400
4-7-78

HR. 2031

FE-2030-TR5

MASTER

SURVEY OF SELECTED AGENCIES CONDUCTED TO DETERMINE THE
EXTENT TO WHICH THE NATION'S COALS ARE ADEQUATELY
CHARACTERIZED

Technical Report No. 5

By
Judith M. Hower
Alan Davis
C. Philip Dolsen
William Spackman

October 1977
Date Published

Work Performed Under Contract No. EX-76-C-01-2030

Coal Research Section
The Pennsylvania State University
University Park, Pennsylvania

U. S. DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FOSSIL
ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$4.50
Microfiche \$3.00

**SURVEY OF SELECTED AGENCIES
CONDUCTED TO DETERMINE
THE EXTENT TO WHICH THE NATION'S COALS
ARE ADEQUATELY CHARACTERIZED**

by

**Judith M. Hower, Alan Davis, C. Philip Dolsen
and William Spackman**

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

PSU-TR-5

**COAL RESEARCH SECTION
THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PENNSYLVANIA 16802**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

eb

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ABSTRACT

A survey was conducted to determine the extent to which the Nation's coals were adequately characterized. Questionnaires were sent to 81 agencies in the coal community selected to form a representative cross section of the organizations concerned with coal characterization. Fifty-nine completed Questionnaires were received. Respondents included representatives of the agencies with the longest experience in characterization and those in the best position to know the status of our knowledge of the composition and properties of the coals comprising the Country's coal fields. Analysis of the responses to the Questionnaire resulted in the following conclusions:

1. the Nation's coals are inadequately characterized for their efficient and effective use, this being particularly true in relation to coal conversion technology and maintaining environmental quality;
2. the number of agencies conducting coal characterization programs is too small to meet the Nation's needs within the time frame required;
3. the scope of coal characterization programs should be expanded to develop a broader spectrum of basic compositional and performance data.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
INTRODUCTION	1
STUDY METHODS	3
RESULTS OF THE STUDY	4
THE SUPPLEMENT TO THE STUDY	31
SUMMARY AND CONCLUSIONS	31
APPENDIX I - United States Coal Data Questionnaire	35
APPENDIX II - Special Responses of the Pittsburgh Energy Research Center to Questions 6 and 7	39
APPENDIX III - Notes Resulting from Personal Contacts at Selected Agencies to Determine Feasibility of Cooperative Efforts in Connection with the PSU/ERDA Research Program	42

Introduction

The development of information on the characteristics of coal and coal seams tends to progress as one approaches the actual utilization of the coal and the extent of characterization varies with the end use of the material. In the earliest stages of coal exploration, seam thickness and lateral extent may be the only characteristics recorded. As exploration proceeds and as the mining phase approaches, it is usual to mount a core drilling program involving closely spaced drill sites in order to define the mining conditions that will be encountered. During this phase additional information on the composition and properties of the coal normally will be obtained. Among the first characteristics on which information is sought are the coal's ash yield, sulfur content and calorific value. Additional characteristics that often are examined at this time include the coal's moisture content, its volatile matter content and the quantity of fixed carbon that it contains. Additional basic information is found in the "ultimate analysis" which provides data on the concentrations of carbon, hydrogen, nitrogen, sulfur, and oxygen. The aggregate of the above would appear to comprise the "minimal coal data" required before utilization proceeds.

The information on coal characteristics which is required beyond the "minimal coal data" depends, to a large degree, on the coal's end use and whether or not it will be cleaned and beneficiated in preparation for use. If the coal is scheduled for combustion in utility

boilers, a grindability index, and ash fusion analysis and information on the elemental chemistry of the ash will be among the data required. If the coal is to be used in metallurgical coke production an additional array of characteristics will be explored. Included in the analytical procedures will be maceral analyses, vitrinite reflectance analyses, free swelling index tests and plastometer tests. Data also will be sought on the coal's coking characteristics, e.g. the pressure it will exert on oven walls, its expansion and contraction characteristics and the strength and reactivity of the coke that the coal will produce.

In producing coking coals it is desirable to optimize mining plans to insure production of coal of uniform (or at least acceptable) characteristics over the life of the mine. This requires the detailed characterization of each coal seam to be mined and the contouring of coal characteristics over the area to be mined. The preparation of the coal requires adequate coal washability data for preparation plant design and operation.

The motivation for adequately characterizing coal prior to use in combustion and carbonization lies in the strong relationship between the coal quality control and the efficiency and effectiveness of the utilization process. Two things indicate that the scope and extent of coal characterization efforts will have to be expanded now, in preparation for the immediate future. One of these is the increasing concern for the quality of our environment and the need to know, for example, the extent to which particular coal reserves are radioactive or contain potentially toxic trace elements. The second is

the eminence of coal gasification and coal liquefaction. In comparison to combustion and carbonization these are sophisticated technologies in which coal characteristics will influence product yield, product quality, by-product yield, reject yield, and operational efficiency.

In view of the above it is important to establish the extent to which the Nation's coal resources are adequately characterized for the today and tomorrow in the realm of coal utilization. The study described in this report has sought to make this determination.

Study Methods

The study reported herein consisted of four steps:

- 1) design and preparation of a suitable questionnaire;
- 2) selection of a representative list of agencies known to produce and/or use analytical data on coal;
- 3) transmittal of the questionnaire to the selected agencies and evaluation and summary of the completed and returned questionnaire;
- 4) analysis of summarized questionnaire data and development of conclusions.

As a supplement to the study, Penn State personnel personally contacted 19 agencies, largely to determine how cooperative efforts might best be developed, and this provided some additional information on the quality and type of data available.

The questionnaire used in the main study was designed so that answers could be supplied by simply checking the correct response

or by recording an "off the cuff" numerical estimate or, at worst, by providing a one to three word answer. The objective was to obtain as much reliable information as possible with a minimum effort on the part of the respondent. It was felt that to pursue a more complicated course of action would result in a very limited response. The final version of the questionnaire as used in the survey is presented in Appendix 1.

