

THE DEVELOPMENT OF NEW USES FOR
VICTORIAN BROWN COAL

by

G.J. Perry, D. Royston and D.J. Allardice
Coal Corporation of Victoria
64 Church Street, Traralgon, 3844
Victoria, Australia

Abstract

The extensive low rank coal deposits in Victoria, Australia, were in 1982 estimated at 197,000 million tonnes (Mt) of which 43,000 Mt are readily recoverable reserves using present day open cut mining technology. At current rates of consumption (37 Mtpa) these reserves would last over 1000 years. In the past 60 years the coal has been used primarily for power generation, although significant quantities have been used for the production of briquettes, town gas and char.

The Victorian State Government recognised the coal resources as one of the State's key competitive strengths for economic development. The unique properties of the coal, together with the ease of open cut mining, make it suitable for a variety of new applications. The need to co-ordinate the orderly development of the brown coal deposits coupled with high commercial interest shown in the brown coal led to the formation by the government in 1985, of a new statutory corporation, the Coal Corporation of Victoria, to lead the commercial development of brown coal for uses other than power generation. Initially 5 Mtpa of high purity Loy Yang coal have been made available for commercial development. Registrations of interest have been received from over 40 local and overseas companies. Several of these are developing firm project proposals to produce value-added products including carbons, chars, and dried brown coal products.

Research and development activities have centred around the natural attributes and unique properties of the coal for a variety of new uses.

The high oxygen content (25% dmif) can be turned to advantage by the development of ion exchange materials for metal extraction in environmental and industrial applications. By carbonization and steam activation activated carbons with high surface areas can be produced.

The high moisture holding capacity of the coal together with its open friable structure and humic acid content make the coal potentially suitable for horticultural and agricultural applications as a soil conditioner.

Research and development of these new products together with many other areas of applied and fundamental research are being

conducted in Victoria by Government research organizations, tertiary institutions and private industry.

This work is leading to new industrial development of Victoria's vast brown coal resources.

The Victorian Brown Coal Resource

In 1982 the Victorian Brown Coal Resource Development Study conducted by Kinhill Pty Ltd and associates (1) estimated the total geological resource of brown coal in Victoria to be 197,000 Mt (coal with less than 10% ash content, dry basis). More recent estimates have increased this figure to over 200,000 Mt (2,3).

85% of the State's brown coal resource is located in the Gippsland Basin, the bulk of it in the Latrobe Region and within 300m of the surface. It has been estimated that a further 220,000 Mt of coal could occur in deep deposits within the Gippsland Basin (3), particularly offshore.

Smaller deposits occur in the Otway Basin (9,000 Mt) and the Murray Basin (20,000 Mt).

The Kinhill study (1) developed criteria to determine the quantity of coal which was economically winnable based on conceptual open cut schemes ranging in size from 162 Mt to 4088 Mt. These criteria adopted a maximum coal depth of 300m, a minimum seam thickness of 3 m and a maximum overburden to coal ratio of 2:1. Using these criteria and the conceptual open cuts, 54,000 Mt was defined as "usable reserves" which could be recovered using present day technology. It was estimated that about 85% of this coal was available at a cost not exceeding twice the cost of coal from the lowest cost prospective open cuts.

Some of these reserves have specific constraints on their development and by exclusion of coal under townships and environmentally sensitive areas this 54,000 Mt of "usable coal" has been reduced to 43,300 Mt of "readily recoverable coal". More than half of this recoverable coal is located in the central Latrobe Valley area.

To put this in perspective a comparison can be made to the lignite resources and reserves in the Fort Union Region of the USA. In this region some 465,000 Mt of lignite has been identified (2) however only 26,300 Mt have been classified as "strippable reserves". It is clear that whilst the total identified resources in the Fort Union Region is far greater than that of the Gippsland Basin (down to 300m depth), the reserves of readily recoverable coal in Australia are significantly greater (and of greater purity - see later).

A further illustration of the significance of the Victorian brown coal reserves can be seen in Table 1 which compares the

ratio of reserves to production for low rank coal (brown coal and lignite) producing countries of the world. This table shows that while Australia ranks second in brown coal reserves to USSR, it only ranks eighth in production. When the reserves to production ratio is considered, Australia with 1170 years more than doubles that of any other country. In contrast the ratio for East Germany, the largest producer, is only 43 years.

By any standard, it can be seen that brown coal provides Australia and particularly Victoria with a resource which is largely under utilized and offers substantial economic opportunities for future development.

Quality of Victorian Brown Coal

Victorian brown coal has been extensively surveyed and a comprehensive data base has been assembled on the properties, characteristics and utilization parameters of the coal. (4)

Latrobe Valley brown coals are soft and strongly banded, due to variations in depositional environments causing the formation of different coal types or lithotypes. Five lithotypes, based on colour, texture, degree of gelification, compaction of ground mass etc have been distinguished in Latrobe Valley coals (5). The presence of these coal types contributes to the variability in chemical and physical properties within coal seams. (6).

Typical values for important coal properties for Latrobe Valley brown coals are shown in Table 2.

