DOE/FE funding or participation in a particular project, emphasizing *quid pro quo*. The team studied these characteristics, examined their worth, condensed them to a handful of simple statements (i.e., the attributes), and developed quantitative measurement scales for them.

Second, the team demonstrated how a variety of opinions can be shaped into statistical weights and converted into mathematical formulas using a decision-analysis methodology. However, users of the methodology need not concern themselves with the theoretical basis in order to use the results. These results can help set funding priorities among a set of proposed agreements and pinpoint areas of needed improvement in specific proposals.

Third, the team conducted a test run of the methodology, using it to rank a set of closed international collaborative R&D agreements. The results give some indications of the methodology's strengths and weaknesses. A strength of the methodology is that the legitimate concerns, preferences, and biases contained in an individual utility function will be captured in the evaluation of a set of agreements, even though the overall ranking is derived from averaging.

Fourth, the team identified a considerable number of potential collaborative R&D activities with developing countries. The countries were selected on the basis of several criteria, and the topics were identified by matching each country's needs or areas of interest with subject areas covered by existing DOE/FE programs. The methodology was then used to produce a preliminary ranking of 23 promising topics, as a first step toward developing specific proposals for DOE consideration.

6.2 FUTURE WORK

Specific follow-on activities to the work performed are already under way or are planned. First, a user-friendly personal computer program for the methodology is being developed and documented. This program will allow DOE/FE staff personnel to assess attribute levels for specific agreements or agreement proposals and use the program utility functions to create internally a new list of rankings for existing and proposed agreements. It could also give DOE/FE planners the ability and flexibility to add utility functions, adjust data, and add proposals to rank with their corresponding attribute assumptions.

Second, as described in this report, the methodology was applied to evaluation of a set of completed agreements and a set of proposed collaborative R&D topics. Another important application is to assess the existing, active agreements in order to better define their value in meeting DOE/FE objectives as defined in this project. Of the currently active agreements, only 16 (about half) are sufficiently advanced to merit attribute assessment in the near term. These agreements are identified in App. D. The other active agreements are, in general, MOUs to which the methodology is not applicable. As of yet, the project team has insufficient data to assess the 16 agreements listed in App. D; however, the team has made rough estimates of the attribute levels and has begun to run a few of the utility functions with them. Plans are to review all of the existing DOE/FE agreements according to the methodology procedures.

Third, in close cooperation with DOE/FE project and technical staff, work is proceeding to refine the proposed topics for collaborative R&D projects. This effort will include interviews with appropriate representatives from the countries involved. After the proposals are put in more definitive form, they will be ranked using the methodology.

Finally, work is planned to develop a parallel methodology for collaborative proposals involving basic research.

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APPENDIX A:

INITIAL SET OF POTENTIAL ATTRIBUTES

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INITIAL SET OF POTENTIAL ATTRIBUTES

This appendix lists the initial set of potential attributes developed for evaluating proposed international R&D agreements. Altogether, 28 attributes were defined, relating to four categories of agreement characteristics: (1) management and structural, (2) financial, (3) technical, and (4) other. The scales of numerical levels associated with the attributes are also presented below.

A.1 MANAGEMENT AND STRUCTURAL CONSIDERATIONS

1. *Project duration*: The duration of an agreement or of an annex to an agreement (in months).

2. *Participants*: The number of active participants (including the United States and other countries). Each government agency that is involved counts as a separate participant (e.g., the U.S. State Department and DOE). (Subcontractors are not considered active participants.)

3. *R&D location*: The location of the R&D covered by an agreement.

   1 = Other country (or countries) only
   2 = United States and other country (or countries)
   3 = United States only

4. *Management structure*:

   1 = Cooperative
   2 = Collaborative
   3 = Joint venture

5. *Initiator*: The party that initiated the agreement.

   1 = United States
   2 = Other country (or countries) in the agreement
   3 = Unactive participant (e.g., World Bank)

A.2 FINANCIAL CONSIDERATIONS

1. *Funding levels*: The total funding (in U.S. dollars) for the agreement or annex.

2. *Industrial funding*: The percentage of total funding that is provided by private industry.

3. *Funding assurance*: An indication of any uncertainties in the financial continuity of the program.

   1 = Budget reviewed periodically with subsequent funding level contingent on progress
   2 = Entire budget committed at the beginning of the agreement

4. *DOE payback*: The percentage return on expenditures. Some agreements allow for direct payback of the DOE investment.

5. *Transfer of funds*: Direction of fund transfers, if any, between countries.

   1 = Each country's contribution spent internally
   2 = Some transfer in both directions, but no significant gain in either direction
   3 = Transfer of most U.S. funds to other countries
   4 = Transfer of most other funds to United States

A.3 TECHNICAL CONSIDERATIONS

1. *Agreement scope*: The type of activities covered by the agreement. (The scale below assumes that the activities with higher values also include all those with lower values, e.g., design of new facilities includes research, planning, and information sharing.)

   1 = Information-sharing and/or technical visits of experts
   2 = Planning of research and/or of energy-related projects
   3 = Research in existing facilities
   4 = Design of new facilities
   5 = Construction and/or operation of new facilities for demonstration or for commercial use

2. *Agreement focus*: The main thrust of the agreement.

   1 = Resource development
   2 = Local environmental issues
   3 = Infrastructure constraints
   4 = Technology development
   5 = Other

3. *Nature of agreement objectives*: The principal nature of the objectives (more than one can be indicated).

   1 = Economic
   2 = Environmental
   3 = Technological
   4 = Political
   5 = All of the above

4. *Expertise exchange*: The balance of the expertise provided for by the agreement.

   1 = Each country contributes expertise at approximately equal levels, with the experts generally supplementing each other
   2 = Each country offers unique expertise and/or facilities in a complementary manner
   3 = Almost all expertise provided by the United States
   4 = Almost all expertise provided by other country(s)

5. *Distribution of benefits*: The anticipated benefits of the agreement.

   1 = Technical knowledge gained predominately by the United States
   2 = Technical knowledge gained by all participants
   3 = Other participants obtain technical knowledge, with no significant benefits to the United States
   4 = Other participants obtain technical knowledge, with financial benefits to the United States expected to follow
   5 = Other participants obtain technical knowledge, with political relationships with the United States enhanced

6. *Time frame of issues*: The time frame of need for the technology or issue being addressed in the agreement.

   1 = Near term (within 5 years)
   2 = Intermediate (5-10 years)
   3 = Far term (at least 10 years away)

7. *Interest level*: The range of U.S. interest in the technology or issue addressed.

   1 = Interest by DOE/FE only
   2 = Widespread interest within the U.S. government
   3 = Some U.S. industrial interest
   4 = Widespread interest by U.S. industry

8. *Unique facilities*: The use or development of unique facilities.

   1 = Existing facility outside the United States
   2 = Existing facility within the United States
   3 = New facility outside the United States
   4 = New facility within the United States

9. *Impact on decision making*: The anticipated impact that the results and conclusions will have on decision makers.

   1 = No significant impact
   2 = Agreement will provide additional information on a developing technology that could influence future R&D

3 = Could affect decisions regarding courses of action for non-U.S. participants, e.g., electrical system expansion or the opening of a new coal mine
4 = Could influence non-U.S. participants to purchase U.S. goods and services in substantial quantities

10. *Increased effort*: Allowance in the agreement for more-rapid progress through the addition of more people and facilities.

1 = No
2 = Yes

11. *Balance of trade*: The likely impact on the U.S. balance of trade as a result of this agreement.

1 = Unknown
2 = Negative
3 = No significant impact
4 = Positive

12. *Aid to industry*: The potential impact on U.S. industry within 10 years following the agreement.

1 = Unknown
2 = Negative
3 = No impact
4 = New technology available for commercial use
5 = New markets created
6 = Both 4 and 5

13. *World stability*: The impact that this agreement could have on world stability.

1 = Negative
2 = No significant impact
3 = Positive

14. *Technical visits*: The number of person-months spent on technical visits during the course of the agreement.

A.4 OTHER CONSIDERATIONS

1. *Custom barriers*: The existence of language or custom barriers that could influence the success of the agreement.

1 = None
2 = Minimal
3 = Noticeable
4 = Significant

2. *Geographic location*: The geographic location of the major non-U.S. participants.

   1 = North America
   2 = Central America
   3 = South America
   4 = Europe
   5 = Africa
   6 = Middle East
   7 = Far East
   8 = Other

3. *Industrialization stage*: The gross national product per capita of the major non-U.S. participant.

4. *Governmental relationship*: The relationship of the government of the participants to the U.S. government.

   1 = Excellent
   2 = Friendly
   3 = Indifferent
   4 = Poor
   5 = Hostile

APPENDIX B:

MODIFIED SET OF ATTRIBUTES FOR THE INITIAL INTERVIEWS

APPENDIX B:

MODIFIED SET OF ATTRIBUTES FOR THE INITIAL INTERVIEWS

This appendix contains the second set of attributes developed for the project, culled from the initial set presented in App. A. This modified set was presented to eight experts for review and discussion, with the following statements regarding the methodology's overall objective and underlying assumption:

- *Objective*: To rank proposed international, bilateral, collaborative agreements in order of highest *desirability* for potential DOE/FE participation.