Eighty-one agencies were selected to receive the questionnaires. These included representative organizations in major sectors of the coal community. Table 1 lists the agencies selected and identifies them with the coal community sector to which they belong. As is evident from the Table, 25 State Geological Surveys received the questionnaires, 15 Federal agencies, 16 ERDA University contractors, 10 representatives of the coal industries, 4 oil industries, 4 independent research corporations, and 5 other agencies representing diverse industrial sectors.

Results of the Study

Fifty-nine of the 81 questionnaires sent to agencies in the coal community were completed and returned. Table 2 provides information on the percentage return from each of the agency classes. The overall return of the 73% of the questionnaires is above normal for this type of survey. Also, the distribution of returns within classes appears to provide a properly balanced, well informed and experienced set of respondents which in turn gives credibility to any conclusion that may be drawn from the study.

Table 1
Coal Community Agencies Receiving
Questionnaires

A. State Geological Surveys

1. Alabama	13. Montana
2. Alaska	14. New Mexico
3. Arizona	15. North Dakota
4. Arkansas	16. Ohio
5. Colorado	17. Oklahoma
6. Illinois	18. Pennsylvania
7. Indiana	19. Tennessee
8. Iowa	20. Texas
9. Kansas	21. Utah
10. Kentucky	22. Virginia
11. Maryland	23. Washington
12. Missouri	24. West Virginia
	25. Wyoming

B. Federal Agencies

1. U.S. Bureau of Mines
2. U.S. Geological Survey
3. Bartlesville Energy Research Center
4. Grand Forks Energy Research Center
5. Laramie Energy Research Center
6. Morgantown Energy Research Center
7. Pittsburgh Energy Research Center
8. Argonne National Laboratory
9. Brookhaven National Laboratory
10. Lawrence Livermore Laboratory
11. Lawrence Berkeley Laboratory
12. Los Alamos National Laboratory
13. Oak Ridge National Laboratory
14. Sandia National Laboratories
15. Pacific Northwest National Laboratory

C. ERDA University Contractors

1. Brigham Young University
2. Lehigh University
3. Montana State University

Table 1 (continued)

4. State University of New York
5. Purdue University
6. University of Arizona
7. University of Illinois
8. University of Montana
9. University of North Dakota
10. University of Tennessee
11. University of Utah
12. Virginia Polytechnic Institute
13. West Virginia University
14. Western Michigan University
15. South Dakota School of Mines and Technology
16. University of Kentucky

D. Other Agencies

1. Coal Industry:
 - a. Amax Coal Company
 - b. Arch Minerals Corporation
 - c. Bituminous Coal Research, Inc.
 - d. Consolidation Coal Company
 - e. Eastern Associated Coal Corp.
 - f. Island Creek Coal Company
 - g. Peabody Coal Company
 - h. Pittsburgh & Midway Coal Mining Co.
 - i. The Pittston Company
 - j. Westmoreland Coal Company
2. Steel Industry:
 - a. Bethlehem Steel Corporation
 - b. U.S. Steel Corporation
2. Oil Industry:
 - a. Exxon Research and Engineering Co.
 - b. Gulf Research and Development Corp.
 - c. Mobil Oil Research and Development Corp.
 - d. Shell Mining Ventures, Inc.
4. Research Corporations:
 - a. Batelle, Columbus
 - b. Hydrocarbon Research, Inc.
 - c. Institute of Gas Technology
 - d. Stanford Research Institute
5. Other:
 - a. Dow Chemical Company
 - b. Fluor Engineers & Constructors, Inc.
 - c. FMC Corporation
 - d. Johns Mansville Corporation
 - e. Rockwell International

Table 2
Percentage of Questionnaires Returned
in Each Agency Class

<u>Agency Class</u>	<u>Number of Questionnaires Sent</u>	<u>Number of Questionnaires Received</u>	<u>Percentage</u>
1. State Geological Surveys	25	24	96%
2. Federal Agencies	15	13	87%
3. ERDA University Contractors	16	11*	69%
4. Other Agencies			
a. Coal Industry	10	4	40%
b. Steel Industry	2	2	100%
c. Oil Industry	4	1	25%
d. Research Corporations	4	2	50%
e. Other	5	2	40%
5. Totals	81	59	73%

*Includes U.S.B.M., U.S.G.S. and 4 ERC Laboratories

The importance of "minimal coal analyses" (or "minimal coal data") was emphasized in the Introduction. The first question in the Questionnaire was: "Does your organization routinely (but not necessarily always) have performed the above "minimal coal analyses" on coals which are being tested or surveyed?" The responses to this question are summarized in

Table 3. Of the 59 responding agencies only 22 routinely conducted (or have conducted) these minimal analysis procedures. Thus, it would appear that in more than 60% of the cases, coals that are being evaluated in exploration, testing, and utilization programs are being subjected to less than these minimal analyses. State Geological Surveys and Federal Agencies employ minimal coal analyses to about the same extent, i.e. 42% and 46% respectively. ERDA University Contractors employ minimal analyses to characterize their coals in only 18% of the cases and the "Other Agencies" surveyed employ these procedures in 57% of the cases.

Table 3
Number of Agencies Performing "Minimal" Coal Analyses

	<u>"Minimal" Coal Analyses</u>		
	<u>Routinely Performed</u>	<u>Not Performed Routinely</u>	<u>No Answer</u>
1. State Geological Survey	10	12	2
2. Federal Agencies	6	5	2
3. ERDA University Contractors	2	8	1
4. Other Agencies	4	7	
5. Totals	22*	32	5

*Two additional agencies indicated that all minimal analyses except forms of sulfur were performed and two additional agencies indicated that all minimal analyses except ultimate analyses were performed.

