7.0 CONCLUSIONS

The heterogeneous nature of coal and the lack of precedents for the sudden emergence of a new major coal conversion industry make any generalizations or predictions subjective and dependent on many qualifying assumptions. Since neither Federal legislative nor administration policy have been firmly established yet, it is not surprising that implementation of solutions for the vaguely defined problems have not proceeded beyond a wide variety of uncoordinated discussions and fragmented proposals.

The selection of processes for study in this report is representative of the range of available technologies but is not exhaustive of all technologies. The exclusion of a particular technology is not necessarily indicative of its quality.

As a part of this study, data have been collected from many sources to allow computation of fuel costs on several different bases. These costs show some processes which have product price advantages. A variety of processes await commercial demonstration.

In using the information presented in this report, it must be kept in mind that data quality varies from the different sources. The confidence index reflects this to a limited degree with respect to the state of process development and quality of cost estimates. Added to these uncertainties are optimistic data from several of the developers of particular systems. This type of bias is not uncommon either within government or the private sector.

The technical review disclosed certain processes, such as Bigas, with more problems than others but none which are considered infeasible for solely technical reasons. All significant process development problems are ultimately reflected in plant costs. The combination of continuing operating difficulties and increased plant cost is sufficient to eliminate a process if better alternatives exist.

Among the gasification processes, the work done thus far may prove useful for specific projects to provide low or medium-Btu gas to industrial systems. None of the high-Btu gas processes appears to have a clear advantage over the Lurgi plus methanation process which is proven and undergoing continuing development.

All of the liquefaction processes included in this study have potential for some particular segments of the fuels market and could displace imported petroleum. No foreign process developer seems to have any attractive alternative to processes now under DOE supported development.

The solid SRC-I process may find application on a limited scale supplying acceptable fuel to electric utilities. However, the threat of constantly increasing environmental regulation could affect prospects for this process.

The electric power systems described in this report could find application, particularly if they soon demonstrate high efficiences and environmentally acceptable operation. Many combined cycle systems are under development and the two described in this report have no clear advantage over some others not included.

The need appears clear for a variety of coal-derived fuels to preclude near-future shortages. Economic incentives will continue to increase. Much of the quantitative information included in this study is preliminary and as such, is reflected in the accuracy of the product cost estimates. As R&D efforts proceed, somewhat better results, meaning higher yields at lower costs, should be obtained.

The methods used to compare process results for this study are easily applied to other coal conversion processes. The results in this report can be readily upgraded when better information becomes available.

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The list below is not intended to include all published references on the subjects in this report. It includes only the reports which were used as primary sources. Numerous working papers and phone conversations with many of the process developers were also used.

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GLOSSARY

B_i	Quantity of product per time
BBL	Barrel - This report uses the petroleum barrel unit equal to 42 U.S. gallons
CO	Chemical symbol for carbon monoxide, a poisonous gas
CO_2	Chemical symbol for carbon dioxide, an inert gas
DOE	U.S. Department of Energy
Ebullating	Boiling
EDS	Exxon Donor Solvent
Endothermic	Adjective for a reaction that requires heat input to proceed
Exothermic	Adjective used for a reaction which generates heat
f_i	Product value factor for product i
Froth Flotation	A process to separate solid mixtures
Head	A term which indicates discharge pressure of pumps and compressors
H/C	Mass ratio of hydrogen to carbon
HHV	Higher heating value for a fuel, the maximum amount of heat released when the fuel is burned including allowance for condensation of steam produced
H_2	Chemical symbol for hydrogen gas
Mol. Wt.	Molecular weight equals total of atomic weights for all elements comprising a single typical molecule
Partings	The waste material within a seam that separates the coal into horizontal layers
Rotary Breaker	A machine to reduce coal particle size
SCF	Standard Cubic Foot - unit of quantity for gases commonly meant to be a cubic foot at 1 atmosphere pressure and 20°C
SNG	Substitute Natural Gas - typically with a HHV over 900 Btu/SCF
SRC	Solvent Refined Coal
Syngas	An industrial term applied to carbon monoxide-hydrogen mixtures
SYD	Sum year digits method of depreciation. A depreciation factor of $n_i/\Sigma_1^n n$ is used for year i, where n is plant life and $n_i = n+1-i$.