- *Assumption*: Other important exogenous and/or dynamic factors, such as budget constraints, current political considerations, and consonance of goals and objectives between the interacting parties, must be evaluated and incorporated at the time of funding decisions.

The format of the modified attribute set includes a statement of each DOE funding objective (referred to as a subobjective) determined under the overall objective given above. Each subobjective is followed by an explanation of the associated attribute and the corresponding attribute scale.

Subobjective 1: *Maximize Probability of Achieving Agreement-Specific Objectives*

Attribute: The probability of achieving agreement-specific objectives consists of a weighted sum of the probabilities determined for the following seven components (the probabilities below are expressed as percentages):

1. Likelihood that project duration is consistent with agreement-specific objectives.

   Range: 0-100%

2. Likelihood that project funding is consistent with agreement-specific objectives.

   Range: 0-100%

3. Likelihood that funding will be assured throughout the duration of the agreement so that the stated objectives can be met. (This component refers to the possibility that funding will not be continued through the entire project at the rate agreed upon at the beginning.)

   Range: 0-100%

4. Likelihood that the management structure is consistent with agreement-specific objectives.

   Range: 0-100%

5. Likelihood that the level of technical exchange is consistent with agreement-specific objectives. (This component refers to technical personnel who spend time working in the other country. It refers to active communication and excludes administrative meetings.)

   Range: 0-100%

6. Likelihood that language and custom barriers will impede achievement of agreement-specific objectives.

   Range: 0-100%

7. Technical difficulty in achieving agreement-specific objectives.

   Range: 0-100%

Subobjective 2: *Optimize Industrial Participation*

Attribute: A constructed scale indicating the level of foreign and domestic industrial participation.

1 = Industrial funding of more than 50% of the project total
2 = Industrial funding of 30-50% of the project total
3 = Some industrial funding (0-30%)
4 = No industrial funding, but other forms of industrial participation
5 = No industrial participation

Range: 1-5

Subobjective 3: *Optimize DOE/FE Contribution to Funding*

Attribute: Percentage of project funding (exclusive of any industrial funding) provided by DOE/FE.

Range: 0-100%

Subobjective 4: *Optimize Transfer of Project Funds*

Attribute: A constructed scale indicative of where the funds allocated for the project will be spent.

1 = Each country's contribution spent internally
2 = Transfer of most U.S. funds to other country
3 = Transfer of most of the other country's funds to the United States

Range: 1-3

Subobjective 5: *Maximize Benefits to Participants from Each Country*

Attribute: A constructed scale indicating the distribution of anticipated benefits to be realized from this agreement.

1 = 75% or more of benefits to other country
2 = 75% or more of benefits to the United States
3 = Technical benefits to the other country and to the United States, or technical benefits to the other country with financial benefits to the United States expected to follow, or technical benefits to the other country with political relations to the United States enhanced.

Range: 1-3

Subobjective 6: *Optimize Commercial Applicability*

Attribute: A constructed scale indicative of the commercial applicability of the information to be obtained as a result of this agreement. If the project is successful, when will the results be commercially applied following completion of the agreement? (If multiple objectives within the agreement have different commercial applicabilities, the commercial applicability that is nearest in time should be used.)

1 = Near term, i.e., less than 5 years following completion of the agreement
2 = Intermediate, i.e., within 5-10 years
3 = Far term, i.e., at least 10 years

Range: 1-3

Subobjective 7: *Maximize Subsequent Benefits to U.S. Industry*

Attribute: A constructed scale indicating the anticipated impact on U.S. industry as a consequence of the agreement.

1 = No significant impact on U.S. industry
2 = New technology available for commercial use
3 = New markets created
4 = Both 2 and 3 above

Range: 1-4

Subobjective 8: *Maximize Merit of Research*

Attribute: A constructed scale indicative of the professional challenge and worthiness of the research in the proposed agreement.

1 = Routine research with little technical challenge
2 = Some potential for technical challenge and/or scientifically significant findings
3 = "Cutting-edge" research with significant technical challenge and/or potential for scientifically significant findings

Range: 1-3

Subobjective 9: *Maximize Level of Potential DOE Payback*

Attribute: The percentage of DOE funds contributed to the project that industry contracts to repay to DOE in the event that sales increase as a result of this agreement.

Range: 0-200% of the DOE contribution

APPENDIX C:

COUNTRY RESEARCH SKETCHES

APPENDIX C:

COUNTRY RESEARCH SKETCHES

BOLIVIA

INDIGENOUS FUELS OF INTEREST: Oil, natural gas, coal, and lignite

POTENTIAL COLLABORATIVE R&D AREAS

- Methodology to increase natural gas quantities for domestic power production
- Assessment of small industrial combustor applications to supplement electricity supply to domestic industries (e.g., cement, textiles)
- Studies in all areas of petroleum research and use

COMMENTS

- The government announced plans for an economic reactivation program in June 1987. Restructuring and partial privatization of several major public sector institutions, notably the Bolivian National Mining Corporation (COMIBOL), are under way.
- Bolivia is starting to develop its recently discovered small oil fields.
- A rural electrification project is being jointly financed by the World Bank and the Andean Development Corporation over the next three years.
- A project has been proposed to develop the San Roque gas field. This project is expected to yield an estimated 200 tons per day of liquid petroleum gas and 5,000 barrels per day of condensate.
- The U.S. State Department is planning to cut off $8.7 million in aid to Bolivia because not enough has been done to eradicate the coca crop used to manufacture cocaine.

POTENTIALLY INTERESTED PARTIES

- InterAmerican Development Bank
- Andean Development Corporation

- World Bank
- COMIBOL

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for petroleum research and development
- Coal technology and, possibly, coal exports, to reduce energy import costs
- Transformers, transmission lines, generators, and other such equipment for the rural electrification project

DOE/FE COLLABORATIVE AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Unconventional Gas Recovery
  1. *Basic research*: physical and chemical properties of gas hydrates
  2. *Applied research*: none
  3. *Development*: none
- Enhanced Oil Recovery
  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry
  2. *Applied research*:
     - Chemical and gas injectant mechanisms
     - Geologic impediments to enhanced oil recovery
     - Mobility control and oil displacement mechanisms
     - Petroleum characterization and thermal recovery strategies
     - Reservoir and injection fluid interactions
     - Alkaline flooding and in-situ combustion
     - Geoscience characterization relative to heterogeneity constraints on thermal processes

- Novel concepts to extract unrecoverable oil

- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

- Combustion Systems

1. *Basic research*: none

2. *Applied research*: none

3. *Development*:

- Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

- Atmospheric fluidized bed (AFB) applications in the commercial, institutional, and residential sectors

- Development and evaluation of advanced systems using pressurized fluidized bed (PFB) combined-cycle technology

BRAZIL

INDIGENOUS FUELS OF INTEREST: Coal and oil shale

POTENTIAL COLLABORATIVE R&D AREAS

- Basic coal science and coal characterization
- Beneficiation of high-sulfur, high-ash domestic coal
- Assessment of southeastern Brazil's environmental problems to define the extent of industrial pollution (primarily particulates, ozone, and hydrocarbons) and propose strategies for abatement

COMMENTS

- A number of projects have unsuccessfully aimed at finding economic ways to wash indigenous coal to remove the ash that is inherently mixed with the organic portion of the coal. While this bench-scale research continues, an agreement could be made to allow coal imports from the United States until an effective economic beneficiation method is developed. Coal imports should be destined mainly for locations north of latitude 20°, which are hard to reach logistically with domestic supplies.
- The government's "buy Brazil" policy restricts U.S. imports, and would, therefore, affect the market for U.S. energy equipment. However, collaborative research on industrial pollution may suggest a need for U.S. clean coal technology, which might lead to negotiations softening the restrictive "buy Brazil" policy.