In an effort to obtain an estimate of the extent to which minimal coal analyses were generated and available to characterize the remaining reserves, each respondent was asked to indicate the approximate number of analyses that the organization had on open file and readily available and which were pertinent to the remaining coal reserves. Ten of the 22 agencies which routinely generate minimal analyses stated that they had less than 100 on file (Table 4). Six organizations indicated that they had more than 1000. These six include 2 state Geological Surveys, the U.S. Geological Survey, the U.S. Bureau of Mines, 1 Energy Research Center and 1 oil company. The U.S. Bureau of Mines stands alone in having 300,000 such analyses for no other agency responding has more than 3000.

Table 4

Number of Minimal Coal Analyses

On Open File and Pertinent to

Remaining Coal Reserves

	<100	100-500	500-1000	>1000
Number of Agencies Performing Minimal Coal Analyses	10*	5	1	6

*Two agencies indicated that all minimal analyses except forms of sulfur were performed and if this were not a limiting factor, they would have more than 1000 analyses on hand.

Several facts must be considered in assessing the significance of the above data. First, many of the analyses were made decades ago and

pertain to worked-out seams or sections of seams. Second, a large amount of the older data was developed using analytical procedures which have since been abandoned and replaced with more accurate methods. Third, in 1976 there were more than 6000 operating coal mines in the U.S. Finally, the Nation's coal reserves include a large and unknown number of coal seams, with no two seams possessing identical characteristics and with no seam remaining constant in its characteristics over its areal extent.

The data presented in Tables 3 and 4, in themselves, lead to the suspicion that the Nation's remaining reserves are inadequately characterized. When considered in the light of the above facts, this suspicion is strengthened considerably.

The respondents to the questionnaire include agencies in a position to assess the degree to which the remaining coal reserves have been adequately characterized. Notable among these are the U.S. Bureau of Mines, the U.S. Geological Survey, and the 24 State Geological Surveys that have detailed knowledge of their particular areas. These agencies were asked to "Estimate the percentage of remaining coal reserves which have been or are being tested or surveyed by your organization for which you believe are adequate "minimal coal analyses" as defined above."

Table 5 presents the responses received from the above request. Two state Surveys indicated the percentage was unknown (i.e. ?) and three provided no response, perhaps indicating that they had no way of making the requested estimate. If these five Surveys are excluded from consideration and the other Survey estimates are averaged, the

Table 5

<u>Estimating Agency</u>	<u>Estimates of the Percentage of the Remaining Coal Reserves Adequately Characterized by Minimal Coal Analyses</u>
1. State Geological Surveys	
Alabama	50%
Alaska	0%
Arizona	?
Arkansas	50%
Colorado	?
Illinois	50%
Indiana	3%
Kansas	0%
Kentucky	--
Maryland	50%
Missouri	50%
Montana	10%
New Mexico	--
North Dakota	"Very Few"
Ohio	100%
Oklahoma	25%
Pennsylvania	<5%
Texas	0-20%
Utah	60%
Washington	--
Wyoming	50-70%
2. U.S. Bureau of Mines	50%
3. U.S. Geological Survey	20%

resulting estimate would be that 67% of the Nation's remaining coal reserves are not adequately characterized by minimal coal data. It is interesting if not meaningful, that the average federal estimate of adequately characterized reserves is 35%, which translates into a 65% figure for the percentage of remaining reserves which are inadequately characterized.

In addition to the data produced through the performance of the minimal analyses procedures, it is Penn State's position that modern technology makes it essential to develop additional information on a coal's composition and properties before it is adequately characterized. This "Basic Compositional and Performance Data" is detailed in Table 6. It should be noted that this list does not include some of the performance data deemed essential by the carbonization industry (e.g. oven wall pressure and expansion and contraction characteristics) and it does not include such data as surface area, porosity, and permeability which are important factors in both coal gasification and coal liquefaction.

The Questionnaire respondents were asked whether their organizations routinely performed (or had performed) each of the analyses listed as items 5 through 15 in Table 6. The responses received are recorded in Table 7. In this case the federal agencies are shown as four groups (items 2-5) in order that their similarities and differences might be observed. The Energy Research Centers, as a group, employ the greatest number of these basic analyses (8 of 11) but when considered individually the numbers range from 5-7 out of a possible

Table 6

Basic Compositional and Performance Data

1. Proximate analysis
2. Ultimate analysis
3. Calorific value determination
4. Sulfur forms analysis
5. Maceral analysis
6. Vitrinite reflectance analysis
7. Ash-fusion analysis
8. Free-swelling Index
9. Gray-King coke type
10. Microhardness determination
11. Hardgrove grindability
12. Mineral species analysis
13. Major and minor element analysis
14. Trace element analysis
15. Washability analysis

Table 7

Number of Agencies Routinely Performing Other Basic Analyses

	Maceral Analysis	Vitrinite Reflectance	Free Swelling Index	Gray-King Coke Type	Vickers Microhardness	Hardgrove Grindability	Washability Analysis	Mineral Species Analysis	Major Element Analysis	Trace Element Analysis	Ash Fusion Analysis	Number of Respondents
1. State Geological Surveys	6	4	9	0	0	9	7	3	13	14	12	24
2. ERDA Energy Research Centers	1	1	2	0	0	2	0	3	3	3	3	4
3. National Laboratories	1	1	0	0	0	0	1	3	3	4	2	7
4. U.S. Bureau of Mines	0	0	1	0	0	1	1	0	1	1	1	1
5. U.S. Geol. Survey	1	1	1	0	0	0	0	1	1	1	1	1
6. ERDA University Contractors	1	1	1	0	0	0	1	2	2	2	3	11
7. Other Agencies	3	3	3	0	1	4	4	3	5	2	4	11
8. Totals	13	11	17	0	1	16	14	15	28	27	26	

11. The National Laboratories, as a group, employ 7 of the 11 analytical procedures but individually the number ranges from 0-5 out of 11.

In contrast with the above the U.S. Geological Survey routinely employs 7 of the 11 procedures and the U.S. Bureau of Mines 6 of the 11. State Geological Surveys as a group employ 9 of the 11 analytical procedures, but the individual variation is great ranging from 0-9. ERDA University Contractors vary from 0-6 in the number of these analyses which they perform and Other Agencies vary from 0-9.