APPENDIX 1 - Product Specifications

A. Solid Products (See Note below)

	SRC-I	Synthane Char
HHV, Btu/LB	16,000	8,000
Density g/cc	1.25	-
Melting Point	over 180°C	-
Boiling Point	over 425°C	-
ULTIMATE ANALYSIS, wt%:		
C	87.14	52.1
H	5.66	1.0
O	3.91	5.1
S	0.88	0.2
N	2.31	0.3
Ash	0.10	41.3

Note: Most values throughout this appendix should be taken as preliminary and typical. They have been taken from various process developers' reports and not all verified with primary sources. Some properties shown have been calculated from report data.

B. LIQUID PRODUCTS

1. Naphtha (Note 1)

	PROCESS				
PROPERTY	SRC-II	EDS	H-Coal	Hygas	Lurgi
Boiling Range	C5-200°C	C5-200°C	C3-200°C	Benzene to C9	Note 2
HHV, Million Btu/BBL	-	5.2	5.5	5.4	5.2
Density, g/cc	.84	.82	.80	.88	-
Sulfur wt%	0.3	1.0	.06	-	-
Nitrogen wt%	0.6	0.2	.07	-	-
H/C	0.14	0.14	-	-	-
Viscosity, Centistokes @38°C	.9	.9	-	-	-

2. Fuel Oil

	PROCESS			
PROPERTY	SRC-II	EDS	H-Coal Syncrude	H-Coal Fuel Oil
Boiling Range °C	200-425	200-540	200-525	200-540+
Flash Point °C	75	92	-	-
Density, g/cc	1.04	1.085	0.93	1.09
HHV, Million Btu/BBL	6.27	6.31	6.13	6.70
Sulfur wt%	0.3	0.8	0.08	0.43
Nitrogen wt%	0.9	1.1	0.37	0.84
Viscosity, SSU @38°C	50	102		
H/C	-	0.08		

Notes: 1. Many properties will vary with different feed coals.

2. Properties not shown could not be found in available reports.

APPENDIX I
(continued)

3. Gas Products

	PROCESS						
	Hygas	Synthane	CO_2 Acceptor	CO_2 Acceptor	Lurgi	Bigas	EDS
			SNG	Syngas			
HHV Btu/SCF	990	940	950	378	980	908	1,300
Mol. Wt.	16.2	17.0	15.8	10.2	15.8	15.0	
Analysis Vol/%							
H_2	.8	1.8	4.6	65.5	3.0	10.0	
CO	.03	0.1	.01	15.7	.05	0.1	
CH_4	97.9	92.4	92.6	11.4	96.0	86.7	
C_2+	0	0	0	0	0	0	
N_2	.4	1.9	2.0	0.8	0.6	.6	
CO_2	.8	3.8	0.5	4.7	0.4	2.6	
H_2O	trace	trace	trace	1.9	trace	trace	

4. Methanol (per Badger Conceptual Design, Reference 20)

Methanol:	Purity	99.85	wt%
	Density	0.7954	g/cc
	HHV	9783	Btu/lb
Methyl Fuel:	Methanol	96.1	wt%
	Water	3.5	wt%
	Density	0.8019	g/cc
	HHV	9407	Btu/lb

5. M-gasoline: 9 PSIA Reid Vapor Pressure
93 Octane clear (RON)
57°A.P.I.

Appendix 2: PRODUCT COST CALCULATION

The particular assumptions and specific amounts used to calculate the product costs shown in Tables 5.4 and 5.5 are as follows:

1) Coal is the principal raw material for all of the plants. Using the same coal heating value and feed rate to all processes is considered the best method to put all processes on a comparable basis.

   A coal price of $\$1.00/10^6$ Btu is used as a realistic delivered price for run-of-mine coal anywhere within the continental United States.

2) All operating and maintenance costs are shown in Table A (page 83) in millions of dollars with the following rationale:

   a) Catalysts, chemical and operating supplies are shown at cost for the amounts required.

   b) Labor cost is for a total payroll as follows:

Category	People	Rate, $/Hr
Operators	120	10
Operating supervision	25	15
Maintenance labor	150	12
Maintenance supervision	30	16
Administrative	30	11

   A 40 % added charge was used to cover all fringe benefits.

   Processes which had more solids handling requirements were assigned additional operators.