POTENTIALLY INTERESTED PARTIES: none or unknown

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports, especially for northern Brazilian locations based on logistics considerations
- Fossil-fuel technology exports, especially clean coal technologies for pollution abatement

DOE/FE COLLABORATIVE R&D AGREEMENTS

- MOU for the development of technology utilizing the Triunfo coal deposits in Rio Grande do Sul (May 1984)

- Implementing Agreement for the exchange of technical information and cooperation in the field of underground coal gasification (Annex I: Jan. 1985 to Jan. 1990)

- Project Agreement for a feasibility study of the application of underground coal gasification to the Triunfo coal deposits (May 1986 to Sept. 1988)

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation

  1. *Basic research*: none

  2. *Applied research*:

     - Promising concepts for physical and chemical coal cleaning

     - Beneficiation and slurry preparation of low-rank coals

     - Selected particle removal and control approaches

     - Selective coalescence and microcharacterization of coal particles

     - Advanced nitrogen oxide (NO_x) and sulfur oxide (SO_x) chemistry

     - Small-scale combustor environmental controls

  3. *Development*: testing of promising advanced concepts for physical cleaning of fine coal

- Combustion Systems

  1. *Basic research*: none

  2. *Applied research*: emission and combustion properties of coal

  3. *Development*:

     - Development of specific coal-derived fuels and operational testing of advanced combustors

     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

- Underground Coal Gasification

  1. *Basic research*: environmental mitigation techniques

  2. *Applied research*: technical support of field tests cofunded by government and industry

  3. *Development*: none

- Oil Shale

  1. *Basic research*: extraction

  2. *Applied research*:

     - Systems analysis of data bases on reference shales

     - Rock fragmentation, in-situ retorting, and advanced process concepts

     - Chemical stability of spent shale piles

  3. *Development*: continuous-mining extraction methods

COSTA RICA

INDIGENOUS FUELS OF INTEREST: Coal and oil

POTENTIAL COLLABORATIVE R&D AREAS

- Studies on the use of small industrial combustors to supply electricity to cement, chemical, and textile plants as a means of reducing dependence on imported fuel oil
- Feasibility study to reduce dependence on electricity for residential cooking
- Evaluation of cogeneration options
- Assessment to expand electrical system using coals from Volio and Zent (on the Caribbean coast) and Venado (located north and west in the interior)
- Macroeconometric modeling to refine an existing model and incorporate price as a variable in it

COMMENTS

- A number of studies have been done on accessing potential coal areas and use.
- Nearly all imported fuel oil is for industrial use.
- A missing link in the electricity grid is along the Caribbean coast where the Volio and Zent deposits are located.
- Electric capacity need is driven by residential cooking requirements at lunch and dinner times.
- A proposed hydrocarbons law would allow private sector participation, for the first time, in all phases of mineral and petroleum exploration and extraction.

POTENTIALLY INTERESTED PARTIES

- U.S. Agency for International Development (AID) Mission
- International Finance Corporation of the World Bank
- InterAmerican Development Bank
- Instituto Costarricense de Electricidad

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for industry conversions and power generation
- Coal exports, to help reduce oil imports and complement indigenous capacity while it is being developed
- Technical training and support; sales of computer modeling hardware, software, and services
- Investment opportunities due to the Caribbean Basin Initiative, e.g., joint ventures, subcontract manufacturing, and licensing

DOE/FE COLLABORATIVE R&D AGREEMENTS

A bilateral investment treaty and a tax information exchange agreement are currently being negotiated, which could lay a foundation for future agreements involving DOE/FE. More importantly, an MOU is currently being developed between DOE/FE and the Costa Rican Ministry of Natural Resources, Energy, and Mining. This MOU would encompass assistance in planning, analysis, and training related to coal imports and/or development of indigenous coal resources for utility and industrial applications.

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Advanced Research and Technology Development
  1. *Basic research*: fundamental properties of coal and coal-derived fuels
  2. *Applied research*: none
  3. *Development*: none
- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization
     - Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale
  3. *Development*: design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

- Enhanced Oil Recovery

  1. *Basic research:* flow, rock and fluid phenomena, and rock chemistry

  2. *Applied research:*

     - Chemical and gas injectant mechanisms
     - Geologic impediments to enhanced oil recovery
     - Mobility control and oil displacement mechanisms
     - Petroleum characterization and thermal recovery strategies
     - Reservoir and injection fluid interactions
     - Alkaline flooding and in-situ combustion
     - Geoscience characterization relative to heterogeneity constraints on thermal processes
     - Novel concepts to extract unrecoverable oil
     - Extraction process measurement techniques and advanced surface/in-situ process parameters

  3. *Development:* cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

DOMINICAN REPUBLIC

INDIGENOUS FUELS OF INTEREST: none

POTENTIAL COLLABORATIVE R&D AREAS

- Assessment of small-industry combustor applications to supplement electricity supply to domestic industries (e.g., cement, sugar, chemicals, and textiles)
- Application of existing cogeneration technology to the industrial, residential, and commercial sectors
- Regional study on linking Caribbean neighbors in an electricity grid

COMMENTS

- The Dominican Republic is 100% dependent on imported fuel.
- Private domestic companies see cogeneration as a means to avoid power interruptions, which hinder production. However, a recent study has identified the following constraints to cogeneration potential: (1) institutional and regulatory barriers, (2) low oil prices, (3) subsidized electricity prices, and (4) industry investment priorities, which favor production capacity increases rather than energy-efficient modifications.
- The national public utility remains unable to provide sufficient electricity, despite tremendous demand growth; power failures and voltage drops are frequent.
- The sole refinery is a strong candidate for AID-sponsored cogeneration.

POTENTIALLY INTERESTED PARTIES

- AID Mission
- AID Science and Technology Office

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports to reduce energy import costs. (However, although U.S. coal is attractive due to logistics and quality considerations, it would compete with Colombian coal.)
- Fossil-fuel technology exports for industry conversions and power generation

DOE/FE COLLABORATIVE AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*: small-scale combustor environmental controls
  3. *Development*: none
- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*: none
  3. *Development*:
     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
     - AFB applications in the commercial, institutional, and residential sectors
     - Development of specific coal-derived fuels and operational testing of advanced combustors

EGYPT

INDIGENOUS FUELS OF INTEREST: Coal, oil, and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Energy planning and training to facilitate implementation of planned nuclear, natural gas, and coal-fired capacity
- Studies of coal-water mixtures for manufacturing use
- Characterization and beneficiation studies pertaining to low-quality coals
- Feasibility studies on industrial fuel switching to gas and coal

COMMENTS

- The Shoubra power-generating complex is expected to represent a significant addition to Egypt's generating capacity. It is being financed by a consortium, with Bechtel providing architectural and engineering services.
- The British Mining Co. did a feasibility study for reopening a coal mine at Magahra (in the Sinai), which was destroyed by the Israelis; work on reopening is just beginning.
- There has been reluctance on the part of AID to provide support for power projects because the government uses heavy subsidies to keep electricity rates artificially low.
- The World Bank has been providing technical assistance to increase Egypt's skills base in natural-gas-related areas.

POTENTIALLY INTERESTED PARTIES

- Egyptian Supreme Council for Energy
- World Bank
- AID*

*Currently, AID is providing (1) $263 million for the Shoubra thermal power plant project (1979-1989), (2) $97 million for several urban electric distribution projects (1977-1989), (3) $17.3 million for renewable energy field testing (1982-1988), and (4) $65 million for the Talkha combined-cycle project (1986-1989).

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for industry conversions and power generation
- Clean coal technology exports using advanced coal combustion systems
- Coal exports to blend with indigenous reserves

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization
     - Emission and combustion properties of coal-derived fuels
  3. *Development*:
     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
     - Development of specific coal-derived fuels and operational testing of advanced combustors
- Advanced Research and Technology Development
  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements
  2. *Applied research*: studies, analyses, and testing related to coal and coal-based technologies
  3. *Development*: none

- Control Technology and Coal Preparation

  1. *Basic research:* none

  2. *Applied research:*

     - Beneficiation and slurry preparation of low-rank coals

     - selective coalescence and microcharacterization of coal particles

  3. *Development:* none

- Enhanced Oil Recovery

  1. *Basic research:* flow, rock and fluid phenomena, and rock chemistry

  2. *Applied research:*

     - Chemical and gas injectant mechanisms

     - Geologic impediments to enhanced oil recovery

     - Mobility control and oil displacement mechanisms

     - Petroleum characterization and thermal recovery strategies

     - Reservoir and injection fluid interactions

     - Alkaline flooding and in-situ combustion

     - Geoscience characterization relative to heterogeneity constraints on thermal processes

     - Novel concepts to extract unrecoverable oil

     - Extraction process measurement techniques and advanced surface/in-situ process parameters

  3. *Development:* cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

GUATEMALA

INDIGENOUS FUELS OF INTEREST: Oil, natural gas, and lignite (thought to be present)

POTENTIAL COLLABORATIVE R&D AREAS

- Use of coal as an oil substitute in small industrial boilers
- Basic research and characterization programs on petroleum and coal
- Exchange of technical personnel to introduce modeling techniques on refining and petrochemical process design and operations
- Study of alternative sources of energy supply
- Energy demand modeling to improve service to rural areas

COMMENTS

- Most of the indigenous oil produced (5000 barrels per day) is exported; active reserves are being exhausted.
- In 1986, 158 tons of coal were imported from the United States. Development of coal fields in Izabel is a possibility.
- In terms of energy use, Guatemala's industrial sector is the largest in Central America.
- The priority in energy planning is to diversify electricity production away from imported oil.
- A World Bank loan of $81 million in 1986 is being used to finance expansion of electric service areas and improved power distribution.
- Zunil, a site of considerable geothermal energy potential, is being developed with assistance from the InterAmerican Development Bank. Amatillan is another potential site.