On aggregate the most frequently performed analyses are: 1) Major Element Analysis (of ash), 2) Trace Element Analysis (of ash) and 3) Ash Fusion Analysis. It was expected that Free Swelling Index Tests, Hardgrove Grindability Tests, and Washability Tests would be more prominently represented than they are. Their failure to be represented by high numbers in the totals may reflect the fact that the Questionnaire respondents were largely data generators and analysis performers with only a minor representation of coal users. Although users needs are reflected in types of data that laboratories and research agencies produce, the perfection of the relationship is not great enough to eliminate all bias.

Table 8 summarizes the information on the extent to which these "Other Basic Analyses" are performed. Of interest in this Table is the fact that none of the 59 responding agencies perform the test which is required to establish the Gray-King Coke Type. This, or data from the Audibert-Arnu Dilatometer are required to classify a coal using the International System. In view of the volume of coal going to the export market it would appear desirable to include data

Table 8

Summary of Information
on Performance of
Other Basic Analyses

	<u>Number of Agencies Performing</u>	<u>Agencies with more than 100 Analyses</u>
1. Maceral Analyses	13	4
2. Vitrinite Reflectance	11	4
3. Free Swelling Index	17	7
4. Gray-King Coke Type	0	0
5. Microhardness	1	1
6. Hardgrove Grindability	16	5
7. Washability	14	3
8. Mineral Species	15	4
9. Major & Minor Elements	29	14
10. Trace Elements	27	7
11. Ash Fusion	26	13

from one of these two tests in any comprehensive characterization program. The Table also shows the number of agencies having more than 100 of each of these analyses on file. Depending on the analysis involved, the number of agencies performing the analysis varies from 1 to 13. Less than 1/4 of the 59 agencies have a significant number of ash fusion and major elements (in ash) analyses and less than 1/8 have a significant quantity of data on trace elements and Free Swelling Indices. Less than 1/12 of the 59 agencies have significant quantities of data on the characteristics established through the other 7 analyses.

In connection with the use of coal characteristics data in achieving correlations between compositional characteristics and physical characteristics, it is important to have a variety of different types of data developed on representative fractions of the same sample. This is also true if one is to use coal characteristics data in the development of predictive technology and it is true when one is concerned with describing the use potential of a given coal at a particular site. With these things in mind, the 59 respondents were asked to indicate the number of coal samples which their organization had fully characterized by performing all of the analyses listed in Table 6. The responses to this request are recorded in Table 9. As is evident there are few instances in which this has been done.

From the results thus far described it is apparent that efforts at coal characterization have been, and are, comparatively limited in terms of the types of data that are routinely generated. Although this was anticipated, the Questionnaire included two questions

Table 9

Number of Organizations
That Have Fully Characterized a
Coal Sample by Performing all
of the Analyses Listed in Tables
1 and 4 on Splits of the Same Sample

1. State Geological Surveys	2
2. ERDA Energy Research Centers	0
3. National Laboratories	0
4. U.S. Bureau of Mines	0
5. U.S. Geological Survey	1
6. ERDA University Contractors	0
7. Other Agencies	1

aimed at determining the adequacy of the "Basic Compositional and Performance Data" for combustion, carbonization, and conversion technologies. The first of these two questions focused on analytical procedures judged essential for adequate coal characterization in conjunction with coal gasification and coal liquefaction. Table 10 summarizes the responses received to this question. The second question asked for a list of analytical procedures which the respondent's organization considered "essential for basic coal characterization for the purposes of relating to coal carbonization and combustion". Table 11 summarizes the responses to this request.

Examination of Tables 10 and 11 will show that a rather large number of recommendations was forthcoming in both instances. This would lead one to conclude that the Penn State coal characterization program should be expanded materially. It should be noted, however, that in the great majority of the cases the recommendations are those of only one or two organizations. Exceptions to this are the Fischer Assay recommended by four organizations in connection with gasification and liquefaction and Gieseler Plasticity measurements coupled with pilot scale coke tests recommended by 3 and 5 organizations respectively in connection with coal carbonization. This lack of coincidence of recommendations is judged to mean that the "Basic Compositional and Performance Data" are generally adequate in scope but that consideration should be given to adding Gieseler Plasticity and a Fischer Assay type analysis to the list.

In spite of the lack of agreement on additional analyses that should be included in a characterization program, there are several

Table 10

List of Analytical Procedures Judged
"Essential for Basic Coal Characterization" in
Connection with Conversion to Gaseous and Liquid Fuels
and Not Listed in Table 6.

<u>Analytical Procedure</u>	<u>Number of Agencies Indicating Procedure</u>
1. Total and Water-Soluble Chlorine	2
2. Radioactive Determination	1
3. Specific Gravity	1
4. Fischer Assay	4
5. Elemental Analysis	1
6. Viscosity of Molten Ash	1
7. Particle-Size Classification	1
8. Low-Temperature Ash Analysis	2
9. Porosity	2
10. Permeability	2
11. Fluidity	1
12. Internal Surface Area	2
13. Environmentally Important Trace Elements	1
14. Other*	1

*In response to the request for suggestions of analytical procedures "essential for basic coal characterization" and not listed in Tables 1 and 4, the Pittsburgh Energy Research Center provided lists of their analytical procedures. These are contained in Appendix II.

Table 11

List of Analytical Procedures Judged
"Essential for Basic Coal Characterization" in
Connection with Coal Carbonization and Combustion
and Not Listed in Table 6.