   The labor allowance shown was in fair agreement with most cost estimates by others for conceptual plants of similar size. It is not uncommon in chemical manufacturing operations of similar types to effect reductions in the labor force with increased operating experience. This often requires additional capital investment for equipment to enhance worker productivity.

   c) Maintenance is included by use of an annual charge of 3% of the capital cost. This amount pays for replacement materials and outside contractor services. Processes with greater solids handling were assigned a higher percentage.

   d) Local taxes and business insurance were covered by 5% of the total capital as an annual cost. This amount may be somewhat less for most site-specific studies.

3) Capital investment includes the total to construct the plant cost from Table 5.1 plus the added investment for buildings, paving, all utilities and other auxilliaries needed for an autonomous plant. A project contingency of 10% is also included.

The effect of capital investment on the product cost is modified by k, the capital factor used in the product cost equation. The value for this factor includes the following:

1. Investment rate-of-return
2. Project life
3. Tax life
4. Investment tax credit
5. Tax rate
6. Interest during construction
7. Capital recovery

A detailed treatment of the fiscal aspects of a comprehensive evaluation is given in ESCOE Report FE-2468-44, "Guidelines for Economic Evaluation of Coal Conversion Processes", published April, 1979. This study uses these guidelines. Based on the recommended parameter values from that report, the values for k, the capital factor, are 0.081 for utility financng and 0.115 for private financing.

4) Product information from Table 4.5 is converted, using a 90% plant operating factor, to the values required for the denominator of the cost equation.

Table A shows the product cost for each of the processes with each of the three cost methods. The calculation of the value basis product cost uses the same total cost in the numerator as the energy basis. The product cost equations are repeated below for convenience.

Product Cost, P:

Energy Basis

Utility financing $$P_u = \frac{F + M + 0.81C}{G} \qquad \text{(A2.3)}$$

Private financing $$P_p = \frac{F + M + .115C}{G} \qquad \text{(A2.4)}$$

Value Basis

Utility financing $$P_{vu} = \frac{F + M + .081C}{\Sigma f_i B_i} \qquad \text{(A2.5)}$$

Private financing $$P_{vf} = \frac{F + M + .115C}{\Sigma f_i B_i} \qquad \text{(A2.6)}$$

APPENDIX 2

TABLE A: COST DATA

		OPERATING & MAINTENANCE COST								PRODUCT COST			
	Capital	Fuel	Catalyst & Chem.	Labor	Maintenance	Local Tax & Ins.	M	G	$\Sigma f_i B_i$*	Energy		Value Basis*	
										Util	Priv	Util	Priv
Process	C	1	2a	2b	2c	2d	2	Btu/Yr.	Btu/Yr	$/Million Btu			
SRC-I	1092	246.	3.0	13.8	33.	55.	104.8	1.299E14	6.588E13	3.38	3.67	6.67	7.23
SRC-II	1262	246.	6.0	12.2	38.2	63.	119.0	1.291E14	8.357E13	3.62	3.95	5.59	6.10
EDS	1270	246.	6.0	12.2	38.5	64.	121.0	1.187E14	8.705E13	3.96	4.32	5.40	5.89
H Coal: Fuel Oil	955	246.	6.0	12.2	29.	48.	95.0	1.266E14	8.222E13	3.30	3.56	5.09	5.48
Syncrude	1134	246.	7.0	12.2	34.3	57.	111.0	1.253E14	9.337E13	3.58	3.89	4.81	5.22
FT	1121	246.	7.0	12.2	34.	56.	109.0	0.894E14	8.077E13	4.99	5.41	5.52	5.99
Methanol	1195	246.	7.0	12.2	34.	60.	113.2	1.043E14	1.004E14	4.37	4.76	4.54	4.95
M-Gasoline	1212	246.	8.5	12.2	35.5	65.	121.0	0.962E14	9.481E13	4.84	5.26	4.91	5.34
CO_2 Acceptor SNG	1084	246.	5.9	12.7	34.6	54.	107.0	1.242E14	1.242E14	3.55	3.85	3.55	3.85
Syngas	942	246.	3.2	12.7	22.5	47.	73.0	1.419E14	1.419E14	2.79	3.01	2.79	3.01
HYGAS	980	246.	4.8	12.2	23.4	49.	69.0	1.202E14	1.181E14	3.45	3.72	3.51	3.79
BIGAS	998	246.	5.8	12.2	23.9	50.	91.9	1.158E14	1.158E14	3.62	3.91	3.62	3.91
Synthane	870	246.	4.5	12.9	24.3	44.	82.0	1.151E14	1.114E14	3.46	3.72	3.58	3.84
LURGI	1151	246.	4.5	12.7	36.7	58.	112.0	1.161E14	1.143E14	3.89	4.22	3.95	4.29
CE Power	1268	246.	3.0	12.0	38.	63.	116.0	0.764E14	1.985E14	6.08	6.65	2.34	3.56
West Power	1066	246.	3.0	12.0	32.	53.	100.0	0.706E14	1.836E14	6.12	6.64	2.35	2.55
Westinghouse Syngas	684	246.	4.5	12.2	20.5	34.3	71.4	1.542E14	1.542E14	2.42	2.57	2.42	2.57