POTENTIALLY INTERESTED PARTIES

- Guatemalan Instituto Nacional de Electrification
- Guatemalan Ministry of Energy and Mines

- World Bank
- United Nations Development Program
- InterAmerican Development Bank

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Exports of coal and coal technology as an alternative to deficit spending on oil
- Manufactured equipment exports, e.g., boilers
- Fossil-fuel technology exports for industry conversions and power generation
- Geothermal power technology exports

DOE/FE COLLABORATIVE AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*: none
  3. *Development*:
     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
     - AFB applications in the commercial, institutional, and residential sectors
- Unconventional Gas Recovery
  1. *Basic research*:
     - Physical and chemical properties of gas hydrates
     - Organic chemistry of deep-source gas
  2. *Applied research*: none
  3. *Development*: development and refinement of a reservoir simulation model

- Enhanced Oil Recovery

  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry

  2. *Applied research*:

     - Chemical and gas injectant mechanisms

     - Geologic impediments to enhanced oil recovery

     - Mobility control and oil displacement mechanisms

     - Petroleum characterization and thermal recovery strategies

     - Reservoir and injection fluid interactions

     - Alkaline flooding and in-situ combustion

     - Geoscience characterization relative to heterogeneity constraints on thermal processes

     - Novel concepts to extract unrecoverable oil

     - Extraction process measurement techniques and advanced surface/in-situ process parameters

  3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

HONDURAS

INDIGENOUS FUELS OF INTEREST: Oil, possibly coal, and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Energy planning, with focus on alternative sources of energy supply, and development of an information system to organize energy data for forecasting
- Methodology to extract natural gas in the Comayagua Valley and along the Caribbean Coast
- Establishment of basic research programs on coal characterization
- Use of coal as an oil substitute in small industrial boilers (e.g., in the cement, textile, and tile- and brick-making industries)

COMMENTS

- Honduras is making a concerted effort to diversify its fuel use away from foreign oil and toward indigenous resources.
- The Honduran Economic Planning Council (CONSUPLANE) has requested assistance in developing and implementing an information system to organize energy data for forecasting and in designing an energy planning methodology.
- The industrial sector uses 30% of the imported petroleum products.
- Geothermal potential is being investigated through an AID grant; the United Nations Development Program uses an Italian firm for geothermal applications.

POTENTIALLY INTERESTED PARTIES

- CONSUPLANE
- Honduran Petroleum Management Commission
- World Bank
- AID

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for industry conversions (both conventional and clean coal technologies)
- Technical training and support; sales of computer hardware, software, and services

DOE/FE COLLABORATIVE AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*: combustion systems characterization
  3. *Development*: design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
- Unconventional Gas Recovery
  1. *Basic research*: organic chemistry of deep-source gas
  2. *Applied research*: none
  3. *Development*: development and refinement of a reservoir simulation model
- Advanced Research and Technology Development
  1. *Basic research*: fundamental properties of coal and coal-derived fuels
  2. *Applied research*: none
  3. *Development*: none
- Enhanced Oil Recovery
  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry
  2. *Applied research*:
     - Chemical and gas injectant mechanisms
     - Geologic impediments to enhanced oil recovery

- Mobility control and oil displacement mechanisms
- Petroleum characterization and thermal recovery strategies
- Reservoir and injection fluid interactions
- Alkaline flooding and in-situ combustion
- Geoscience characterization relative to heterogeneity constraints on thermal processes
- Novel concepts to extract unrecoverable oil
- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

INDIA

INDIGENOUS FUELS OF INTEREST: Coal, oil, and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Characterization and beneficiation studies relating to low-quality coals mined in western India
- Use of premium-quality Assam coal for blending purposes
- Studies of coal-water mixtures to mitigate transport bottlenecks
- Studies on thermal coal-cleaning processes
- Feasibility studies on cogeneration and small coal plants

COMMENTS

- The government has emphasized the development of the coal industry and exploration for oil and gas, and has embarked on a major construction program for coal-based thermal power plants located near the mines. At present, noncommercial fuels (vegetables, animal wastes, etc.) account for approximately 40% of total energy consumption, while coal accounts for 32%, oil and gas for about 20%, and primary electricity for 8%.
- The government appears to favor the import of technology in cases where the lead time required to develop it indigenously would delay important development programs.
- Foreign technology-licensing agreements have resulted in increased imports of components, without which the items being manufactured under license cannot be produced.
- Bharat Heavy Electricals Ltd., the largest manufacturer in India of large generation, transmission, and distribution equipment, has a mediocre record in terms of equipment reliability. Some believe that India must look beyond its borders for quality equipment.
- Collaborative research is underway on coal beneficiation, fluidized-bed performance, lignite FBCs, coal-water mixtures, and coal gasification. In collaboration with the government of India, AID supported a R&D program (see below) on new and advanced coal and biomass conversion technologies.

POTENTIALLY INTERESTED PARTIES

- AID
- World Bank
- Association of Indian Engineering Industries
- Indian Department of Nonconventional Energy Sources

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports -- conventional and clean coal technologies
- Power generation and transmission equipment

DOE/FE COLLABORATIVE R&D AGREEMENTS

- Participating Agency Service Agreement between AID and the DOE Pittsburgh Energy Technology Center, authorizing the latter to implement the Alternative Energy Resources and Development Project in Coal and Biomass Conversion in India (March 1983 to March 1987)

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*:
     - Promising concepts for physical and chemical coal cleaning
     - Beneficiation and slurry participation of low-rank coals
     - Selected particle removal and control approaches
     - Selective coalescence and microcharacterization of coal particles
  3. *Development*: none
- Advanced Research and Technology Development
  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements

2. *Applied research:* studies, analyses, and testing related to coal and coal-based technologies

3. *Development:* none

- Combustion Systems

1. *Basic research:* none

2. *Applied research:* emission and combustion properties of coal-derived fuels

3. *Development:* development of specific coal-derived fuels and operational testing of advanced combustors

- Coal Liquefaction

1. *Basic research:* physical, chemical, and thermodynamic properties of polycyclic compounds

2. *Applied research:*

   - Dynamics of coal liquefaction

   - Biological and novel catalytic approaches

3. *Development:* none

- Enhanced Oil Recovery

1. *Basic research:* flow, rock and fluid phenomena, and rock chemistry

2. *Applied research:*

   - Chemical and gas injectant mechanisms

   - Geologic impediments to enhanced oil recovery

   - Mobility control and oil displacement mechanisms

   - Petroleum characterization and thermal recovery strategies

   - Reservoir and injection fluid interactions

   - Alkaline flooding and in-situ combustion

- Geoscience characterization relative to heterogeneity constraints on thermal processes

- Novel concepts to extract unrecoverable oil

- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development:* cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

INDONESIA

INDIGENOUS FUELS OF INTEREST: Coal, natural gas, and oil

POTENTIAL COLLABORATIVE R&D AREAS

- Transfer and adaptation of technologies (conventional or advanced) to increase energy production and efficiency, especially in thermal power plants
- Assessment of U.S. coal-based technology transfers
- Energy planning and training
- Feasibility studies on cogeneration and industrial fuel switching to coal
- Transportation modeling to support the development of infrastructure, land transportation systems, ports, and handling facilities required with increased use of coal
- Basic coal science and coal characterization

COMMENTS

- The major thrust of the government's energy plan is to maintain the level of oil export earnings, by diversifying domestic consumption away from oil to alternative and more-economic energy resources such as coal, hydropower, geothermal energy and gas.
- Coal deposits of economic significance are confined to the islands of Sumatra and Kalimantan, while the greatest potential energy demand is on Java.
- Plans for two coal-fired generating units in West Java, Suralaya III and IV, are underway. Monenco of Canada will participate in the construction and Babcock and Wilcox of Canada will manufacture the boilers. Suralaya I and II (two 400-MW units) use some Australian coal, but a switch to Sumatran coal is anticipated.
- Paiton I and II, two coal-fired units planned for East Java and designed by a consortium that included Sargent & Lundy of Chicago, were not constructed due to adverse local and world economies.
- A recent *Chicago Tribune* article (Sept. 27, 1987) gives the government of Indonesia high marks for increasing the export of nonoil products and leading its economy toward recovery. The United States is the primary importer of Indonesia's nonoil goods, followed by Japan and then Singapore.

- Captive capacity is not known, but estimates run as high as 40% of the country's total installed electrical capacity. Government policy is to replace uneconomic captive generation sources as rapidly as the National Electricity Authority (PLN) can extend the grid.

- Private power potential is being studied by AID, along with the possibility of replacing existing boilers with cogeneration on Java, where about 30% of all industries and some villages use captive power. Opportunities may exist for potential replacement by advanced coal combustion systems and/or clean coal technology.

- Indonesia has good R&D capabilities for oil and gas, but not for coal. The AID-sponsored Energy Research Laboratory Project will provide an institutional structure for coal R&D projects. The Battelle Memorial Institute is involved in this project.