For a proper assessment of coal quality not only the properties of the coal must be considered, but also the intended applications. The high moisture and oxygen content of the coal are usually considered major disincentives for its utilization however as will be shown later these properties are beneficial for some potential applications. The primary assessment of the quality of brown coal is for combustion based on bed moisture and ash contents and net wet specific energy.

Average moisture contents of coal in the Latrobe Valley range between 52% and 67% bed moisture. The bed moisture is substantially higher than the moisture holding capacity of these coals. (6) See Table 3.

Apart from thin bands of inferior coals normally found near the top and bottom of coal seams, the average ash contents of Latrobe Valley coals range between 1% and 5% on a dry basis. In areas of the Loy Yang deposit, substantial quantities of coal with less than 1% ash occur. The level of minerals and inorganics are generally lower than the ash (or ash yield) due to the high relative levels of exchangeable cations associated with the coal compared to discrete minerals. (7). Sodium, calcium, magnesium, iron and aluminium are normally present in

intimate combination with the coal substance as salts of carboxylic acids.

Certain inorganic cations present, can affect the combustion and fouling properties of the coal (8). High levels of calcium and magnesium lead to the formation of carbonates during hydrogenation leading to reactor blockages (9). Calcium is also believed to contribute to the inferior weathering properties of briquettes manufactured from Morwell brown coal, compared with the better Yallourn coal on which briquette production is now based.

The occurrence of minerals is sporadic, is of less significance and is usually restricted to quartz, kaolinite, pyrite and marcasite.

The Latrobe Valley coals show variations in ultimate analysis between seams and also within seams with changes in lithotype. While average values are listed (Table 2), observed variability can be (on dry basis) Carbon 64 to 71 per cent, Hydrogen 4.4 to 6.6 per cent, Oxygen 19 to 28 per cent, Sulphur 0.1 to 5 per cent, Chlorine 0.02 to 0.6 per cent and Nitrogen is fairly constant at approximately 0.6 per cent.

The high concentration of oxygen, present in the carboxylic, hydroxyl and carbonyl functional groups of the coal substance, is the most notable aspect of the ultimate analysis. The H/C ratio of brown coal approximates that of a high volatile bituminous coal, although much of this hydrogen is associated with oxygenated functional groups and is released as water during pyrolysis.

The high moisture contents of the brown coals are reflected in their relatively low net wet specific energies, which range from 6.5 to 11.5 MJ/kg (2800 to 4950 BTu/lb). All seams show an increase in specific energy with increasing depth beneath the surface, although significant variations with lithotype are also apparent.

Current Utilization of Brown Coal in Victoria

Electrical Power Generation

Power generation will continue to be the major user of brown coal for the foreseeable future. In 1985/86 the total capacity of installed power generation plant in Victoria based on brown coal was 4460 MW which generated 79% of the electricity supplied. The first 1000 MW of the Loy Yang project, planned for 8 x 500 MW units, are operating, with a further 1000 MW under construction. Based on current projections in electricity demand, construction of a further 1000 MW has been approved with a decision on the final two 500 MW Loy Yang B units still under consideration along with other options.

Briquette Production

Briquettes produced from Yallourn coal have been available in Victoria since 1924 and have been used for power generation, steam raising, industrial and domestic heating. Briquette production reached a peak of 1.9 Mt per year during 1966 but has declined since low cost natural gas became available from Bass Strait. Production in 1985/86 was 851,000 t from a design production capacity at the Morwell briquette factory of 1.3 Mt per year. Consumption was distributed as follows:

- 0.26 Mt for use as an auxiliary fuel in power stations.
- 0.625 Mt to the industrial sector including some
- 0.158 Mt for char production and
- 0.061 Mt for export.
- 0.020 Mt for domestic use, mainly heating.

To manufacture briquettes, Yallourn coal is crushed and dried to 15% moisture content and is briquetted by pressing through an extrusion form without any added binder. Approximately 2.7 tonnes of the 67% moisture content coal has to be processed to make 1 tonne of briquettes and a further 1 tonne of coal must be burned to generate steam for drying the process coal. The efficiency of this drying step is considerably improved by using back pressure steam from electricity generation turbines, with 170 MW capacity.

The uniformly shaped briquettes (nominally 58 x 37 x 43 mm) can be stored conveniently, transported economically, are readily ignitable and, given suitable equipment, can be burned slowly or at high rates. The net heating value of 21.3 MJ/kg, together with the low ash content (2.1% dry basis) and the low sulphur content (0.3% dry basis) make briquettes ideal for solid fuel heating applications and as a feedstock for value-added products.

The responsibility for briquette distribution and marketing was transferred to the Coal Corporation of Victoria on 1 January 1985 and new strategies are being pursued vigorously to increase export sales as well as sales to Australian domestic and industrial customers.

The past decline in briquette sales is being reversed based on the increased local use of briquettes as an industrial fuel and through exports. Exported briquettes are used as a fuel (domestic and commercial) and as a chemical feedstock for humic acid production for use in fertilizer mixes, and, potentially to produce activated carbon. There are prospects for further export markets including Europe and North America, where a solid fuel with low pollution potential is required. The surplus production capacity for briquettes currently available (400,000 tpa) may require supplementing with new production facilities over the next ten years, possibly to produce some other form of dried brown coal fuel.