* Reference Gasoline

Appendix 3: COST SENSITIVITY AND INFLATION

The cost equations used in this report are in a form sufficiently simple to allow cost sensitivity to be easily calculated by either differentiating the equation or calculating the alternative case. The energy cost breakdown into portions attributable to coal, capital, and remaining operating costs shown in Table 5.3 should also be helpful for limited senstivity analysis.

All product costs are calculated and shown in 1979$. All inputs, including start-up and investment are also 1979$. Since inflation is expected to affect all processes, the comparative results presented are not distorted by lack of a sophisticated inflation model. This does not mean the processes would be equally affected in the near future by inflation. The particular inflation rates for labor, materials, and capital construction may cause a change in process ranking This possibility is complicated further in that process and system improvements are expected for some of the products but not all. As stated earlier, a more specific study can be expected to give more meaningful results.

PLANT SIZE SENSITIVITY

Plant size will have a direct effect on product cost from all plants where capital investment is not a constant cost per unit of production. A common equation which prevails for relating capital investment to capacity for chemical manufacturing plants is:

$$\frac{C_2}{C_1} = \beta^{\gamma} \qquad (5.1)$$

where C_1 is the capital investment for the base case plant and C_2 is the base cost from a larger plant with β as the size ratio of the larger to the smaller plant. This is an empirical relation described in many handbooks as the "six-tenths rule". However, typical values for γ are found to range from 0.6 to 0.75 for common types of manufacturing plants.

If a complete cost estimate is available for a base case, the product cost from a larger plant can be determined if a value for γ is known. First an analysis of the product cost must be made to determine those costs that are directly due to feed materials and all consumable chemicals, incremental labor, and purchased utilities where the amount required is directly proportional to the amount of product produced. This fraction of the total cost that is, in effect, the cost without overhead and capital related charges is called α.

The product cost from base case P_1, must be on a unit basis. Thus, the cost for product, P_2, on a unit basis, from the larger plant can be approximated from the following relationship:

$$P_2 = (\alpha + (1 - \alpha) \beta^{\gamma-1}) P_1 \qquad (A3.3)$$

This relation can be used with the data in this report by using values for F plus M from Table 5.3 to approximate α. A reasonable value for γ would be in range of 0.60 to 0.75. To the extent that the value used for α remains independent of β, the results will be accurate.

Appendix 4: COAL RESOURCES

(Prepared by: Thomas A. Boyce, Mining Engineer in Residence)

RESOURCE AVAILABILITY

The necessary coal resources to provide feed materials to the various coal conversion processes described herein are verified and accessible at costs consistent with Department of Energy studies. The quantities required to displace oil and also supply current and new direct uses are available. This discussion does not include all considerations involved with mining the known coal reserves.

DEFINITION OF RESOURCE AND RESERVE

The total coal resource is that coal which is currently or potentially extractable under prevalent economic and technological conditions. According to the U.S. Bureau of Mines and U.S. Geological Survey nomenclature, the total coal resource is subdivided by degree of geologic assurance and economic feasibility (Figure 1). An identified resource is a coal deposit which has been determined by geologic evidence. It may be classified as either demonstrated, where its location, quality, and quantity have been determined by evidence supported by measurements, or it may be classified as inferred, where it has been determined by projection of geologic data. An identified resource, if determined to be extractable, is termed a reserve. A sub-economic resource is not a reserve but may become a reserve as a result of later changes. An undiscovered resource is one which may reasonably be expected to exist in known coal areas (hypothetical) or undiscovered areas (speculative).