POTENTIALLY INTERESTED PARTIES

- Puspiptek (a national energy laboratory)
- AID
- World Bank
- International Monetary Fund
- Secretariat to the Indonesian Energy Committee (a cabinet-level position)
- National Energy Coordinating Board (Bakoren)
- National Electricity Authority (PLN)
- Indonesian Ministry of Mines and Energy
- Indonesian Directorate General of Power

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for industry conversions and power generation
- Clean coal technology exports using advanced coal combustion systems
- Cogeneration technology exports
- Computer hardware and software exports to run energy and transportation models

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Combustion Systems

  1. *Basic research*: none

  2. *Applied research*:

     - Combustion systems characterization

     - Emission and combustion properties of coal-derived fuels

  3. *Development*:

     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

     - Development of specific coal-derived fuels and operational testing of advanced combustors

- Advanced Research and Technology Development

  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements

  2. *Applied research*: studies, analyses, and testing related to coal and coal-based technologies

  3. *Development*: none

- Enhanced Oil Recovery

  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry

  2. *Applied research*:

     - Chemical and gas injectant mechanisms

     - Geologic impediments to enhanced oil recovery

     - Mobility control and oil displacement mechanisms

     - Petroleum characterization and thermal recovery strategies

     - Reservoir and injection fluid interactions

     - Alkaline flooding and in-situ combustion

- Geoscience characterization relative to heterogeneity constraints on thermal processes

- Novel concepts to extract unrecoverable oil

- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

JORDAN

INDIGENOUS FUELS OF INTEREST: Oil shale and heavy oil

POTENTIAL COLLABORATIVE R&D AREAS

- Comparative study of coal and heavy fuel oil, specifically an economic comparison of various imported (i.e., U.S.) coals, for use in power generation
- An oil shale demonstration program, assuming a positive feasibility study and interest in the technology
- Study of coal-water mixtures and pulverized-coal injection to permit retrofitting of oil-burning units in industry and power generation facilities

COMMENTS

- Jordan is entirely dependent on imports for its commercial energy needs. The country has experienced high growth in energy consumption over the last decade.
- A feasibility study is under way to examine the possibility of using the fluidized-bed technology of Pyropower (a U.S. company marketing Finnish technology) with Jordanian oil shale.
- Soviet technology for mining oil shale may enter the Jordanian market.
- Jordan's disincentive to reduce its oil imports is the receipt of considerable assistance from Saudi Arabia, which might be sacrificed if Jordan achieved relative energy independence.
- Jordan has imported very small quantities of U.S. coal.
- The World Bank is assisting Jordan to expand power capacity, to be fueled initially by heavy oil.

POTENTIALLY INTERESTED PARTIES: AID Mission

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports for use in small industrial boilers and dual-fueled electricity-generating units
- Fossil-fuel technology exports

DOE/FE COLLABORATIVE R&D AGREEMENTS

- Participation by DOE/FE in the Heavy Crude and Tar Sands Project cosponsored by the United Nations Institute for Training and Research and the United Nations Development Program (multilateral, ongoing since 1979)

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization
     - Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale
     - PFB dynamics, systems analysis, and technology economic analyses
     - emission and combustion properties of coal-based fuels
  3. *Development*: none
- Oil Shale
  1. *Basic research*: extraction
  2. *Applied research*:
     - Systems analysis of data bases on reference shales
     - Rock fragmentation, in-situ retorting, and advanced process concepts
     - Chemical stability of spent shale piles
  3. *Development*: continuous-mining extraction
- Enhanced Oil Recovery
  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry
  2. *Applied research*:
     - Chemical and gas injectant mechanisms

- Geologic impediments to enhanced oil recovery
- Mobility control and oil displacement mechanisms
- Petroleum characterization and thermal recovery strategies
- Reservoir and injection fluid interactions
- Alkaline flooding and in-situ combustion
- Geoscience characterization relative to heterogeneity constraints on thermal processes
- Novel concepts to extract unrecoverable oil
- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

SOUTH KOREA

INDIGENOUS FUELS OF INTEREST: Anthracite (for household heating)

POTENTIAL COLLABORATIVE R&D AREAS

- Energy planning and training in conjunction with the Korean Electric Power Corp., to facilitate implementation of planned nuclear and coal-fired capacity
- Studies of coal-water mixtures for manufacturing use; studies could involve foreign industry participants identified through joint workshops by the DOE Pittsburgh Energy Technology Center and the South Korean government on coal utilization technology
- Assessment of small industrial, residential, and commercial combustor applications
- A joint PFB coal-combustion project involving the DOE Morgantown Energy Technology Center and the Korean Institute of Energy and Resources (KIER). (KIER has also recently indicated interest in collaborating with ANL in coal technologies.)

COMMENTS

- Thermal coal imports are currently blended with domestic anthracite for household heating; demand is increasing while domestic anthracite reserves are declining. Retrofitting may be required in the household sector as well as the industrial sector.
- The World Bank is trying to convince the government to abandon plans for nuclear power generation and to use coal-fired generation instead.
- Government policy is to promote the substitution of coal and other primary fuels for oil in utility and other industrial uses. The South Korean EXIM Bank is said to be willing to provide up to 70% of long-term financing in ventures that result in significant supply to South Korea.

POTENTIALLY INTERESTED PARTIES

- KIER
- Korean Advanced Institute of Science and Technology
- Korean Electric Power Corp.
- Yukong Ltd. (formerly the Korean Oil Corp.)

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports, depending on the extent to which nuclear power for electricity generation is curtailed
- Fossil-fuel technology exports for industrial, residential, and commercial applications

DOE/FE COLLABORATIVE R&D AGREEMENTS

MOU for a Cooperative Laboratory Relationship (Nov. 1981 to Nov. 1986)

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

Combustion Systems

1. *Basic research*: none
2. *Applied research*: none
3. *Development*:
   - Development of specific coal-derived fuels and operational testing of advanced combustors
   - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
   - AFB applications in the commercial, institutional, and residential sectors

MALAYSIA

INDIGENOUS FUELS OF INTEREST: Coal and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Transfer and adaptation of technologies (conventional or advanced) to increase energy production and efficiency
- Basic coal science and coal characterization
- Methodology to increase natural gas quantities for domestic power production
- Energy planning and training
- Feasibility studies on industrial fuel switching to coal

COMMENTS

- Despite domestic reserves of lignite and subbituminous coal, no commercial coal production occurs. Malaysia has large indigenous gas reserves, which are expected to provide the country with approximately a 40-year supply.
- The government has adopted a "Four-Fuel Policy" (oil, gas, hydropower, and coal) and remains committed to completion of the Port Kelang generation facilities under that policy.
- Consumption of imported coal is expected to increase fourfold after the completion of Port Kelang.
- Phase 1 of the Port Kelang plant and three other thermal power stations are due to convert from oil to local natural gas in 1990.
- Phase 2 (two 300-MW units) of Port Kelang will be the last major power plant added to the National Electricity Board peninsular grid this decade.
- Under consideration for Phases 3 and 4 are two 1,000-MW increments, each composed of two 500-MW triple-fired coal/gas/oil units. Phase 3, expected to be commissioned in 1993 at the earliest, will be gas-fired; Phase 4 is expected to be coal-fired (late 1990s).
- Indonesia has supplied the major share of cement companies' coal requirements since cement makers converted to coal use in 1980; however, Australian and Chinese suppliers are increasing their share of Malaysia's depressed cement industry coal market.

POTENTIALLY INTERESTED PARTIES

- AID
- World Bank

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports (both conventional and clean coal technologies)
- Power generation and transmission equipment exports
- Computer hardware and software exports to run energy and transportation models

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Advanced Research and Technology Development
  1. *Basic research:* fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements
  2. *Applied research:* studies, analyses, and testing related to coal and coal-based technologies
  3. *Development:* none
- Combustion Systems
  1. *Basic research:* none
  2. *Applied research:*
     - Combustion systems characterization
     - Emission and combustion properties of coal-based fuels
  3. *Development:* none
- Unconventional Gas Recovery
  1. *Basic research:*
     - Physical and chemical properties of gas hydrates

- Organic chemistry of deep-source gas

2. *Applied research*:

   - Geologic studies of tight gas sands, gas hydrates, and deep-source gas

   - Simulation, testing, and analysis

3. *Development*: development and refinement of a reservoir simulation model

MOROCCO

INDIGENOUS FUELS OF INTEREST: Coal, oil shale, and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Mechanization of the Jerada mine to increase its production of high-quality anthracite (collaboration could include a detailed benefit/cost study and U.S. engineering assistance).
- Feasibility study of switching existing power plants from oil to coal using coal-water mixtures or other fine-coal technologies
- Use of imported (i.e., U.S.) coal at the planned Mohammedia III and IV 300-MW power plant and/or planned thermal plant at Jorf Lasfar (collaboration could include assessment of applicable U.S. coals and clean coal technologies)
- Feasibility study of FBCs to reduce environmental and fuel-handling concerns at local and plant levels
- Study of the comparative feasibility of batch retorting and direct combustion for the Timahdit oil-shale deposits
- Energy planning assistance and training to improve the nation's skills base

COMMENTS

- Morocco is highly dependent on energy imports. (It imported 90% of all commercial energy used in 1986.)
- The government plans a massive shift from fuel oil to coal for industrial and utility uses by 1996. In 1986, 83% of coal imports came from the United States.
- The power system is projected to be short of capacity by 1989.
- Fine-coal technologies could be a good choice for coal-fired plants because of (1) ease of transportation, (2) ability to overcome port capacity problems if slurry is imported, (3) relative economic advantages, and (4) relative ease of cleaning.
- The Timahdit oil-shale deposit has been extensively studied since 1974. A U.S. firm has recommended the T-3 batch retorting process for energy recovery, while Soviet and West German studies recommend direct combustion. (The shale has a low calorific value, a high ash content, and a high proportion of residual carbon.)