Char Production

Since 1970 Australian Char (Holdings) Pty Ltd has been manufacturing industrial carbon by carbonising Yallourn coal briquettes using direct-heating from circulating hot gases in vertical retorts. The process operates with a carefully controlled temperature profile through the retort to a final temperature of 800°C. This minimises breakage and loss of lump strength in carbonising whole briquettes (10). The product is a hard lump char (25 mm nominal diameter), and has a high purity (95% fixed carbon). It is marketed for use as a metallurgical recarburiser, in alloy manufacture, and as an electrochemical reductant and chemical feedstock. The annual production of this lump char is nominally 60,000 tonnes and about 75% of the char is exported to Japan, South Korea and Europe.

Australian Portland Cement Ltd at Traralgon also produces char by carbonising briquettes in a partial combustion type retort from which the hot gases are used for drying the marl. Most of the char is used as an integral fuel in pelletised clinker which is fired in a vertical cement kiln.

A proportion of the brown coal char produced in Victoria is blended with a binder and ignition agent and formed into a high quality barbeque fuel for local and export use.

Availability for Brown Coal for New Industries

The Victorian Government has identified the State's brown coal resources as one of its key competitive strengths for future economic development. The Government has therefore agreed to provide private enterprise with access to this low cost, high quality brown coal in the central Latrobe Valley. Previously this attractive coal had been reserved for future power generation.

To encourage this initiative the Coal Corporation of Victoria is offering at least 5 Mtpa of high purity Loy Yang coal as part of the "Coal For Industry Program". Prices of \$A0.50 to \$A1.00/GJ are achieved by taking advantage of the economics in scale of operation at the Loy Yang Open Cut which will produce up to 32 Mtpa for electricity generation.

Run of mine Loy Yang coal is one of the lowest cost, high purity, organic carbon feedstocks available in commercial quantities in the world today. The weighted average and distribution of moisture, ash, specific energy and the main coal constituents over the whole open cut are given in Table 4. Data in Table 4 illustrates that Loy Yang coal is ideally suited to many premium applications due to its low levels of ash forming constituents and low content of specific elements of concern in potential applications.

Under the "Coal For Industry Program" Loy Yang coal may be used for any development consistent with the Government's

policy of encouraging the wider use of brown coal and the development of industries using this resource. In the late 70's and early 80's the dominant development interest was in converting Victorian brown coal to oil, with several significant project proposals submitted. Sophisticated liquefaction technologies are now financially unattractive with the present atmosphere of reduced oil prices. The emphasis in the present Coal For Industry registrations of interest has shifted to value added products such as activated carbons and carbon reductants (chars) and to a lesser extent upgraded solid fuels (in view of the depressed export coal prices).

At present the technical and economic merits of the several proposals are being assessed and the Coal Corporation of Victoria is confident that a firm timetable for commercial development of Loy Yang coal will be developed during 1987.

New Research & Development Activities

A number of alternative applications for Victorian brown coal are being evaluated at the research and development stages. The Coal Corporation of Victoria has a responsibility to encourage the upgrading of brown coal into usable, economic and efficient product forms, and to co-ordinate and support public and private sector research and development programs.

Consequently the Corporation has a strong interest and involvement in most of the brown coal research and development activities presently being undertaken in Australia on Victorian brown coal.

Pilot Scale Developments

* Brown Coal Liquefaction (Victoria) Project.
The Brown Coal Liquefaction (Victoria) Pty Ltd (BCLV) project, operated by a Japanese consortium, is the largest low rank coal liquefaction project in the world. It uses a two stage hydrogenation process developed specifically for Victorian brown coal (11).

The cost of construction of the Pilot Plant exceeds \$A400 million, with the Japanese Government providing the bulk of this funding. The Victorian Government through the Coal Corporation of Victoria is providing a package of assistance to support the project. Construction of Stage 1 began in November 1981 and it started up in November 1985; construction of Stage 2 is now complete and integrated operation to produce liquid products is scheduled for later this year.

Stage 1 converts 50 t/d (dry coal basis) of brown coal to 30 t/d coal liquefied bottoms (CLB or solvent refined coal) and 5 t/d naphtha. The first stage uses a disposable iron based catalyst operating at 200 - 250 bar and 430 - 460°C. In Stage 2, the CLB intermediate will be further refined by secondary hydrogenation to produce a total yield of about 25 t/d of middle distillate and naphtha. This represents a

scale-up factor of 100:1 from the mini-pilot plant which has operated since 1979 at Kobe in Japan.

Operation of the Morwell pilot plant is scheduled to continue until late 1989.

While the current operation at the Brown Coal Liquefaction (Victoria) coal to oil pilot plant will continue on strategic grounds, this technology is not expected to be economic until early next century. Nevertheless the fact that the project is continuing reflects the Japanese and Australian Governments' awareness of the strategic importance of having coal liquefaction technology available, despite the presently depressed world oil prices.