Note that quantities to be included in the various categories in Figure 1 are in many respects judgmental on the part of the estimator. In addition, quantities will vary with time to account for actual extraction, changing economics and additional exploration data.

Many national estimates are based on a compilation of state estimates, introducing not always consistent local judgment. Criteria for the states reflect the data sources used, including U.S. Geological Survey, U.S. Bureau of Mines, state geological surveys, coal mining

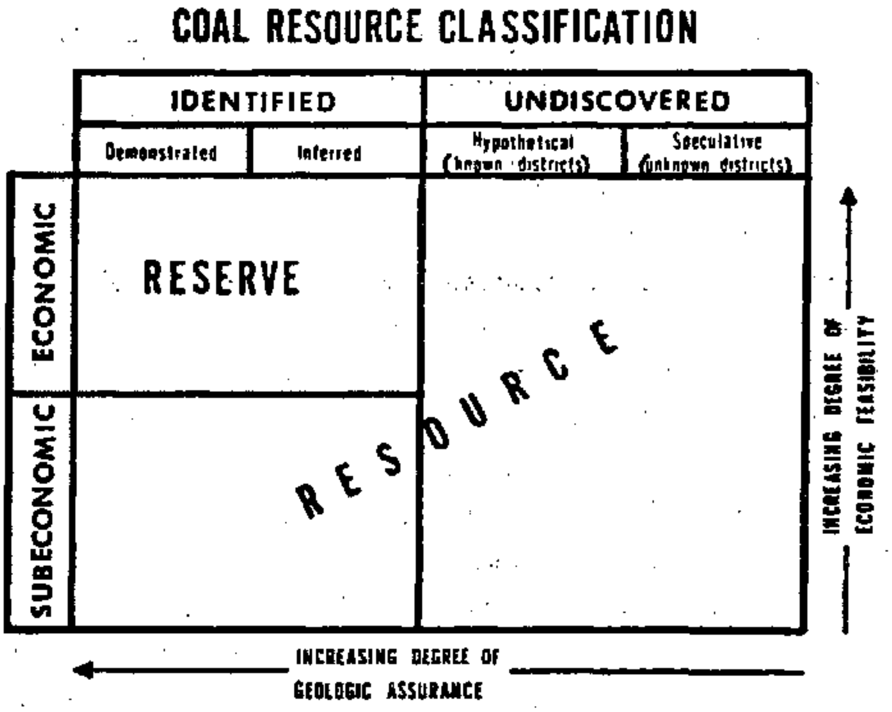

Figure 1. Coal Resource Classification

(According to U. S. Geological Survey and U. S. Bureau of Mines Nomenclature) companies, and railroad companies. Another variable in the resource and reserve estimating process is the availability of field data. In some coal fields an entire county may have to be inferred from one or two test holes.

Three published national estimates are often quoted as indications of coal availability in the United States:

> ESTIMATED REMAINING COAL RESOURCE OF THE UNITED STATES, JANUARY 1, 1972 - 3,224,000 million of short tons
> Data from U.S. Geological Survey Professional Paper 820 (Averitt, 1973)
>
> ESTIMATED STRIPPABLE RESOURCE AND RESERVE OF COAL IN THE UNITED STATES, JANUARY 1, 1968 - 44,986 million of short tons
> Data from U.S. Bureau of Mines Information Circular 8531 (1972), Table 2
>
> DEMONSTRATED RESERVE BASE OF COAL IN THE UNITED STATES, JANUARY 1, 1974 - 443,948 million of short tons
> Data from U.S. Bureau of Mines (1974)

The scope of each of these estimates varies considerably. Thus, it should be cautioned that interpretation of estimates be based on an understanding of the scope and assumptions used. Better information is being developed routinely. Verified data are adequate to feel secure that U.S. coal reserves are adequate for projected usage through the next 100 years.

GEOGRAPHIC DISTRIBUTION AND VARIATION IN CHARACTERISTICS

The major coal fields of the United States are shown in Figure 2. While delineations are made for the general categories of anthracite, bituminous, subbituminous, and lignite, it should be emphasized that the coal in place occurs with almost infinite variation in chemical and physical characteristics. For example, the publication "U.S. Coal Mine Production by Seam - 1976" (Keystone Coal Industry Manual, 1977) lists nearly 5,000 separate seams indicating high, low, and mean site specific values for:

Average Proximate Analysis

Moisture	Ash
Volatile Matter	Sulfur
Fixed Carbon	Heating Value

Other Properties
- Ash-Softening Temperature
- Free-Swelling Index

Ranges of values within a single county for a single seam are often as much as ± 50% of the mean.