- Technical assistance is being provided by the World Bank to define geological opportunities for natural gas exploration and to promote private investment in exploration.

POTENTIALLY INTERESTED PARTIES

- AID Mission*
- Moroccan Office National de L'Electricite

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports for the planned Mohammedia III and IV power plant and for cement and phosphate plants, in order to extend reserves of indigenous high-quality anthracite (to the early or mid-1990s)
- Fossil-fuel technology exports (both equipment and expertise) for use in utilities and/or industry

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*:
     - Beneficiation and slurry preparation of low-rank coals
     - Small-scale combustor environmental controls
  3. *Development*: testing of promising advanced concepts for physical cleaning of fine coal
- Combustion Systems
  1. *Basic research*: none

*For 1987-1991, approximately $14 million has already been committed for an energy program.

2. *Applied research:*

   - Combustion systems characterization

   - Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale

   - PFB dynamics, systems analysis, and technology economic analyses

   - Emission and combustion properties of coal-derived fuels

3. *Development:*

   - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

   - Proof-of-concept testing and development of coal-slurry feed system and updated U.S.-designed tube bundle

   - Development of specific coal-derived fuels and operational testing of advanced combustors

- Oil Shale

  1. *Basic research:* extraction

  2. *Applied research:*

     - Systems analysis of data bases on reference shales

     - Rock fragmentation, in-situ retorting, and advanced process concepts

     - Chemical stability of spent shale piles

  3. *Development:* continuous-mining extraction methods

PAKISTAN

INDIGENOUS FUELS OF INTEREST: Coal, lignite, oil, and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Staff training at the Fuel Research Laboratory of the Pakistan Council for Scientific and Industrial Research (FRL/PCSIR) and assessment of (1) opportunities for coal/lignite use in the utility, industry, and residential/commercial sectors, and (2) conversion from oil to coal in the cement industry
- Use of low-quality lignite at the Lakhra coal field (Sind Province) for mine-mouth power generation. Collaboration could include: (1) lignite characterization studies to determine applicability to FBC technology, (2) lignite beneficiation studies to improve quality, and (3) staff training at the FRL/PCSIR.
- Studies of coal-water mixtures using low-rank, high-sulfur indigenous coal and pulverized-coal injection to permit retrofitting of oil-fueled generating units
- Research on coal briquettes as a substitute for wood fuels
- Electric system expansion planning and transmission scheme management
- Energy planning and training
- Feasibility studies on cogeneration and small coal plants
- Research, using small experimental FBC units, on combinations of coals and limestone
- Technology transfers focusing on boiler and furnace design and on cogeneration

COMMENTS

- The research areas proposed are consistent with the energy strategy outlined in the Sixth Five-Year Plan (1983-88).
- Hydropower represents 60% of power generation. Shortages and forced load shedding are common in the winter dry season, when dam water levels diminish significantly.
- The United States is a leading supplier of power-generating equipment and is expected to remain so, because of the large number of AID dollars available to Pakistan for financing foreign-exchange requirements for power development and rural electrification. These AID funds may be used for private-sector imports of energy-related equipment and materials, especially for reducing electricity

generation and distribution losses. Other countries providing credit for this purpose, as well as for current and future power development plans, include Czechoslovakia and the Soviet Union.

- A New Fuels Laboratory in Karachi has been financed by AID. It will have a coal R&D capability and is expected to be operational in early 1988.

- Feasibility studies and design work have been funded by AID for a lignite mine at Lakhra for a conventional 500-MW plant, performed by Gilbert Commonwealth, J.T. Boyd, and ICF (all U.S. firms).

- Pyropower (a U.S. firm marketing Finnish technology) is studying the feasibility of an FBC facility at the Lakhra site and may join with Bechtel and local companies to build three 400-MW units.

- The Ghuddu 400-MW complex, financed by the Asian Development Bank, will use natural gas in a combined-cycle arrangement with efficiency of over 40%, making it the most efficient thermal plant in Pakistan. Gibbs and Hill are providing architectural and engineering services.

- Arthur D. Little Co. has been advising the Pakistani government on approaches to attract private investment for the Dhodak condensate field.

- Under AID funds, Bechtel is studying the feasibility of a 1,250-MW complex at Jamsboro that would use imported coal.

POTENTIALLY INTERESTED PARTIES

- AID Mission
- World Bank
- Pakistani Water and Power Development Authority
- Karachi Electricity Supply Corp.

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports to blend with indigenous lignite reserves
- Fossil-fuel technology exports for mine-mouth lignite power generation facilities
- Coal-fired boiler technology exports

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation

  1. *Basic research*: none

  2. *Applied research*:

     - Beneficiation and slurry preparation of low-rank coals

     - Selective coalescence and microcharacterization of coal particles

     - Small-scale combustor environmental controls

  3. *Development*: none

- Advanced Research and Technology Development

  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements

  2. *Applied research*: studies, analyses, and testing related to coal and coal-based technologies

  3. *Development*: none

- Combustion Systems

  1. *Basic research*: none

  2. *Applied research*:

     - Combustion systems characterization

     - Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale

     - PFB dynamics, systems analysis, and technology economic analyses

     - Fluidization research on particle motion, heat transfer, and bed internals

     - Emission and combustion properties of coal-based fuels

  3. *Development*:

     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

- Proof-of-concept testing and development of coal-slurry feed system and updated U.S.-designed tube bundle
- Development and evaluation of advanced PFB combined-cycle systems
- Innovative vortexing combustor development
- Testing and evaluation of advanced AFB concepts
- AFB applications in the commercial, institutional, and residential sectors
- Development of specific coal-derived fuels and operational testing of advanced combustors
- Limestone injection multistage burner

- Enhanced Oil Recovery

1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry
2. *Applied research*:
   - Chemical and gas injectant mechanisms
   - Geologic impediments to enhanced oil recovery
   - Mobility control and oil displacement mechanisms
   - Petroleum characterization and thermal recovery strategies
   - Reservoir and injection fluid interactions
   - Alkaline flooding and in-situ combustion
   - Geoscience characterization relative to heterogeneity constraints on thermal processes
   - Novel concepts to extract unrecoverable oil
   - Extraction process measurement techniques and advanced surface/in-situ process parameters
3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

PANAMA

INDIGENOUS FUELS OF INTEREST: Coal

POTENTIAL COLLABORATIVE R&D AREAS

- Evaluation of the extent and quality of coal resources to identify their potential and uses
- Feasibility study of small coal-fired units and combined-cycle plants as potential sources of additional capacity
- Study of the potential of small coal-fired plants to supply low-cost electricity to residential areas

COMMENTS

- Panama depends on imported oil and hydropower energy.
- The Institute of Hydro Resources and Electrification (IRHE), which is the state-owned power company, follows a policy of alternative energy substitution for petroleum. Almost all electricity requirements are now being met by hydropower.
- Coal deposits have been identified, but not proven. The IRHE is very interested in studying these deposits.
- Residential customers pay higher electricity prices than do commercial, industrial, and government customers.

POTENTIALLY INTERESTED PARTIES

- AID Mission
- IRHE
- National Commission of Energy (CONADE)
- MIPPE (a national economic planning commission)

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports for use in thermal power stations

- Fossil-fuel technology exports, especially integrated coal-gasification combined-cycle technology

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*: small-scale combustor environmental controls
  3. *Development*: none
- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization
     - Emission and combustion properties of coal-based fuels
  3. *Development*:
     - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
     - Development and evaluation of advanced PFB combined-cycle systems
     - Development of specific coal-derived fuels and operational testing of advanced combustors
- Advanced Research and Technology Development
  1. *Basic research*: none
  2. *Applied research*: studies, analyses, and testing related to coal and coal-based technologies
  3. *Development*: none

PEOPLE'S REPUBLIC OF CHINA

INDIGENOUS FUELS OF INTEREST: Coal, oil, gas, and oil shale

POTENTIAL COLLABORATIVE R&D AREAS

- Transfer and adaptation of conversion or combustion technologies (conventional or advanced) to increase energy production and efficiency, especially in thermal power plants (300- to 600-MW coal-fired units)
- Coal beneficiation studies to reduce coal supply volumes and increase quality
- Studies on coal-water mixtures to mitigate transport bottlenecks
- Coal-liquefaction and/or coal-gasification studies for energy use in the transportation, residential, and commercial sectors
- Assessment of the People's Republic of China (PRC) environmental problems to define the extent of industrial pollution (especially SO_2 and particulates) and propose strategies for abatement
- Basic coal science and coal characterization

COMMENTS

- Although the PRC's coal reserves are relatively low in sulfur, the large quantities of coal consumed have resulted in high concentrations of SO_2 and particulates, especially in northern cities. Current environmental protection regulations contain environmental quality standards and administrative guidelines, but no specific emission standards.
- Current government-sponsored research focuses on clean coal technologies for industry and utility boilers, e.g., FBCs and flue-gas desulfurization.
- Cogeneration technology in the PRC is not advanced by international standards, but it is sought for energy conservation. Priority is said to be in district-heating systems.
- Electrical power is distributed through 30 grids. Installed capacity will continue to be unable to keep up with demand. Industry purchases 80% of the electricity.