* Solar Dried Brown Coal Slurry Process

The solar drying of slurried brown coal is a process which produces a dry, high density, storeable lump coal. Raw coal (60% moisture) is mixed in a ratio of 3:1 with water and milled to form a very fine (8-10 micron particle size) concentrated non-settling suspension. The slurry is pumped into ponds or drying pans to a suitable depth and is allowed to dry by evaporation. As the moisture evaporates, the slurry shrinks and cracks to form homogeneous lumps with an equilibrium moisture content of about 12%, similar to brown coal briquettes. (12).

A 2200 t/yr pilot plant has been constructed for the State Electricity Commission of Victoria with a \$A2.1 million grant from the Australian Government's National Energy Research Development & Demonstration Program, and is now in operation in the Latrobe Valley. Solar dried brown coal can be produced at relatively low cost for small scale production (350,000 tpa) using public sector finance but does not benefit from economies of scale to the same extent as other drying technologies. A relatively low cost lump fuel, as a possible substitute for briquettes, can be produced utilizing solar energy for drying, however production is seasonally variable and requires large land areas, the environmental implications of which have not been fully assessed.

* Multiple Effect Steam Fluidized Bed Drying

A process using superheated steam for drying brown coal was developed by Potter at Monash University (13).

In the process -1 mm coal fed to two fluidised bed dryers in parallel, is indirectly heated by low pressure steam which condenses inside the tubes submerged in the fluidised bed. The coal bed is fluidised by a portion of the water vapour generated and recycled to the bottom of the bed. The vapour generated in the first stage containing fine coal particles is cleaned and then compressed and supplied to the second stage as the heating steam. The vapour compressor is driven by high pressure steam from a boiler plant, and this steam ends up as heating steam for the first stage. The second stage vapour is condensed and directed to the water treatment plant, together

with the first stage vapour condensate condensed in the second stage heater.

The process is being studied in a small pilot plant scale at Monash University but larger pilot scale development is necessary to confirm the potential of the process to produce low cost fine and granular dried brown coal.

The multiple effect (steam from one stage providing heat for another) conceptual process, has been assessed in a consultant's study, as having potentially the lowest production cost at high production levels (3 Mt/yr) and with private sector financing.

* Production of Activated Carbons
Among the unique characteristics of Victorian brown coals are their high surface area and porosity. These features are preserved and enhanced in carbonisation and make them ideal feedstocks for active carbon production (14).

The Coal Corporation of Victoria, in a joint venture with Australian Char (Holdings) Pty Ltd, is operating a 1 t/day pilot plant to produce activated carbons from brown coal char, briquettes and other brown coal derived feedstocks. The Pilot Plant uses a 760mm internal diameter Hereschoff type kiln and consists of a cylindrical vertical shell lined with refractory which encloses a series of six circular hearths. The furnace is fired with natural gas and designed for a maximum temperature of 1000°C and adjustable residence time within the range 30 to 300 minutes.

Results to date have been encouraging, with good yield of medium to highly active carbons being produced from brown coal char and briquette grus.

Activated carbon is an important adsorbent used in industrial and environmental applications and currently Australia imports all of its activated carbon requirements. In 1985/86 this amounted to 4263 tonnes with an average cost per tonne of over \$A2000. The direct production of activated carbons from low cost, high purity brown coal derived feedstocks represents an attractive opportunity for development of a new brown coal based industry in Victoria for both local and export sales.

Research Scale Activities

At present a wide variety of research is being conducted within Australia in areas related to Victorian brown coal. Research projects ranging from fundamental studies on coal structure and composition, to development of new value added products and processes, and environmental and occupational health issues related to brown coal utilization are being actively pursued.

The Coal Corporation of Victoria has a direct involvement in most of these research initiatives and in many cases provides financial

support to University groups, CSIRO etc. Table 5 summarises the variety of research activities presently receiving support from the Corporation.

Three of these research areas are discussed below to exemplify the range of opportunities for development of new products from Victorian Brown coal.

* Preparation of Activated Carbons

In a separate initiative to the pilot plant investigations discussed previously, laboratory scale investigations are being conducted to prepare attrition-resistant active carbons with high activity from brown coal.

Victorian brown coal is inherently a soft material, whilst activated carbons, particularly if they are to be regenerated for re-use, require a certain degree of hardness or attrition resistance. Attrition resistance is particularly important if carbons are used by the gold mining industry in the carbon-in-pulp (CIP) process. Both physical and chemical modification of brown coal feedstocks have been investigated to overcome the inherent softness of brown coal and produce active carbons with acceptable levels of hardness.

Digestion of brown coal with alkali promotes the collapse of the pore structure and the release of humic acid material. After drying this alkali treated coal forms a dense, relatively homogeneous, gellified, brittle material, (15). Incorporation of potassium cations has been found to yield carbons of high surface area ($1100 \text{ m}^2/\text{g}$) when this alkali treated coal is carbonized (16). This process has been patented.

