

## CHAPTER 1

### INTRODUCTION

#### 1.1 BACKGROUND

The fossil fuel technologies being researched and developed for converting U.S. fossil resources into liquid transportation fuels have been, and are, facing tough economic competition from foreign oil. For nearly twenty years, research has been conducted intensively in the U.S. to develop coal liquefaction technologies to reduce the long-term dependency on imported oil. This large body of accumulated knowledge and experience needs to be assessed to determine the technology status and the readiness of coal liquefaction technologies.

The Office of Program Analysis in the Office of Energy Research of the U.S. DOE (DOE/OER/OPA) has the responsibility to assess long-term research needs associated with the development of new fossil-fuel technologies. In 1980 this office assembled a Fossil Energy Research Working Group (FERWG) to conduct an in-depth assessment of coal liquefaction research needs aimed at commercializing technologies to produce synthetic coal liquids. At that time, the U.S. was in the midst of an energy crisis, described by President Carter as the "moral equivalent of war". Imported oil prices had escalated from \$2.50 per barrel in 1972 to \$34/bbl, and spot prices had reached \$40/bbl. This sudden rise in energy costs, its destabilizing effect on the economy, and the apparent vulnerability of the economy to foreign pressures galvanized an ambitious program by the Federal government and private industry to commercialize technologies to produce synthetic transportation fuels. As the result, the FERWG-II report (1) identified a wide range of important research areas and commercial process development activities (Appendix A summarizes FERWG's most important recommendations.).

However, since 1980 the energy crisis has abated temporarily, and imported oil prices have dropped drastically. Interest in synfuels has

waned. This lull in National interest has resulted in a significant reduction in Federal funds and an almost complete suspension of industrially funded research and development. Since 1980 the majority of Federally funded research activities has shifted from large, commercial-scale demonstration projects to smaller-scale and applied research areas. Also, the absence of commercialization activities has afforded the research community time and resources to address more fundamental research areas. Several years of fundamental efforts have resulted in an accumulation of new knowledge which needs to be assessed. New and improved coal liquefaction technologies have proliferated, providing alternative approaches and new areas of research opportunities not anticipated in the 1980 FERWG-II report.

After nearly a decade of the current oil glut, imports are increasing steadily and are expected to reach 50 percent of total consumption within 2-3 years. This timetable may be accelerated by the current low oil prices, which are forcing cutbacks in domestic exploration and production, and increased reliance on foreign oil. Growing dependency on foreign oil and its potential effect on the U.S. economy make it increasingly important to identify, explore, and implement coal liquefaction technologies to insulate the U.S. from long-term economic shocks from increases in imported oil prices.

In 1987 Science Applications International Corporation (SAIC) assembled a Coal Liquefaction Research Needs (COLIRN) Assessment Panel composed of multidisciplinary researchers from Government laboratories, industry, and universities and others with experience in identifying, developing, and evaluating coal liquefaction research activities. This assessment conducted by SAIC is the first carried out on coal liquefaction since the FERWG-II report issued in March 1980. This current assessment addresses new areas of coal liquefaction research and contains recommendations that will be critical to bring coal liquefaction to technical and economic readiness in the next 5-20 years.

## 1.2 ASSESSMENT OBJECTIVES

The overall purpose of this study was to perform an independent assessment of the research needed to bring coal liquefaction to technical and economic readiness for commercialization. A time frame of 5-20 years for this research was considered in this assessment, which thus included needs in both the short term and the long term. Short-term research is needed to improve relatively well-developed processes in all technology areas; long-term research is needed both to develop fundamental understanding and to utilize new knowledge and emerging concepts as the basis for better processes. Research priorities were to be established based on each program's perceived importance to reach the objective of commercial readiness.

To meet these overall goals, the assessment had a number of specific objectives as follows:

- o Identify and describe the most technically and economically promising coal liquefaction approaches.
- o Identify and describe those process areas and operations which have potential for effecting significant and meaningful process cost reductions.
- o Identify and describe present major problems and concerns with current coal liquefaction processes, and the research needed to address these concerns.
- o Establish a priority for the research needs identified during the assessment.
- o Estimate the degree of risk for the research needs identified during the assessment.