MEHCANICAL VS. CHEMICAL COAL UPGRADING

Coal is a particularly heterogeneous material. There are variations within any given seam and more dramatic variations as location changes. The generic types have simplifying names such as bituminous, subbituminous and lignite which are only the beginning of a meaningful description.

There is no such thing as an identifiable coal molecule but rather a family of combinations of carbon and hydrogen atoms with random lesser amounts of nitrogen, sulfur and oxygen and trace amounts of many ash forming minerals. Molecular weight is a simple measure of molecular complexity. Methane, the main ingredient of natural gas, has a molecular weight of 16. The principal liquids that comprise gasoline range in molecular weight from 58 to 200. The molecular weight of coal materials is estimated to be over 10,000.

Mechanical breaking is the necessary first operation to flow removal of the coal from the source. Foreign materials may be included with the coal and later classed as ash. There are mechanical operations such as crushing, screening, separation based on density and washing which make the coal more desirable for use as an energy product. Since certain amounts of the impurities, especially nitrogen and sulfur, are chemically combined, there is no mechanical process which can completely remove these elements. The degree to which mechanical beneficiation is effective is very much determined by the particular coal resource.

The development of every real coal conversion plant must take into account resource properties and site specific considerations.

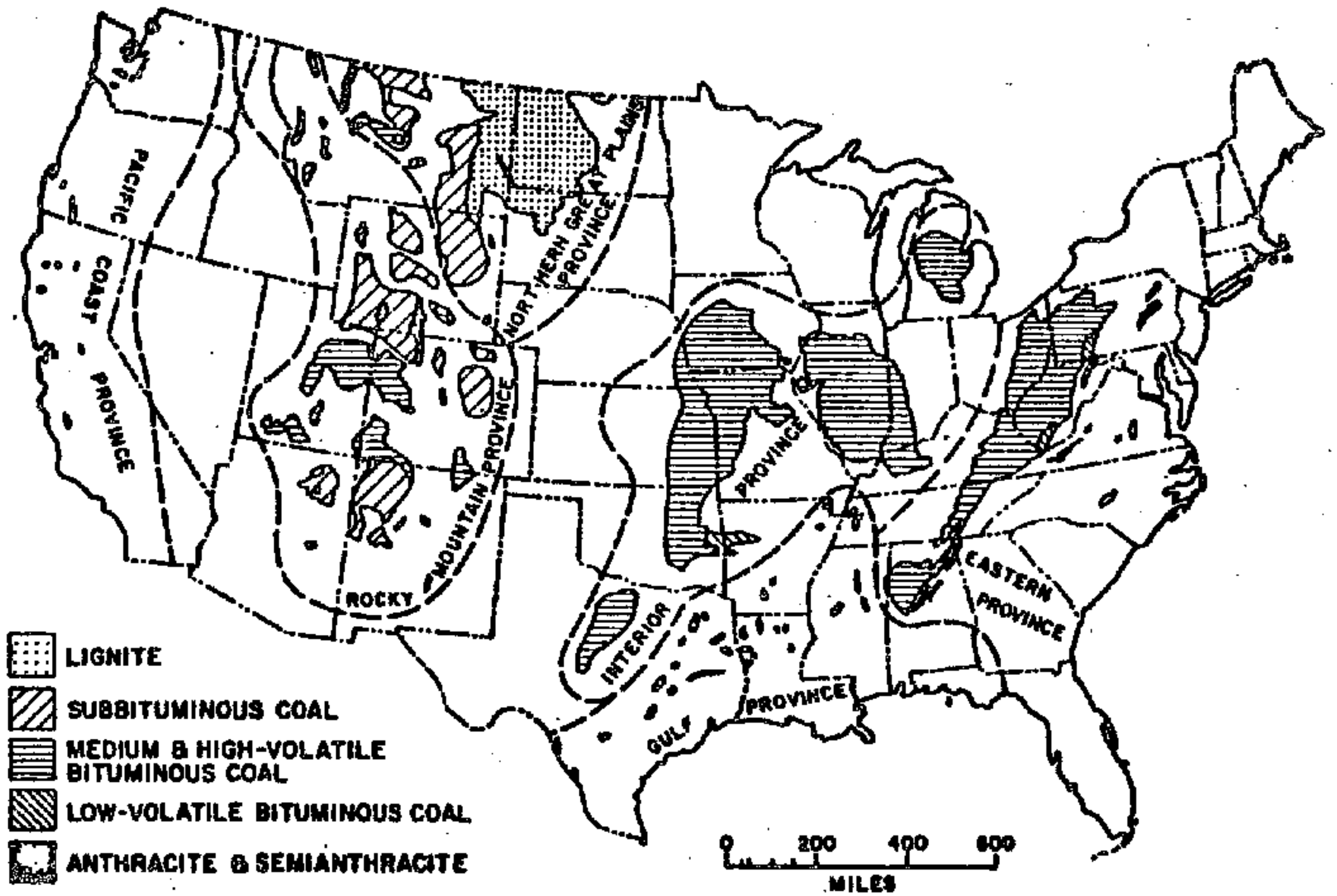

Figure 2: Bituminous and subbituminous coal and lignite fields of the conterminous United States

MECHANICAL COAL UPGRADING

Coal preparation is used for treating run-of-mine coal to meet market specifications. Commonly, this is accomplished by mechanical sorting of particles in water. Prepared coal normally has defined physical property specification, higher calorific value, and lower moisture, sulfur and ash contents than raw coal. It is a superior quality coal which has advantages to the user.

Coals, as they occur in the ground, are extremely heterogenous with characteristics that vary widely from seam to seam within an individual seam. They tend to be adulterated with "deleterious dirt" which results in ash or sulfur products upon conversion. Complicating the inherent complexity and heterogeneity of coals is the mining process which introduces additional adulterants, including roof and floor rock, mineral partings within the seam, and other foreign materials. Therefore, run-of-mine coal usually requires some sort of preparation.

Data on size distribution of incoming feed coal is required. Detailed washability information on the various size fractions of the raw coal is also required.