By the use of alkali digestion together with additional chemical modification followed by carbonization and/or steam activation, hard activated carbons with high surface areas can be produced from Victorian brown coal. Some of these carbons show an excellent capacity for adsorption of gold from cyanide solutions and therefore have potential to satisfy the stringent requirements of the CIP gold industry.

* Ion Exchange Materials from Brown Coal

The high oxygen content of Victorian brown coal, half of which is attributable to the coal's carboxylic and phenolic functional groups, together with the coal's large internal surface area make brown coal a potential medium for ion exchange. It has been found that pre-loading the coal with an alkali metal e.g. calcium, enhances the ion exchange capacity of the coal. (17). The use of calcium loaded brown coal has achieved 99% removal of metals from 1000 ppm solutions of copper, lead, mercury, uranium and cobalt. (17).

However Loy Yang brown coal without pre-treatment can also remove, by ion exchange, metal ions from aqueous solution to a significant extent. (18).

The degree of metal removal is dependent on the pH of the solution, the particular metal ion and its concentration. Figure 1 demonstrates the removal of silver (1000 ppm solution) as a function of pH using both Loy Yang run of mine coal (ion exchange) and NaOH (precipitation). It can be seen that without any pH adjustment Loy Yang coal removes 70% of the silver from solution. Furthermore at approximately pH 6.5 90% is removed with Loy Yang coal, the same removal is not achieved by precipitation until pH10.

Victorian brown coal due to its ion-exchange properties has the potential to remove metals species from industrial waste waters or hydrometallurgical liquors in a cost effective manner. Commercial prospects are being evaluated.

* Agricultural/Horticultural Applications

Victorian brown coal has many chemical and physical properties in common with soil organic matter which are essential to soil fertility. These properties include high water holding capacity, good nutrient holding capacity (due to ion-exchange) and open friable structure. It is believed that the high humic acid content of Victorian brown coal could play an important role in agricultural applications due to the plant growth promoting properties of humic acids. (19).

Potting trials have demonstrated the utility of brown coal for (a) amelioration of saline soil by increasing organic matter content and improving soil structure and (b) for improvement of plant growth in sandy soils by increasing water and nutrient holding capacity. (20). The advantages of brown coal have been recognized for many years and potting mixes in Victoria already contain a proportion of brown coal. Field trials are presently underway to investigate the use of brown coal in "broad acre" applications e.g. wheat growing, vegetable production.

Research work is also being conducted to use brown coal as a fertilizer support, by enriching the coal in nitrogen and phosphorus.

This is one of the few uses for brown coal where the high moisture content is not a disadvantage, as drying is not essential prior to horticultural or agricultural application.

Conclusion

Victoria has extensive reserves of high quality brown coal, coupled with sixty years of experience in large scale extraction and processing of this unique resource. This provides a key economic advantage to the State by ensuring the continued availability of low cost electricity and solid fuel and by providing the basis for new industries to produce value-added brown coal products for local and export markets.

Research and development programs which are now in place will ensure that commercial development of the resource will take place in a realistic time frame.

Victorian brown coal development is on the threshold of a new era with high potential for new industries, new markets and new jobs based on the production of new value-added products.

Acknowledgements

The authors wish to thank the Coal Corporation of Victoria for permission to publish this paper and their colleagues for assistance in its preparation.

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TABLE 1 - WORLD BROWN COAL RESERVES AND ANNUAL PRODUCTION

COUNTRY	ANNUAL PRODUCTION ¹ Mt.	RESERVES ² Mt.	RESERVES/ PRODUCTION RATIO (YEARS)	COUNTRY	ANNUAL PRODUCTION ¹ Mt.	RESERVES ² Mt.	RESERVES/ PRODUCTION RATIO (YEARS)
East Germany	300.0	13,000 ³	43	Bulgaria	31.5	3,700	117
USSR	159.0	89,100	560	Romania	29.8	-	-
West Germany	120.7	35,150	291	Canada	26.5	2,117	80
Czechoslovakia	100.4	2,860	28	Spain	23.5	411	17
Yugoslavia	66.0	15,000	227	Turkey	22.9	1,728	75
USA	63.0	31,980	516	Hungary	21.4	4,000	187
Poland	57.7	12,000	208	Austria	3.1	60	19
Australia	37.0	43,300 ⁴	1,170	Italy	2.0	-	-
Greece	35.2	1,550	44	France	1.9	-	-
China	32.0	-	-				
TOTAL						1,157.4	

NOTES:

1. The Annual Production figures are based on 1985 production estimates (ref. Braunkohle Vol 38, March 1986, page 60).
2. Reserve figures based on Survey of Energy Resources in 1983 by the World Energy Conference unless noted otherwise.
3. Reserve figures based on the following reference:
Concise Guide to World Coalfields IEA Coal Research, 1983 ISBN 92-9029-088-9
4. The Australian reserves figure is based on the Victorian Reserves quoted in "Victoria's Energy - Strategy and Planning Options" November 1985. No South Australian brown coal reserves have been included as these are small and have not been clearly defined.