<u>Analytical Procedure</u>	<u>Number of Agencies Indicating Procedure</u>
1. Gieseler Plasticity	5
2. Pilot Scale Tests	3
3. Heat of Carbonization	1
4. Viscosity of Molten Ash	2
5. Specific Gravity	1
6. Chlorine	1
7. Density	1
8. Coal Carbonization Assays	1
9. Low Temperature Ash Analysis	1
10. Expansion-Contraction Tests	2
11. Coking Pressure Tests	1
12. Coke Strength under Plant Conditions	1
13. Audibert-Arnu Dilatometer Test	1
14. Permeability	1
15. Elemental Analysis of Ash in Coke	1
16. Other*	

*In response to the request for suggestions of analytical procedures "essential for basic coal characterization" and not listed in Tables 1 and 4, the Pittsburgh Energy Research Center provided lists of their analytical procedures. These are contained in Appendix II.

types of data that clearly are of importance and should be included in at least some characterization efforts. Notable among these are surface area measurements, permeability measurements, and measurements of porosity including total pore volume and pore size distribution. Such analyses are, in fact, a part of the PSU coal characterization program, but they are regarded as "Special Analytical Data" (Table 12) because the analyses are performed on a restricted number of samples.

Table 13 concerns another aspect of the questionnaire survey. Included in the Questionnaire was the request for the respondent to "indicate whether it would be possible for your organization to supply The Pennsylvania State University with samples of coal from operating mines or coal prospects over the next four years". The intent was that these samples would be supplied to supplement PSU's sampling effort and would provide suitable samples for use in the PSU/ERDA research program. Table 13 summarizes the responses to this request. Examination of the Table will show that there are 30 sample sources available to PSU affording access to a variety of sample types. Of particular value is the fact that 16 State Geological Surveys and the U.S. Geological Survey have indicated a willingness to assist. This provides for a geographically broad coverage that will assist in screening areas and seams that are unstudied by PSU, enabling the proper scheduling of sites for PSU's standardized sampling operation.

Still another aspect of the Survey is displayed in Table 14. Although somewhat inappropriate the respondents were asked whether it would be useful from their organization's standpoint for PSU to

Table 12

Description of "Special Analytical Data"

"Special Analytical Data" includes:

1. Surface area data
2. Porosity data
3. Adsorptive capacity data
4. Reactivity data
5. Permeability data
6. Pyrite size consist data
7. Equilibrium Moisture data
8. Pyrolysis data
9. Liquefaction data
10. Gasification data

Table 13

Potential Sources of Coal Samples
for the ERDA Research Program
at the Pennsylvania State University

<u>Source Agency</u>	<u>Types of Samples</u>						<u>Total</u>
	<u>Number of Potential Sources</u>	<u>Channel</u>	<u>Column</u>	<u>Core</u>	<u>Run-of-Mine</u>	<u>Other</u>	
1. State Geological Surveys	16*	15	2	9	10	2	38
2. ERDA Energy Research Centers	1	0	0	0	1	1	2
3. National Laboratories	2	0	0	0	2		2
4. U.S. Bureau of Mines	1**				1**		1
5. U.S.G.S.	1	1	1	1			3
6. ERDA University Con- tractors	3	2	2	1	1		6
7. Other Agencies	6	3	3	3	4	2	15
Total Samples							67

*Some indicated that funding would be required to permit the supply of samples

**Samples would be supplied provided confidentiality is maintained in the case of the U.S.B.M.

Table 14

Agencies Indicating a Desire to Have PSU
Perform Certain Coal Analyses on Samples
Which the Agency Would Supply

Agency	Type of Analysis											
	Maceral Analysis	Vitrinite Reflect	F.S.I.	Gray-King Coke Type	Vickers Microhardness	Hardgrove Grindability	Washability Analysis	Mineral Species Analysis	Major Element Analysis	Trace Element Analysis	Ash Fusion Analysis	Total
1. State Geological Surveys	13	8	8	8	7	11	11	10	10	11	12	109
2. ERDA Energy Research Centers	0	0	0	0	0	1	1	1	1	1	1	6
3. National Laboratories	3	3	2	2	2	2	2	3	3	3	2	27
4. U.S. Bureau of Mines												
5. U.S. Geological Survey	1	1		1	1	1	1	1				7
6. ERDA University Contractors	1	1	1	1	1	1	1	1	1	2	1	12
7. Other Agencies	2	2	2	1	1	2	1	3	3	4	1	22
8. Totals	20	15	13	13	12	18	17	19	18	21	17	183

perform certain analyses on coal samples which would be supplied by their organization. The implication intended was that the data generated would be returned to the respondent's organization for its use. The question is somewhat out-of-place because the organizations being surveyed are data generators and analysis performers, hence, would have minimal needs for someone else to produce data for them. In spite of this, there was a significant number of agencies that felt they could benefit from this kind of cooperation and service. As may be seen from the Table, the State Geological Surveys expressed a considerable interest in this kind of an interchange as did the U.S. Geological Survey. At first glance, the small number of ERDA University Contractors expressing an interest in this sort of cooperation appears peculiar and is inconsistent with the numerous requests for data that are, in fact, received by PSU from ERDA contractors. The explanation for this lies in the manner in which the request was worded in the Questionnaire (see Appendix I). Question 8 asked whether the respondent's organization could supply Penn State with samples from mines or prospects. Most ERDA University Contractors are not sampling oriented and only two agencies responded in the affirmative. Question 10 was phrased as follows: "If your response to Question 8 was YES, please indicate whether it would be useful for The Pennsylvania State University to perform any of the following analyses ..." By relating Question 10 to Question 8 in this fashion, only three agencies were eligible to respond and two of these expressed a desire to receive PSU generated analytical data.

Examination of Table 14 will show that the interest in the receipt of PSU generated data is the highest for trace element analyses and maceral analyses and lowest for microhardness, Gray-King, and F.S.I. data. Ranked according to the level of interest expressed the analyses fall in the following order:

1. Trace Element Analysis
2. Maceral Analysis
3. Mineral Species Analysis
4. Hardgrove Grindability Analysis
5. Major Element Analysis (in ash)
6. Washability Analysis
7. Ash Fusion Analysis
8. Vitrinite Reflectance Analysis
9. Gray-King Coke Type Determination
10. Free Swelling Index Determination
11. Microhardness Determination

Considering the problems inherent in the inappropriateness of this question in the Questionnaire and the problem of the way it was related to Question 8, the level of interest in all of the above analyses is high. This suggests that the "Basic Compositional and Performance Analyses" as conceived in the PSU/ERDA program do, in fact, form the desired core of an adequate coal characterization system.