POTENTIALLY INTERESTED PARTIES

- Chinese Ministry of Coal Industry

- Chinese Ministry of Water Resources and Electric Power
- Chinese Ministry of Petroleum Industry
- Chinese Academy of Sciences

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports (both conventional and clean coal technologies)
- Technical training and support services, including design, operation, consultation, and feasibility studies
- Computer hardware, software, and services for modeling purposes

DOE/FE COLLABORATIVE R&D AGREEMENTS

- Fossil energy research and development in enhanced oil recovery research (Annex III: planned)
- Protocol on cooperation in the field of fossil energy research and development
  1. Annex I: International property rights
  2. Annex VI: Information exchange on AFB combustion technology

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research:* none
  2. *Applied research:*
     - Promising concepts for physical and chemical coal cleaning
     - Beneficiation and slurry preparation of low-rank coals
     - Selected particle removal and control approaches
     - Selective coalescence and microcharacterization of coal particles
     - Advanced NO_x and SO_x chemistry
     - Small-scale combustor environmental controls

3. *Development*:

   - Molten caustic-leaching concept to clean fine coals

   - Testing of promising advanced concepts for physical cleaning of fine coal

   - Acid-rain control technology

   - Proof-of-concept work on advanced processes to reduce NO_x and SO_x emissions

- Advanced Research and Technology Development

  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements

  2. *Applied research*: studies, analyses, and testing involving coal and related technologies

  3. *Development*: none

- Coal Liquefaction

  1. *Basic research*: physical, chemical, and thermodynamic properties of polycyclic compounds

  2. *Applied research*:

     - Dynamics of coal liquefaction

     - Fischer-Tropsch technology

     - Biological and novel catalytic approaches

  3. *Development*: none

- Combustion Systems

  1. *Basic research*: none

  2. *Applied research*:

     - Combustion systems characterization

     - Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale

- PFB dynamics, systems analysis, and technology economic analyses
- Fluidization research in particle motion, heat transfer, and bed internals
- Emission and combustion properties of coal-based fuels

3. *Development:*
   - Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors
   - Proof-of-concept testing and development of coal slurry feed system and updated U.S.-designed tube bundle
   - Development and evaluation of advanced PFB combined-cycle systems
   - Innovative vortexing combustor development
   - Testing and evaluation of AFB concepts
   - AFB applications for the commercial, institutional, and residential sectors
   - Development of specific coal-derived fuels and operational testing of advanced combustors
   - Limestone-injection multistage burner

- Surface Coal Gasification

1. *Basic research:*
   - Fundamental chemistry, reaction mechanisms, and control of product-yield distribution
   - Novel approaches to gas separations

2. *Applied research:*
   - Coal gasification systems
   - Techniques for environmental characterization of power systems, sampling of operating systems, and evaluation of hot-gas cleanup candidate technologies

3. *Development:* support of integrated operations of industrial coal-gasification systems for production of power and industrial fuel gas

- Enhanced Oil Recovery

  1. *Basic research*: flow, rock and fluid phenomena, and rock chemistry

  2. *Applied research*:

     - Chemical and gas injectant mechanisms

     - Geologic impediments to enhanced oil recovery

     - Mobility control and oil displacement mechanisms

     - Petroleum characterization and thermal recovery strategies

     - Reservoir and injection fluid interactions

     - Alkaline flooding and in-situ combustion

     - Geoscience characterization relative to heterogeneity constraints on thermal processes

     - Novel concepts to extract unrecoverable oil

     - Extraction process measurement techniques and advanced surface/in-situ process parameters

  3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

- Oil Shale

  1. *Basic research*: extraction

  2. *Applied research*:

     - Systems analysis of data bases on reference shales

     - Rock fragmentation, in-situ retorting, and advanced process concepts

     - Chemical stability of spent shale piles

  3. *Development*: continuous-mining extraction methods

PERU

INDIGENOUS FUELS OF INTEREST: Oil and coal

POTENTIAL COLLABORATIVE R&D AREAS

- Feasibility study of in-situ gasification of hard-to-mine coal reserves
- Feasibility study of the potential for conversion of installed thermal-power capacity from petroleum to coal, using coal-water mixtures
- Feasibility study on the use of indigenous coal for industrial steam and/or utility applications
- Feasibility study on the use of small combustors to meet power needs in remote areas
- Detailed benefit/cost assessment of a national investment in building up coal capability (extraction, transportation, handling, etc.), instead of hydropower
- Evaluation of urban air pollution in the Lima area to characterize air emissions and recommend mitigation measures

COMMENTS

- Peru faces depletion of its oil reserves by 1990 unless conservation and/or other measures are taken.
- Although coal plays a minor role in the energy economy, the Peruvian government is said to be committed to its use.
- An infrastructure for coal extraction and transportation does not exist. Some obstacles to increased coal use include a lack of suitable equipment and expertise to operate it, inappropriate geological conditions for large-scale mechanized mining, an absence of detailed geological surveys, and the difficulty of transporting coal from mountain mines to potential consuming areas on the coast.
- Peru has one of the lowest rates of per capita power consumption in Latin America.
- The generation of electric power is a key component of the Peruvian plan to encourage investment in industry, develop rural areas, and create employment.

POTENTIALLY INTERESTED PARTIES

- AID Mission

- Consejo Nacional de Energia
- Electroperu

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports, specifically coal-burning equipment
- Need for U.S. personnel to install and operate coal-burning equipment

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*:
     - Promising concepts for physical and chemical coal cleaning
     - Selected particle removal and control approaches
     - Advanced NO_x and SO_x chemistry
     - Small-scale combustor environmental controls
  3. *Development*:
     - Acid-rain control technology
     - Proof-of-concept work on advanced processes to reduce NO_x and SO_x emissions
- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization
     - AFB applications in the commercial, institutional, and residential sectors

- Development of specific coal-derived fuels and operational testing of advanced combustors

3. *Development:* none

- Underground Coal Gasification

1. *Basic research:* environmental mitigation techniques

2. *Applied research:* technical support of field tests cofunded by government and industry

3. *Development:* none

- Advanced Research and Technology Development

1. *Basic research:* none

2. *Applied research:* studies, analyses, and testing involving coal and related technologies

3. *Development:* none

- Enhanced Oil Recovery

1. *Basic research:* flow, rock and fluid phenomena, and rock chemistry

2. *Applied research:*

- Chemical and gas injectant mechanisms

- Geologic impediments to enhanced oil recovery

- Mobility control and oil displacement mechanisms

- Petroleum characterization and thermal recovery strategies

- Reservoir and injection fluid interactions

- Alkaline flooding and in-situ combustion

- Geoscience characterization relative to heterogeneity constraints on thermal processes

- Novel concepts to extract unrecoverable oil

- Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development*: cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

PHILIPPINES

INDIGENOUS FUELS OF INTEREST: Lignite, coal,* and oil shale

POTENTIAL COLLABORATIVE R&D AREAS

- Feasibility studies on cogeneration and small coal plants
- Characterization and beneficiation studies relating to low-quality coals
- Studies of coal-water mixtures using indigenous coal and pulverized-coal injection to permit retrofitting of oil-burning units in industry and power-generating facilities
- Energy planning and training
- Electric system expansion planning and transmission scheme management

COMMENTS

- The research areas proposed are consistent with the government's policy of diversifying power generation by developing indigenous energy sources.
- Environmental concerns forced the cancellation of a planned 675-MW nuclear plant.
- A U.S. company has proposed to supply a coal-water mixture for the Sucat power plant, which now uses oil.
- Political instability continues during the Aquino administration, hindering domestic growth.

POTENTIALLY INTERESTED PARTIES

- Bureau of Energy Utilization of the Philippine Ministry of Energy
- Energy Managers Association of the Philippines
- AID

*Both subbituminous and bituminous.

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Coal exports to blend with indigenous Philippine reserves
- Fossil-fuel technology exports for industry conversions and power generation
- Coal-fired boiler technology exports
- Cogeneration technology exports

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation
  1. *Basic research*: none
  2. *Applied research*:
     - Beneficiation and slurry preparation of low-rank coals
     - Selective coalescence and microcharacterization of coal particles
     - Small-scale combustor environmental controls
  3. *Development*: none
- Advanced Research and Technology Development
  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements
  2. *Applied research*: studies, analyses, and testing involving coal and related technologies
  3. *Development*: none
- Combustion Systems
  1. *Basic research*: none
  2. *Applied research*:
     - Combustion systems characterization

- Development of combustion data and operating parameters and evaluation of PFB components at a subpilot scale

- PFB dynamics, systems analysis, and technology economic analyses

- Fluidization research in particle motion, heat transfer, and bed internals

- Emission and combustion properties of coal-based fuels

3. *Development*:

- Design, fabrication, and testing of prototype combustors for retrofit applications in the industrial, commercial, and residential sectors

- Proof-of-concept testing and development of coal-slurry feed system and updated U.S.-designed tube bundle

- Development and evaluation of advanced PFB combined-cycle systems

- Innovative vortexing combustor development

- Testing and evaluation of AFB advanced concepts

- AFB applications in the commercial, institutional, and residential sectors

- Development of specific coal-derived fuels and operational testing of advanced combustors

• Oil Shale

1. *Basic research*: extraction

2. *Applied research*:

- Systems analysis of data bases on reference shales

- Rock fragmentation, in-situ retorting, and advanced process concepts

- Chemical stability of spent shale piles

3. *Development*: continuous-mining extraction method.