Three main benefits of coal beneficiation can be:

a. An increase in Btu content per unit weight of the coal.
b. A reduction in the ash content of the coal.
c. The net reduction of sulfur.

Five general levels of coal cleaning are recognized as shown below. These levels are defined to help classify and establish costs for physical - as opposed to chemical - coal cleaning, in order to determine the extent of pyritic sulfur removal for different United States coals. These levels may also be used to classify the degree of ash removal and heating value improvement.

In review, the levels may be summarized briefly as:

Level I: Basically a crushing and screening operation, where no washing or cleaning is required. Some extermal impurities may be removed by the use of a rotary breaker.

Level II: Minimum washing, where impurities are removed by coarse coal cleaning only.

Level III: Separation by washing the coarse and medium sizes only, using simple washing techniques.

Level IV: Complete washing down to zero sizes, including froth flotation and closed water circuit.

Level V: Crushing to increase improvement with multiple cleaning, using dense media, froth flotation, and producing a high-grade clean coal and a middling product.

The selection of the proper level depends on the input flow characteristics and the required feedstock specifications and will eventually be impacted by the viability of markets for middlings and fines.

A large number of processes are being investigated to find new methods to reduce the mineral and organic sulfur in coal as well as the ash content. These include:

a. Dry magnetic separation
b. Hydrothermal caustic leaching
c. Aqueous ferric sulfate leaching
d. Hydrothermal oxygen leaching
e. Wet oxidation
f. Organic liquid separation
g. Sulfur digesting bacteria
h. Microwave radiation

COAL BLENDING

Blending of raw coals prior to treatment, and blending of product coals prior to conversion can be important in coal conversion. This is because of the possible stringent physical and/or chemical specification limits imposed by the equipment and the process.

The physical and chemical characteristics of run-of-mine coals vary greatly. Blending ensures that a coal of uniform analysis will be fed to the processing plant. Blending can also eliminate the need for selective in-pit mining.

The capital costs associated with large-scale blending systems are high. This cost impact emphasizes the need for careful consideration of blending and the full effects on the conversion process. The coal feed requirements must be accomplished by the most economical methods in the proper location. These choices are a matter of specific design. The conversion plant must have provision for handling and preparation of the coal which may vary over a range of conditions.

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