The last request contained in the Questionnaire asked each respondent to "identify those geographic areas in which your organization is (or expects to be during the next four years) carrying out coal exploration and/or coal characterization programs. Table 15

Table 15

List of Areas to be Subjected to
Coal Exploration and/or Coal Characterization
During the Next Four Years*

<u>State</u>	<u>Specific Geographic Area</u>
1. Alabama	Warrior Coal Field Plateau Coal Field
2. Alaska	Lisborne Coal Field Healy Coal Field Susitna Coal Field Kenar Coal Field Matanuska Coal Field Jarvis Creek Coal Field Yukon Coal Field
3. Arizona	Deer Creek Pinedale
4. Arkansas	Gulf Coastal Plain
5. Colorado	Statewide
6. Illinois	Statewide
7. Indiana	Southwestern Indiana
8. Iowa	Southeastern Iowa
9. Kansas	Linn County Bourbon County Crawford County Cherokee County Neosho County Montgomery County Wilsons County Osage County Franklin County
10. Kentucky	Eastern Kentucky Western Kentucky
11. Maryland	Allegheny County Garrett County
12. Missouri	North-Central Missouri Western Missouri

Table 15 (continued)

13. Montana	Statewide
14. New Mexico	San Juan Basin Raton Field Datil Mountain Field Several Smaller Fields
15. North Dakota	Williston Basin
16. Ohio	Eastern Ohio
17. Oklahoma	Statewide
18. Pennsylvania	Southwestern Pennsylvania Western Pennsylvania Armstrong and Adjacent Counties
19. South Dakota	Western South Dakota
20. Tennessee	Eastern Tennessee
21. Texas	Wilcox Formation-South Texas Jackson Formation- Southeastern Texas Claiborne Formation- South Texas Cretaceous Coals-South Texas
22. Utah	Wasatch Plateau Book Cliffs Kaiparowits Plateau Alton Field
23. Virginia	Southwestern Virginia
24. Washington	Statewide
25. West Virginia	Kanawha County Boone County Webster County Mercer County Preston County Northern Panhandle and entire area underlain by the Pittsburgh Seam

Table 15 (continued)

24. Wyoming

Hanna Coal Field
Hams Fork Region
Green River Region
Poudre River Basin
Bighorn Basin

*The U.S. Bureau of Mines and the U.S. Geological Survey listed "all areas", "all regions" and "all basins."

lists the responses on a state-by-state basis. As will become evident from a perusal of the Table, 23 states have been identified as targets of coal exploration and/or coal characterization programs during the next four years and 68 specific areas are listed.

The Supplement to the Study

As mentioned in the section on Study Methods, the main supplement to the study was provided by visitations of PSU personnel to 19 selected agencies. This was done largely to explore ways to develop cooperative efforts, but it also provided an additional opportunity to learn more about the quality and quantity of existing coal data and to discuss the ways in which the characterization program at Penn State might usefully be modified. Appendix III presents a summary of the results of these visitations. No recommended changes in the coal characterization program were forthcoming but specific interest was expressed by several agencies in contracting with Penn State to assist in coal sampling or coal analysis as a means of strengthening the organization's coal research effort.

Summary and Conclusions

A survey was conducted to determine the extent to which the Nation's coals were adequately characterized. Questionnaires were sent to 81 agencies in the coal community selected to form a representative cross section of the organizations concerned with coal characterization. Fifty-nine completed Questionnaires were received. Respondents included representation from the agencies with the longest

experience in characterization and those in the best position to know the status of our knowledge of the composition and properties of the coals comprising the Country's coal fields. Analysis of the responses to the Questionnaire revealed the following facts:

1. In the opinion of the respondents, 50-80% of the Nation's remaining coal reserves are inadequately characterized.
2. Less than one-half of the agencies perform a "minimal coal analysis" on coal samples on a routine basis.
3. Only 12 agencies have more than 100 "minimal coal analyses" on open file.
4. None of the responding organizations routinely conduct the package of analyses designated "Basic Compositional and Performance Analyses".
5. Less than 1/4 of the responding agencies have significant quantities of ash fusion analysis and major element (in ash) analysis.
6. Less than 1/8 of the responding agencies have significant quantities of data on trace element contents and free swelling properties.
7. Less than 1/2 of the responding agencies have significant quantities of data on the coal characteristics established through any of the following analyses:
 - a. Maceral analysis
 - b. Vitrinite reflectance analysis
 - c. Hardgrove grindability analysis
 - d. Washability analysis

- e. Microhardness analysis
 - f. Gray-King Coke Type analysis
 - g. Mineral species analysis
8. In total, five coal samples have been fully characterized by performing all of the analyses required to develop what was designated "Basic Compositional and Performance Data".
 9. The responses to questions on the types of analyses necessary to relate coal characteristics to behavior in industrial processes led to the conclusion that the basic coal characterization performed by Penn State is generally adequate but that consideration should be given to adding the Gieseler Plastometer Test and Fischer Assay.
 10. Thirty agencies including sixteen state Geological Surveys and the U.S. Geological Survey were willing to act as potential sources of coal samples for characterization by Penn State. Sixty-eight specific areas were identified in which coal exploration will be carried out by the agencies during the contract period.
 11. It appeared that Penn State could usefully cooperate with the coal research community by providing analytical data. The agencies which were interested in providing samples indicated in a significant number of cases that they would like to have analyses performed for them.

From the above and from the contents of this report it is concluded that:

1. the Nation's coals are inadequately characterized for their efficient and effective use, this being particularly

true in relation to coal conversion technology and maintaining environmental quality;

2. the number of agencies conducting coal characterization programs is too small to meet the Nation's needs within the time frame required;
3. the scope of coal characterization programs should be expanded to develop a broader spectrum of basic compositional and performance data.