In meeting these objectives this assessment of long-term coal liquefaction research needs addressed the critical issues and alternative approaches to coal liquefaction by emphasizing the following aspects:

- o The understanding of new fundamental and applied research that has emerged in recent years
- o The emergence of potentially technically and economically promising approaches
- o Process areas and operations with potential for significant cost reduction
- o Identification of the scientific and technical base necessary to produce technology improvements
- o Identification of major problems with and unknowns of coal liquefaction processes
- o The technical and economic reasons for changing certain research directions
- o The need to develop innovative approaches to coal liquefaction.

The assessment methodology was designed to emphasize the development of recommendations based upon new fundamental knowledge and innovative approaches. The COLIRN panel then prioritized these recommendations on the basis of perceived risks and benefits.

### 1.3 DEFINITION OF COAL LIQUEFACTION TECHNOLOGIES

Coal liquefaction technologies have undergone significant changes and technical improvements in recent years. In the past there were three different routes to produce liquids from coal: (1) direct conversion of coal to liquid fuels (direct liquefaction), (2) the conversion of synthesis gas from coal to liquid fuels (indirect liquefaction), and (3) thermal treatment of coal (pyrolysis and so-called mild gasification). Recent developments have expanded this list to five, with the addition of (4) production of liquid fuels from combined coal and petroleum feedstocks (coprocessing) and (5) biological conversion of coal or synthesis gas to liquids (bioconversion).

Additionally, indirect liquefaction has taken two routes -- the traditional Fischer-Tropsch method to make a wide range of hydrocarbons, and emerging oxygenate processes to make alcohols and ethers. This interest in oxygenates has been spurred by their growing use as octane enhancers in gasoline and as clean burning fuels to reduce air pollution.

Another liquefaction technology -- the direct conversion of light hydrocarbons to liquid fuels without involving the production and conversion of synthesis gas -- is also emerging, although there may be some question about whether this should be classified as a coal liquefaction technology.

Another recent development in coal liquefaction technologies has been the sharpened focus on the desired product mix, which was brought about by the realities of liquefaction economics. Liquefaction is too expensive to be used as a source of solid or liquid boiler fuels or of coke. The current liquefaction technologies, therefore, produce exclusively transportation fuels, either directly or after refining of the coal liquids. The one major exception is pyrolysis, from which the principal product is char.

#### 1.4 REPORT ORGANIZATION

This chapter presents an introduction to this coal liquefaction R&D needs assessment including (1) the background to the study, (2) the assessment objectives, (3) a description of coal liquefaction technologies, and (4) a description of this report.

Chapter 2 contains a brief description of the methodology used for the assessment. Additional information about assessment methodology is included in the Appendix, including the members of the expert panel (Appendix C), panel meeting reports (Appendix D), and database development and recommendation prioritization (Appendix E).

Chapter 3 discusses the conclusions and recommendations reached as the result of this assessment. Included in this discussion is a description of the status and the important features of each coal liquefaction technology. The research recommendations found to have high priority by the expert panel are described in detail, including their background and supporting rationale. Other conclusions and recommendations developed by the panel regarding future directions for coal liquefaction R&D are also found in this chapter.

Brief reviews of the different coal liquefaction technologies then follow in Chapters 4 to 8. These reviews are not meant to be encyclopedic; several outstanding reviews of liquefaction have appeared in recent years and the reader is referred to these, wherever applicable. Instead, these chapters contain reviews of selected topics that serve to support the panel's recommendations or to illustrate recent accomplishments, work in progress, or areas of major research interest. Each of these review chapters contains a summary section which summarizes the most important research recommendations brought out in the panel discussions and supported by the material presented in the review.

REFERENCE FOR CHAPTER 1

1. Fossil Energy Research Working Group (S.S. Penner, Chairman), "Assessment of Long-Term Research Needs for Coal Liquefaction Technologies," Report for DOE Contract No. DE-AC01-79ER10007, March 1980.