TAIWAN

INDIGENOUS FUEL OF INTEREST: Coal

POTENTIAL COLLABORATIVE R&D AREAS

- Transfer and adaptation of coal technologies (conventional or advanced) to increase energy production and efficiency
- Basic coal science and coal characterization
- Coal beneficiation studies
- Energy planning and training to facilitate implementation of planned nuclear and coal-fired capacity
- Feasibility studies in industrial fuel switching to coal

COMMENTS

- Despite 200 million tons of coal reserves, Taiwan's domestic production has declined from 3.9 million tons in 1972 to approximately 1.5 million tons/yr currently, due to increasingly difficult mining conditions and competition from oil. Mine tragedies at Haishan and Meishan, killing 170 miners, led to the closing of many of the country's 120 pits.
- Government policy is to promote the substitution of coal and other primary fuels for oil in utility and other industrial uses.
- Improvement of the PRC-Taiwan relationship could soften the prohibition on the use of coal from mainland China.

POTENTIALLY INTERESTED PARTIES

- AID
- World Bank

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports (conventional and clean coal technologies)
- Coal exports to blend with indigenous reserves

DOE/FE COLLABORATIVE R&D AGREEMENTS: none

RELATION TO OR APPLICABILITY OF U.S. DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation

  1. *Basic research*: none

  2. *Applied research*:

     - Beneficiation and slurry preparation of low-rank coals

     - Selective coalescence and microcharacterization of coal particles

  3. *Development*: none

- Advanced Research and Technology Development

  1. *Basic research*: fundamental properties of coal and coal-derived fuels, flow characteristics, and diagnostic instrumentation requirements

  2. *Applied research*: studies, analyses, and testing related to coal and coal-based technologies

  3. *Development*: none

- Combustion Systems

  1. *Basic research*: none

  2. *Applied research*:

     - Combustion systems characterization

     - Emission and combustion properties of coal-based fuels

  3. *Development*: none

THAILAND

INDIGENOUS FUELS OF INTEREST: Lignite and natural gas

POTENTIAL COLLABORATIVE R&D AREAS

- Use of low-quality lignite at Mae Moh, Krabi, and/or Sin Pun for mine-mouth power generation. Collaboration could include beneficiation and characterization studies (with liquefaction potential).
- Use of high-quality lignite at Lamphun for industrial use in the cement, fertilizer, and petrochemical sectors
- Methodology to increase natural gas quantities at competitive prices for domestic power generation
- Separation procedures to increase extraction quantities of liquefied petroleum gas

COMMENTS

- The research areas proposed are consistent with the energy strategy outlined in the Thai Sixth National Economic and Social Development Plan (1987-1991).
- Planned Mae Moh generating units will have lignite-fired natural circulation boilers of the condensing reheat type, and will consist of a tandem compound multicylinder turbine-generation set.
- Japan is Thailand's main supplier of power-generating equipment and is likely to remain so, because of its cheap financing packages.
- Pyropower (a U.S. firm marketing Finnish technology) has proposed a test installation of its FBC technology to use domestic high-sulfur lignite.

POTENTIALLY INTERESTED PARTIES

- AID Mission
- Thailand Development and Research Institute

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Fossil-fuel technology exports for mine-mouth lignite power generation facilities

- Coal exports to blend with indigenous low-sulfur lignite reserves (by the early- to mid-1990s), to extend the lifetime of the lignite reserves and to take advantage of cheap medium- and high-sulfur coal imports.

DOE/FE COLLABORATIVE R&D AGREEMENTS

An MOU is currently being developed between DOE/FE and the Thai Energy Ministry covering broad fossil energy planning, analysis, and training issues, particularly relating to lignite development and use.

RELATION TO OR APPLICABILITY OF DOE/FE DOMESTIC PROGRAMS

- Control Technology and Coal Preparation

  1. *Basic research:* none

  2. *Applied research:*

     - Promising concepts for physical and chemical coal cleaning

     - Beneficiation and slurry preparation of low-rank coals

     - Selected particle removal and control approaches

  3. *Development:* none

- Combustion Systems

  1. *Basic research:* none

  2. *Applied research:* coal-derived fuel testing and characterization of emission and combustion properties

  3. *Development:* development of specific coal-based fuels and operational testing of advanced combustors

- Unconventional Gas Recovery

  1. *Basic research:*

     - Physical and chemical properties of gas hydrates

     - Organic chemistry of deep-source gas

2. *Applied research*:

   - Geologic studies of tight gas sands, gas hydrates, and deep source gas

   - Simulation, testing, and analysis

3. *Development*: development and refinement of a reservoir simulation model

VENEZUELA

INDIGENOUS FUELS OF INTEREST: Oil and coal

POTENTIAL COLLABORATIVE R&D AREAS

- Coal-liquefaction and/or coal-gasification studies to diversify energy use in the utility, residential, and commercial sectors, which now depend heavily on oil
- Assessment of the use of indigenous coal in all sectors
- Energy planning and diversification modeling

COMMENTS

In a recent *Washington Post* article, the Venezuelan government declared its intention to turn around the economy's total dependence on oil. Education on energy alternatives in all sectors and subsectors is needed.

POTENTIALLY INTERESTED PARTIES

- World Bank
- Venezuelan Ministry of Energy and Mines
- United Nations Institute for Training and Research

POTENTIAL MARKET OPPORTUNITIES FOR THE UNITED STATES

- Commercial exports of coal technology and clean coal technologies
- Modeling techniques for energy planning

DOE/FE COLLABORATIVE AGREEMENTS

- MOU for energy research and development (General Agreement) (March 1980 to March 1988)
- Active annexes:

  1. Characterization of heavy crude oil (July 1980 to March 1988) - Annex I

2. Cooperation in supporting research at universities and laboratories (oil) (July 1980 to March 1988) - Annex II

3. Enhanced oil recovery projects (July 1980 to March 1990) - Annex III

4. Enhanced oil recovery thermal processes (Sept. 1980 to Sept. 1986) - Annex IV

5. Coal preparation, combustion, and related activity (Feb. 1982 to March 1988) - Annex VIII

6. Subsidence due to fluid withdrawal (July 1983 to Dec. 1986) - Annex IX

7. On-site training of engineers (March 1984 to March 1988) - Annex X

RELATION TO OR APPLICABILITY OF DOMESTIC DOE/FE PROGRAMS

- Coal Liquefaction

  1. *Basic research*: physical, chemical, and thermodynamic properties of polycyclic compounds

  2. *Applied research*: dynamics of coal liquefaction

  3. *Development*: none

- Underground Coal Gasification

  1. *Basic research*: environmental mitigation techniques

  2. *Applied research*: technical support of field tests cofunded by government and industry

  3. *Development*: none

- Surface Coal Gasification

  1. *Basic research*: novel approaches to gas separations

  2. *Applied research*: none

  3. *Development*: support of integrated operations of industrial coal-gasification systems for power production and for production of industrial fuel gas

- Combustion Systems

  1. *Basic research*: none

2. *Applied research:* PFB dynamics, systems analysis, and technology economic analyses

3. *Development:*

   - Development and evaluation of advanced PFB combined-cycle systems

   - Development of specific coal-based fuels and operational testing of advanced combustors

- Enhanced Oil Recovery

1. *Basic research:* flow, rock and fluid phenomena, and rock chemistry

2. *Applied research:*

   - Chemical and gas injectant mechanisms

   - Geologic impediments to enhanced oil recovery

   - Mobility control and oil displacement mechanisms

   - Petroleum characterization and thermal recovery strategies

   - Reservoir and injection fluid interactions

   - Alkaline flooding and in-situ combustion

   - Geoscience characterization relative to heterogeneity constraints on thermal processes

   - Novel concepts to extract unrecoverable oil

   - Extraction process measurement techniques and advanced surface/in-situ process parameters

3. *Development:* cooperative industry field demonstrations of promising laboratory-scale enhanced oil recovery processes for mature oil fields

APPENDIX D:

EXISTING AGREEMENTS TO BE ASSESSED

Non-U.S
Partner

Brazil

Canada

Israel

Italy

Korea

Spain

Venezuel

APPENDIX D:

EXISTING AGREEMENTS TO BE ASSESSED

Non-U.S. Partner	Subject
Brazil	Underground coal gasification (information exchange)
Canada	Tar sands data base Evaluation of in-situ steam processes for tar sands Tar sands and heavy oil (information exchange) Monitoring of frontal movements of heavy oil/tar sands
Israel	Personnel and information exchange Oil shale extraction Oil shale fracturing Organic sulfur in oil shale matrix Coal chemistry
Italy	Advanced environmental control technology (information exchange) Coal liquefaction
Korea	Personnel and information exchange
Spain	Industrial catalysts Application of underground coal gasification (in Spain)
Venezuela	Enhanced oil recovery thermal processes