Appendix I
United States
Coal Data Questionnaire

UNITED STATES COAL DATA QUESTIONNAIRE

For the purposes of this survey we will regard a 'minimal coal analysis' as including all of the following analyses:

1. Ultimate analysis
2. Proximate analysis
3. Calorific value
4. Forms of sulfur

1. Does your organization routinely (but not necessarily always) have performed the above 'minimal coal analysis' on coals which are being tested or surveyed? YES NO
☐ ☐

2. Approximately how many such minimal coal analyses does your organization have on open file and readily available which are pertinent to remaining coal reserves? For the purposes of this survey it is necessary only to consider coal reserves occurring in seams of greater than 30 inches and at depths of less than 3000 feet.

Number of minimal coal analyses on file _____

3. Estimate the percentage of remaining coal reserves which have been or are being tested or surveyed by your organization for which you believe there are adequate 'minimal coal analyses' as defined above. Again, it is only necessary to consider those reserves which occur in seams of greater than 30 inches and at depths of less than 3000 feet.

Estimate of adequate coverage of reserves with 'minimal coal analyses' _____ %

4. Which of the following analyses are routinely performed by or for your organization? Please indicate the approximate number of such analyses which you have on open file and readily available. If approximate numbers are known, complete Section A only; if such numbers are not known, you should use Section B to provide an estimate within broad limits.

	SECTION A	SECTION B					
	No. on file	None	0-100	100-500	500-1000	1000-3000	>3000
Maceral analysis							
Vitrinite reflectance analysis							
Free-Swelling Index							
Gray-King Coke Type							
Vickers Microhardness							
Hardgrove grindability							
Washability analysis							
Mineral species analysis (e.g. kaolinite, quartz, etc.)							
Major element analysis							
Trace element analysis							
Ash fusion analysis							

5. Approximately how many coal samples has your organization characterized by having ALL of the analyses listed in Q. 4 performed on splits of the same sample? _____

6. Specify any analytical procedure, other than the 'minimal coal analysis' and those listed in Q. 4, which your organization considers to be essential for basic coal characterization for the purposes of relating to conversion of coal to liquid or gaseous fuels.

(attach list if necessary)

7. Specify any analytical procedure, other than the 'minimal coal analysis' and those listed in Q. 4, which your organization considers to be essential for basic coal characterization for the purposes of relating to coal carbonization and combustion.

(attach list if necessary)

8. Please indicate whether it would be feasible for your organization to supply The Pennsylvania State University with samples of coal from operating mines or coal prospects over the next four years.

YES	NO
☐	☐

9. If your response to Q. 8 was YES, please indicate whether the samples you could provide to Penn State would be

Channel samples _____
Column samples _____
Core samples _____
Run of Mine samples _____
Other (Specify) _____

10. If your response to Q. 8 was YES, please indicate whether it would be useful for The Pennsylvania State University to perform any of the following analyses on the samples of coal which you would supply.

Maceral analysis _____
Vitrinite reflectance analysis _____
Free-Swelling Index _____
Gray-King Coke Type _____
Vickers Microhardness _____
Hardgrove grindability _____
Washability analysis _____
Mineral species analysis _____
Major element analysis _____
Trace element analysis _____
Coal ash fusibility _____
Ash fusion analysis _____

11. Please identify those geographic areas in which your organization is (or expects to be during the next 4 years) carrying out coal exploration and/or characterization programs.

Appendix II
Special Responses
of the
Pittsburgh Energy Research Center
to
Questions 6 and 7

The Analytical Chemistry Branch provides to the engineering and research divisions of PERC routine physical and chemical analyses and special analytical services. Research is conducted for the development of new analytical chemical methods and improvement of established techniques for analysis of coals and related materials and products. The major techniques and their applications are listed below:

Gas Chromatography - Routine gas analysis of products of coal combustion and conversion processes. Controlled by a data processing system that collects, computes, and reports data from as many as 30 gas chromatographs.

Atomic Absorption Spectrophotometry and Specific Ion Electrode - Analysis of metals in catalysts, seed materials in MHD, and trace elements in coals and conversion products.

X-Ray Diffraction and Fluorescence - Analysis of compounds and elements in catalyst materials, deposits, and effluents of coal combustion and conversion

Automated Surface Area-Pore Volume Analysis - Determination of internal structure and external surface in catalysts and fine particulate materials.

Micro C-H-N-O-S Analysis - Elemental analysis of minus 10 mg samples of coal and coal products.

Rapid Sulfur Analysis - Determination of sulfur content of fuels in 50 mg samples in 15 minutes.

ASTM Elemental Analysis - Measurement of C-H-N-O-S and ash contents by standard methods.

Solvent Analysis - Determination of benzene and hexane solubles and insolubles in coal liquids.

Viscosity Determination - Measurement of viscosity of coal liquids.

Water Analysis - Determination of biological and chemical oxygen demands (BOD, COD) in waste waters.

The Spectrometry Branch makes use of a variety of modern instrumental techniques to study the physical and chemical structure of coal and coal products and properties of air, water, and waste pollutants. These techniques and their major applications are shown in the following list:

High Resolution Mass Spectrometry - Characterization of liquid and solid products of coal conversion.

Low Resolution Mass Spectrometry - Analysis of gases from SYNTHANE and other processes.

Gas Chromatography-Mass Spectrometry - Analysis of light oil products and other liquid streams.

Spark Source Mass Spectrometry - Characterization of minor and trace elements in SYNTHOIL and SYNTHANE process streams.

Secondary Ion Mass Spectrometry - Depth profiles of elemental composition of conversion catalysts.

High Pressure Liquid Chromatography - Analysis of SYNTHOIL liquids.

Flame Photometric Chromatography - Sulfur analysis in SYNTHANE and SYNTHOIL gases.

Infrared Spectrometry - Determination of organic functional groups in coal liquids and composition of coal minerals. Studies of adsorbed species on catalysts.

Laser Raman Spectrometry - Investigation of deactivation of coal conversion catalysts.