## CHAPTER 2

### ASSESSMENT METHODOLOGY

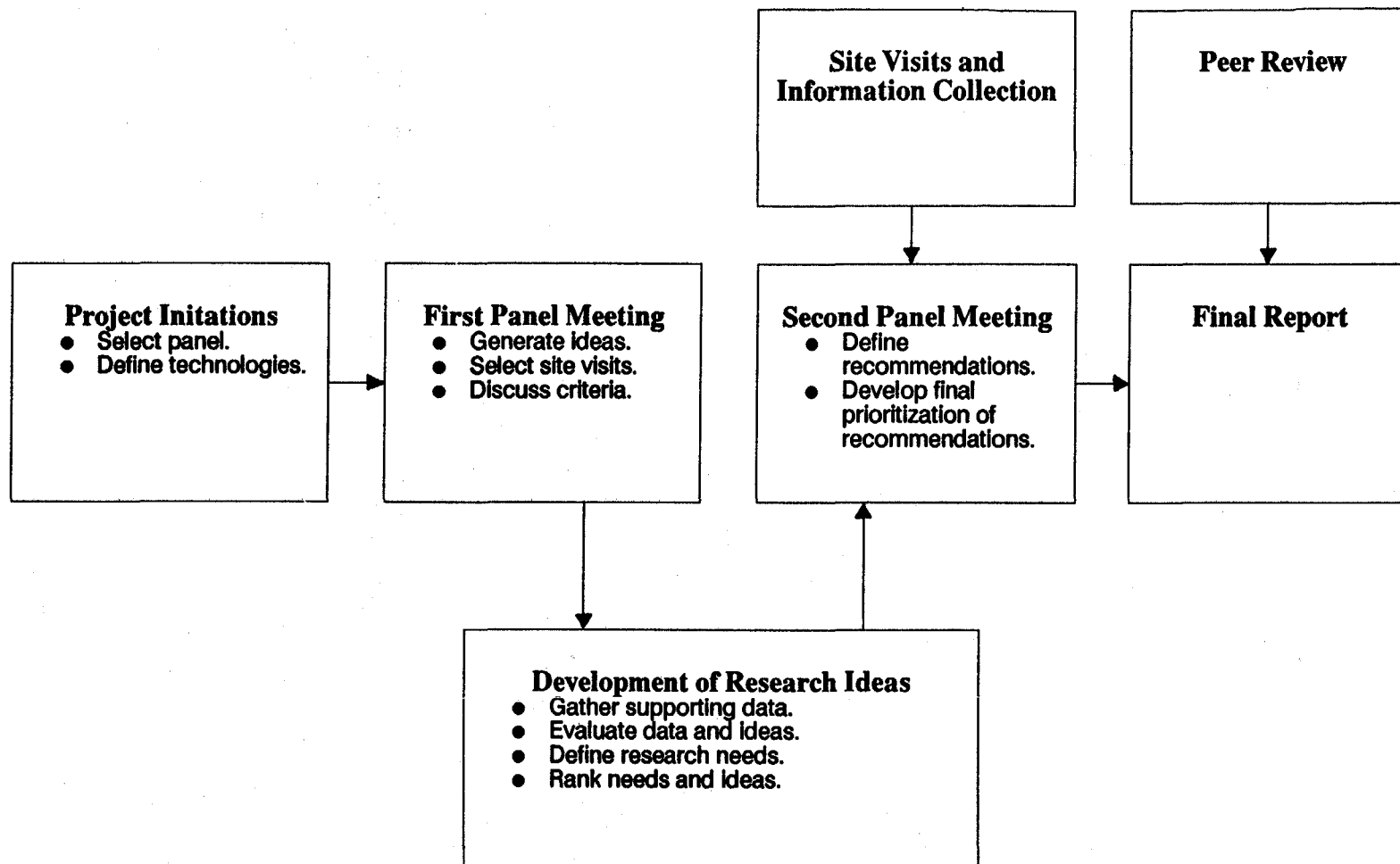
#### 2.1 TECHNICAL APPROACH

SAIC used the following overall technical approach for conducting this independent assessment of long-term coal liquefaction research needs:

- o Selection of an SAIC principal investigator who is technically competent, familiar with coal liquefaction R&D issues, and experienced in organizing a project team to conduct various assessment activities.
- o Selection of members for an expert panel whose collective expertise covers all facets of the significant coal liquefaction R&D areas.
- o Identification of the most technically and economically promising coal liquefaction approaches and research activities through inputs obtained from the expert panel members.
- o Conduct of site visits by the expert panel members to important coal liquefaction research facilities to verify and update information regarding current and future proposed activities.
- o Meetings of the expert panel to assess priorities and risks for research needs.
- o Documentation of the final findings, including prioritization of R&D needs and development of technical rationale to support the findings.
- o Peer review of draft findings, and incorporation of these comments and minority opinion in the final report.

This approach is depicted in Figure 2-1.





2-2

**Figure 2-1. Overall Technical Approach for Conducting R&D Needs Assessment in Coal Liquefaction.**

## 2.2 SELECTION AND ROLE OF THE COLIRN PANEL

### 2.2.1 Selection

In keeping with the changed environment for DOE-sponsored R&D in coal liquefaction, SAIC selected a panel made up of experts who are knowledgeable about the recently developed basic information and oriented towards the basic and applied research in coal liquefaction. However, the panel members' experience spanned the scientific, technical, economic, environmental, and application areas of coal liquefaction. The panel members are all currently active in coal liquefaction R&D and have demonstrated up-to-date technical competency and expertise directly related to coal liquefaction. The COLIRN panel consisted of 12 members, including the SAIC principal investigator. The panel members were:

- o Dr. Harvey Schindler, Principal Investigator and Panel Chairman, SAIC
- o Dr. Francis Burke, Consolidation Coal Company
- o Professor Kwang Chao, Purdue University
- o Dr. Burtron Davis, Kentucky Energy Cabinet Laboratory
- o Dr. Martin Gorbaty, Exxon Research and Engineering Company
- o Professor Kamil Klier, Lehigh University
- o Dr. Carl Kruse, Illinois State Geological Survey
- o Professor John Larsen, Lehigh University
- o Dr. Robert Lumpkin, Amoco Corporation
- o Dr. Michael McIlwain, Idaho National Engineering Laboratory
- o Mr. Norman Stewart, Electric Power Research Institute (EPRI)
- o Professor Irving Wender, University of Pittsburgh.

The technical qualifications and the experience of the panel members are summarized in Appendix C. The technical strengths and the diversity

of experience represented by this team included fundamental coal structure and science, applied technology research, process development, and product application in all coal liquefaction technologies. The diversity of experience of the panel members also provided a spectrum of viewpoints to the assessment.

### 2.2.2 Role

In this assessment of coal liquefaction R&D needs, the COLIRN expert panel played the central role and, representing the coal liquefaction community as a whole, provided a technically competent review. As expert researchers with extensive hands-on experience in coal liquefaction, panel members were responsible for providing up-to-date information on the status of liquefaction research, identifying R&D goals, and defining the activities required to reach the goals. The panel was also responsible for assessing all of this information and developing a set of recommendations and research priorities. In summary, the role of the COLIRN panel was to provide a balanced and objective analysis of research needs and opportunities in coal liquefaction.

Specifically, the expert panel reviewed available information, directed SAIC's efforts to fill information gaps, assessed R&D risks, recommended R&D initiatives, evaluated the recommendations, and set R&D priorities. The expert panel developed recommendations in two meetings. The first meeting was preliminary, but focused the panel on information gaps, necessary analyses, and information gathering activities needed to prepare a final comprehensive set of R&D priorities and recommendations. After conducting selected site visits and other information collection and analysis activities, the panel reconvened at a second meeting to arrive at a final set of recommendations.

### 2.3 SITE VISITS AND OTHER EXPERT INPUTS

This assessment included a number of activities aimed at collecting current information on coal liquefaction R&D. Both the expert panel and the SAIC support team conducted activities in this task. The panel contacted researchers, visited research sites, and gathered data. The principal investigator notified panelists of the dates of each site visit, established the format and the agenda for each visit, and disseminated gathered information to all panel members. The principal investigator also informed DOE/OER/OPA of the sites to be visited and the schedule.