TABLE 2 - ANALYSES FOR VICTORIAN BROWN COALS

	Gippsland Basin					Oway Basin			Murray Basin
	Yallourn	Monwell	Yallourn Hth Extn	Loy Yang	Gelliondale	Aitona	Bacchus Marsh	Anglesea	
Seam	Yallourn	Monwell 1	Larrobe	Monwell 1 & 2	Gelliondale				
Moisture (%)	66.4	61.3	52.3	62.8	64.8	58.7	60.5	46.4	56.0
Ash (%db)	1.7	3.0	4.9	1.4	5.7	12.6	7.4	3.8	10.8
Volatiles (% db)	50.3	48.3	47.4	49.8	49.4	47.2	49.8	47.0	
Fixed Carbon (% db)	48.0	48.7	47.7	48.9	44.9	40.2	42.8	49.2	
Minerals and Inorganics (% db)	1.3	2.0	3.8	1.4	3.3		3.5	2.2	
Carbon (% dmif)	67.5	69.2	69.5	68.5	67.0	68.6*	67.6	70.1	
Hydrogen (% dmif)	4.8	4.9	4.9	4.8	4.8	4.9*	4.9	5.0	
Nitrogen (% dmif)	0.57	0.60	0.63	0.59	0.48		0.59	0.71	
Organic Sulphur (% dmif)	0.24	0.30	0.23	0.35	0.70		1.60	2.75	
Oxygen (% dmif)	26.9	25.0	24.7	25.8	27.0		25.2	21.5	
Total Sulphur (% db)	0.28	0.33	0.36	0.38	0.72	2.6	1.74	2.85	
GQSE (MJ/kg)	26.1	26.4	26.0	26.2	25.0	22.5	25.6	27.4	
NSSE (MJ/kg)	7.8	9.1	8.8	7.9	7.0	7.4	8.3	13.1	8.9

NOTES:

db - dry basis

* - Values are db not dmif

dmif - dry mineral and inorganic free basis

GQSE, NSSE - gross dry and net wet specific energies

TABLE 3 - BED MOISTURE AND MOISTURE HOLDING CAPACITY FOR SELECTED VICTORIAN COALS

Coal Field (Selected Values)	Bed Moisture (As Received)		Moisture Holding Capacity % (Equilibrium Moisture)*
	Kg/Kg Dry Coal	Weight Percent	
Yallourn-Maryvale	1.82	64.2	38.4
Horwell-NarraCan	1.54	60.5	38.2
Loy Yang	1.63	61.9	42.1
Flynn	1.76	63.5	41.2
Yallourn North Ext	0.98	49.5	41.2
Coolungoolun	1.19	54.4	35.0
Gomandale	1.27	56.0	39.0
Gelliondale	1.83	64.6	35.3
Stradbroke	1.41	58.4	37.1
Anglesea	0.87	46.6	32.9
Bacchus Marsin	1.53	60.4	31.2

* Determined at 97% humidity and 30°C

TABLE 4 - LOY YANG COAL ANALYSIS - ANALYSIS OF BORE HOLE SAMPLES,
LOY YANG OPEN CUT

	WEIGHTED AVERAGE (all coal seams)	CUMULATIVE FREQUENCY DISTRIBUTION		
		5%	50%	95%
Moisture (% wb)	62.7	59.2	62.7	65.9
Ash (% db)	1.4	0.8	1.2	3.9
Volatile Matter (% db)	51.4	49.1	51.6	54.3
Carbon (% db)	68.4	65.6	68.8	70.7
Hydrogen (% db)	4.9	4.6	4.9	5.2
Nitrogen (% db)	0.5	0.4	0.5	0.6
Sulphur (% db)	0.4	0.2	0.3	0.7
Oxygen (% db)(by difference)	24.3	Not Available		
Specific Energy, MJ/kg Gross Dry	26.6	25.1	26.7	27.8
Net Wet	8.0	6.9	8.0	9.1

wb - wet basis

db - dry basis

TABLE 5 - BROWN COAL RESEARCH PROJECTS

New Products/Processes

Preparation of Carbon Fibres
 Coal Based Molecular Sieves
 Characterization/Applications of Humic Acids
 Fungal Processing of Brown Coal

CSIRO Division of Fossil Fuels
 University of NSW/CSIRO Energy Chemistry
 CSIRO Division of Fossil Fuels
 AMDEL/Flinders University (South Australia)

Char Applications

Brown Coal Char for Zinc Slag Reduction
 Pyrometallurgical Uses of Brown Coal Char

University of Melbourne
 University of Wollongong

Agricultural/Horticultural Uses

Brown Coal as a Soil Conditioner
 Plant Growth Stimulants in Brown Coal

Victoria Department of Agriculture
 Australian National University

Environmental/Occupational Health

Rehabilitation of Brown Coal Areas
 Microbial Oxidation of P.N.A. Hydrocarbons
 Atmospheric Studies of Coal Liquefaction Pilot Plant
 Genotoxicity of Brown Coal Products

University of Melbourne
 University of Melbourne
 Gippsland Institute of Advanced Education
 Latrobe University