Ultraviolet Spectrometry - Analysis of aromatics in coals and products, phenols in waste waters, and organic groups and compounds.

Fluorescence Spectrometry - Detection of possible carcinogens in coal liquids.

Nuclear Magnetic Resonance - Determination of structure and element distributions in coal products.

Electron Spin Resonance - Determination of paramagnetic species (free radicals, charge carriers, transition metal ions) in coals and products.

Low Temperature Ashing - Preparation of nearly undisturbed minerals from coals and products for more authentic analysis.

Scanning Electron Microscopy and X-Ray Analysis - Observation, photography, and micro-analysis of small areas on catalysts and of fly ash and coal minerals.

Appendix III
Notes
Resulting from Personal Contacts
at
Selected Agencies
to
Determine Feasibility
of
Cooperative Efforts
in Connection with
the
PSU/ERDA Research Program

Notes

Resulting from Personal Contacts

at

Selected Agencies

1. Arizona

A. Arizona Bureau of Mines

1. No coal research underway at present.
2. All operating mines are within confines of Indian Reservations in the Black Mesa Field.
3. Receipt of coal samples from the Bureau not practical.

2. Arkansas

A. Arkansas Geological Commission

1. Geological research underway.
2. Primary interest is in lignite fields.
3. Receipt of coal samples from the commission is feasible and they are willing to assist in the PSU/ERDA research effort.

3. Colorado

A. U.S. Geological Survey

1. Has extensive coal geology research program underway.
2. Has extensive study of trace elements in coal underway.
3. Is cooperating with various states in core drilling program.
4. Is willing to cooperate with PSU in an exchange of samples and data.
5. Will assist PSU/ERDA research effort by providing cores from the Montana, Wyoming areas.

4. Illinois

A. Illinois Geological Survey

1. Geological and utilization research extensive and long standing.
2. Possesses extensive computerized data base developed from the analysis of 250,000 drill cores.
3. Survey personnel will provide assistance, advice, and information for the PSU/ERDA research effort.

B. Southern Illinois University

1. Geological and petrological research underway.
2. Has created Coal Extraction and Utilization Research Center.
3. New U.S. Bureau of Mines Station adjacent to the University.
4. Desires to sub-contract with PSU to assist in sample collection for the PSU/ERDA research effort.

5. Indiana
 - A. Indiana Geological Survey
 1. The Survey has a deep drilling program underway.
 2. Geological research underway.
 3. Cooperation with the PSU/ERDA research effort indicated.
6. Kansas
 - A. Kansas State Geological Survey
 1. The Survey can assist the PSU/ERDA research effort by providing lists of operating coal mines and new mine openings.
7. Kentucky
 - A. Kentucky Geological Survey
 1. Has extensive coal geology research effort underway.
 2. Will assist in the PSU/ERDA research effort but supplying samples may not be feasible.
8. Missouri
 - A. Geological Survey of Missouri
 1. Has a drilling program underway and is willing to make samples available to the PSU/ERDA research effort.
 2. Recommended drilling and sampling in Mercer and Harrison Counties.
 3. Is willing to assist the PSU/ERDA research effort by collecting particular samples requested by PSU.
9. Montana
 - A. Montana Bureau of Mines and Geology
 1. Is involved in cooperative drilling program with U.S.G.S.
 2. Is establishing an Analytical Laboratory to perform coal analyses.
 3. Has a coal geology research program underway.
 - B. Montana Department of Natural Resources and Conservation
 1. Is concerned with coal development in Montana and its environmental impact.
 2. The Energy Planning Division may be able to supply samples to the PSU/ERDA research effort when and if new exploratory drilling programs are undertaken.
10. New Mexico
 - A. New Mexico Bureau of Mines and Mineral Resources
 1. The Bureau occasionally obtains cores and might be able to supply samples to the PSU/ERDA research effort.
 2. The Bureau can supply a list of active mines and mine contacts.

11. North Dakota
 - A. North Dakota Geological Survey
 1. The Survey is currently involved with a drilling program and typically the samples are analyzed by the U.S.G.S.
 2. Cooperation with the PSU/ERDA research effort is possible.
 3. Mining activity and coal production in North Dakota are increasing.
 4. The Survey is cooperating with the University of North Dakota in their ERDA sponsored research.
12. Oklahoma
 - A. Oklahoma Geological Survey
 1. The Survey does not have the personnel to assist in a sampling program but it can provide information on mines and mine contacts as a means of assisting the PSU/ERDA research effort.
 2. The Survey has an active coal geology research program underway and offers short courses in coal geology.
13. Texas
 - A. University of Texas, Bureau of Economic Geology
 1. Has a coal geology research program underway.
 2. Can supply PSU with information on mines and mine contact.
 3. Can supply PSU with coal samples to assist in the PSU/ERDA research effort.
 - B. Texas A & M University
 1. Is establishing a coal research program.
 2. Is involved with a major underground gasification project.
 3. Will have a core drilling program underway.
 4. Will establish an analytical laboratory to conduct coal analyses.
 5. Desires to sub-contract to PSU to assist in the PSU/ERDA research effort:
 - a. by sampling under PSU guidance,
 - b. by providing core samples,
 - c. by performing analyses.
14. Utah
 - A. The University of Utah
 1. Is expanding into coal characterization research.
 2. Has a large, active coal utilization research program underway.
 3. Desires to sub-contract to PSU to assist in the sampling operations associated with the PSU/ERDA research effort.

15. West Virginia

A. West Virginia University

1. Has a coal research program underway.
2. Desires to sub-contract to PSU to provide samples for the PSU/ERDA research effort.

16. Wyoming

A. Wyoming Geological Survey

1. Has an active coal geology research program underway.
2. Has an active drilling program underway with samples being analyzed by the U.S. Bureau of Mines and the U.S. Geological Survey.
3. Will conduct some channel sampling in the Hanna Basin and will supply PSU with splits of samples to assist the PSU/ERDA research effort.