The approach for each site visit included:

- o Contacting the site to schedule the visit.
- o Conducting the visit to gather the information.
- o Preparing a trip report and circulating it to the panel, site representatives visited, and DOE/OER/OPA.

For each site visit SAIC invited nearby organizations working in coal liquefaction to attend and make presentations about their work. During each site visit the SAIC team collected information from presenters and recorded the meeting proceedings for the site visit report. R&D recommendations developed as a result of the visit were incorporated into the project database. These site visit reports were then distributed to all the panel members to keep them updated on project progress.

The following site visits were made by the expert panel during the course of this assessment.

<u>Site</u>	<u>Date</u>
Pittsburgh Energy Technology Center	January 7, 1988
Wilsonville PDU, Wilsonville, AL	March 9, 1988
SAIC, Paramus, NJ	March 14, 1988

AMOCO, Naperville, IL

March 22, 1988

ARCO Chemical, Newtown Square, PA

April 12, 1988

Morgantown Energy Technology Center

April 27, 1988

EPRI, Palo Alto, CA

May 17, 1988

## 2.4 COLIRN PANEL MEETINGS

An important element of the methodology used in conducting this assessment of coal liquefaction R&D needs was holding two formal meetings of the whole COLIRN expert panel. The initial two-day panel meeting at the beginning of the project was held to conduct a preliminary evaluation of R&D needs and to define the information needed for the assessment. The second full panel meeting was held to finalize the recommendations of the study. The panel meetings were organized and chaired by the principal investigator and structured to give the experts the primary role in making R&D recommendations and guiding study efforts.

### 2.4.1 First Panel Meeting

Prior to the first panel meeting, each panel member was sent a set of briefing materials for the meeting. The purpose of these briefing materials was to bring the panel members up to speed on the study objectives, background for the assessment, procedures, and methodology, as well as to stimulate their thinking about the project. In this way the panel members were fully briefed prior to the first panel meeting so that they were ready to begin their discussions of coal liquefaction R&D, and the time during the panel meeting was utilized in an optimum way.

Specific activities during the meeting included:

- o Holding a session of the full panel to review and revise criteria for selecting R&D directions, agree on ground rules, identify technology cost and performance goals, and refine SAIC's outline of the study final report.
- o Breaking up into three subpanels organized by technology area-- direct liquefaction, pyrolysis, and indirect liquefaction-- to conduct a preliminary evaluation of R&D needs in each area.
- o Reconvening the full panel to review subpanel findings and agree on the next steps, including site visits, other information-gathering efforts, and panel member assignments.

The first panel session produced preliminary R&D recommendations and identified information gaps and requirements. The conclusions of the panel meeting were summarized in a report. One part of the report focused on the activities of the meeting itself and reported on the procedures and the conduct of the meeting. The major part of the report was concerned with the preliminary R&D recommendations and other information developed during the meeting. Also included in this report were the presentations and other material from the panelists. A summary of this report on the first panel meeting is included in Appendix D to document the methodology of the assessment.

#### 2.4.2 Second Panel Meeting

A second two-day session of the panel was held to finalize R&D recommendations and priorities.

Prior to this meeting, each panel member received briefing materials, which included a copy of the complete database of research recommendations, the accumulated information on supporting rationales for the recommendations, and the scoring data on the recommendations.

Briefly, the meeting consisted of:

- o A session to review evaluation criteria and suggest issues to consider in presenting the final results of the study.
- o Sessions organized by technology area -- direct liquefaction, coprocessing, bioliquefaction, pyrolysis, indirect liquefaction, and direct conversion of methane -- to review technology status, discuss the research recommendations, and do ranking and prioritization.
- o A final session to review the findings and discuss the remainder of the project activities and schedule.

A meeting report similar to the report on the first meeting was prepared. The report focused on the activities of the meeting and

reported on the discussion which took place. Comments and opinions were also included in this report on a number of issues. The final recommendations and the results of the evaluation and prioritization are discussed in Chapter 3. A summary of the report of the second panel meeting is included in Appendix D.

The complete database of research recommendations developed and discussed during this assessment is included in Appendix E.