Conversion

Liquefaction of VBC - Coal Structure Effects
 Gasification of VBC

Monash University
 CSIRO Division of Energy Chemistry

Physical Processing

Press Dewatering
 Bonding and Briquetting
 Agglomeration/Dewatering
 Pipeline Transportation
 Briquette Performance in Domestic Appliances

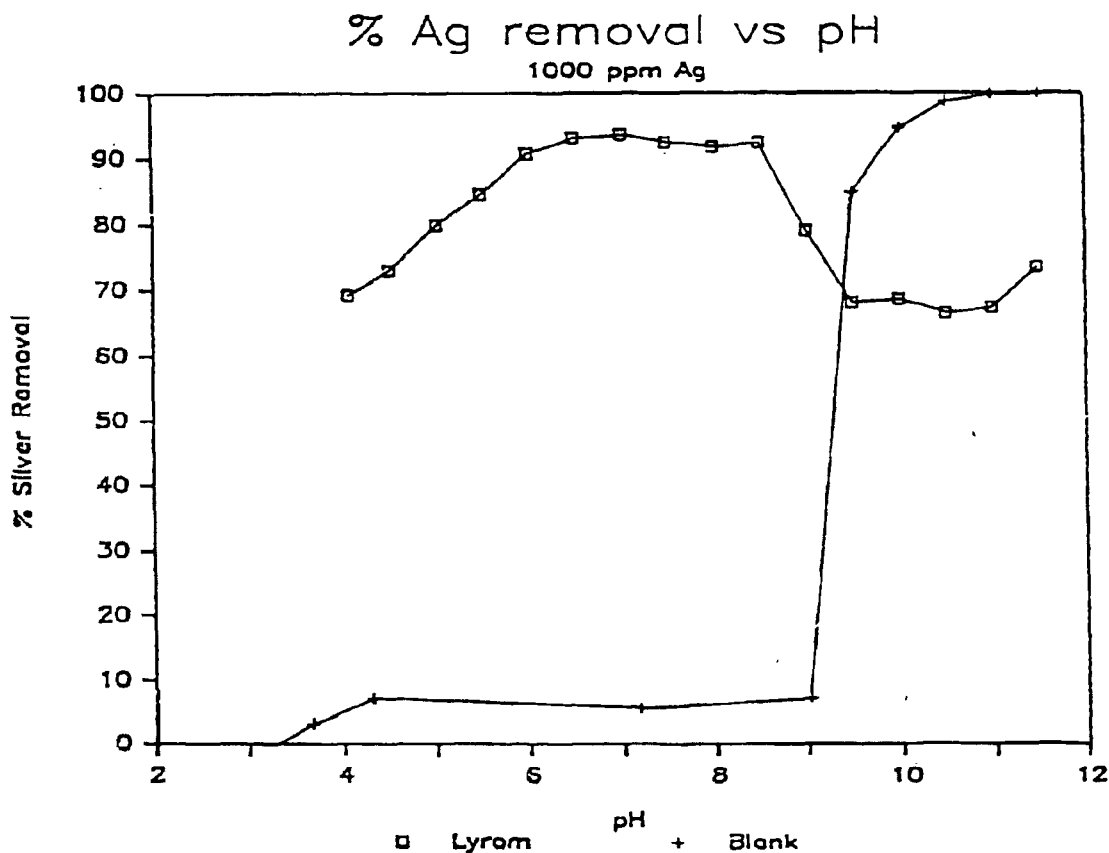
CSIRO Division of Energy Technology
 Gippsland Institute of Advanced Education
 Swinburn Institute of Technology
 University of Melbourne/Swinburne Institute
 University of Tasmania

Analytical Development

Sorption Isotherms of Pretreated Coals
 FTIR Characterization

South Australian Institute of Technology
 BHP Central Research Laboratories

Fig. 1 Effect of pH on removal of silver with brown coal (Lyrom)



ENDESA'S ACHIEVEMENTS ON LOW RANK COAL

UTILIZATION AT TERUEL, SPAIN

Joaquin Calvo & Emilio Menéndez
PhD Mining Engineer & Mining Engineer
ENDESA, Príncipe de Vergara 187, 28002 Madrid, Spain

ENDESA's role in the Spanish energy field is presented. This was last year 50% of the coal market and 32% of the total electricity production in Spain.

Among ENDESA's power plants, C.T. Teruel is located on a low rank coal basin containing high sulphur. Studies on coal preparation and clean combustion have been developed to enable coal mining and power plant work under pollution limits. The decisions taken are presented in this paper: short term: blending with high quality coal or natural gas; medium term: 500 t/h washing plant; long term: pressurized fluidized bed combustion boiler.

ENDESA IN THE SPANISH ENERGY FIELD

ENDESA is an electricity producer company, 95% state owned. It was founded in 1944, and after bidding for coal and entering the coal producer business in 1972 it had an important growth during the 70s, becoming very successful in the early 80s.

At the end of 1983, ENDESA bought stocks of five different companies:

- GESA, Gas and electricity of Baleares Islands
- ENHER, Hydro-power based at N.E. Spain
- UNELCO, Electric company in Canary Islands
- ENECO, Electric company in Cordoba
- ENCASUR, Coal Mining Company

becoming a holding company by controlling all of them but ENECO (50%).

ENDESA's economic good health continued, and on December 85 negotiations for a 4 billion U.S. dollars purchase ended up, which mainly included 40% of Ascó nuclear plant (1860 Mw in operation), 72% of Vandellós II (930 Mw nuclear unit under advanced construction), 62% of E.R.Z. (Zaragoza's Electric Company) and five hydro-electric plants of 221 Mw in total.

At the end of 1986 ENDESA's holding had, in five different basins, eleven mining operations, five of them underground and six opencast mines, and 22% of the electrical installed power in Spain. The distribution in Gw was as follows:

<u>Company</u>	<u>Coal</u>	<u>Fuel & Gas</u>	<u>Hydro</u>	<u>Nuclear</u>	<u>Total</u>
ENDESA	4,245	49	577	744	5,615
ENECO	194	-	-	-	194
ENHER	-	-	1,244	-	1,244
E.R.Z.	-	-	179	-	179
GESA	250	383	-	-	633
HIFRENSA	-	-	-	115	115
TERBESA	-	475	-	-	475
TERMOEBRO	62	-	-	-	62
UNELCO	-	711	1	-	712
	<u>4,751</u>	<u>1,618</u>	<u>2,001</u>	<u>859</u>	<u>9,229</u>

The role of ENDESA's holding in the 1986 Spanish energy field might be shown with the following figures:

Coal production (in thousands of metric tons) :

Puentes (brown lignite).....	12,179
Teruel (low rank sub.bituminous)	1,247
Lignitos,S.A. (low-rank sub.bituminous)..	184
Puertollano (steam coal).....	847
Peñarroya (anthracite & steam coal)	985
1986 ENDESA's coal production.	15,442
1986 Spain's coal production.	38,082
%.....	40.6

Coal purchases (in thousands of metric tons):

National Coal.....	5,965
Low-rank sub.bituminous coal	2,515
Anthracite & steam coal....	3,450
Imported Coal.....	1,772
Lignite briquetes.....	119
Steam coal.....	1,653

These purchases mean 30% of the coal produced in Spain by other companies and 61% of the power plant imports in 1986.

Coal handling (in thousands of metric tons):

	<u>ENDESA's holding</u>	<u>Spain</u>	<u>%</u>
Production...	15,442	38,082	40.6
Purchases...	5,965	-	-
Imports.....	1,772	8,500	-
Total handling	23,179	46,582	49.8

Coal consumption (in thousands of metric tons):

	<u>ENDESA's holding</u>	<u>Spanish Power Plants</u>	<u>%</u>
Anthracite & steam coal	4,988	13,789	36.2
Low-rank sub.bituminous	4,411	5,496	80.3
Brown lignite.....	12,048	16,374	73.6
Imported coal.....	1,662	2,461	67.5

Electrical energy production (in Gwh) :

	<u>ENDESA's holding</u>	<u>Spain</u>	<u>%</u>
Coal power plants	29,050	56,262	51.6
Nuclear plants.....	5,101	37,460	13.6
Hydroelectric.....	3,980	27,300	14.6
Fuel & Gas plants...	<u>3,411</u>	<u>7,538</u>	<u>45.3</u>
Total.....	41,542	128,560	32.3

TERUEL'S BASIN

It is located in the province of Teruel, some 400 km NE of Madrid. Population in this area is low, 11 inhab/km², as well as industrialization. Teruel is poor in both natural and industrial resources, where mining and electricity production are a basic economical activity; 12% of the working population is employed at the mines, representing mining and electricity generation 20.5% of the province's gross added value.

Coal reserves are quite important, amounting over one billion tons as the following chart shows:

	<u>Known recoverable</u>	<u>Total</u>
For underground	236 Mt	877 Mt
For opencast	156 Mt	156 Mt
Total	392 Mt	1,033 Mt

Unfortunately the quality is poor:

	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
Moisture (%)	16	23	20
Ash (%).....	26	43	30
Volatile ma- terials (%).	20	26	24
Sulphur (%)..	4	8	5,4
Gross calorific value(Kcal/kg).	2,500	4,300	3,500

Besides the low rank of this coal, its underground mining is very difficult because of the deposits' geology and the chemical characteristics of the coal.

Coal seams' thickness vary from almost nothing up to 15 meters, but they are not steady, dipping 10° to 35°; coal is very reactive. Roof (black clay) and bottom (clayish marl) are weak; coal seams very often lay under sand full of water. As a result mechanization is limited; room and pillars or "soutirage" helped with heading machines are the most usual coal winning methods.

The water existence over the seam does not specially prevent the selfcombustion of this coal. For safety reasons, when water is found, drainage is necessary by means of boreholes and pumping from the outside or by drainage galleries inside; as permeability is generally low, drainage is expensive. Because of the selfcombustion ability, Teruel's miners became real experts in mine ventilation and fire prevention; the use of foam is common at these mines.

Over this flash it's easy to understand that underground mining at Teruel requires a pretty big list of personnel and a nice load of technique. Very seldom production pays for the expenses, in spite of the price way higher than the average. But social reasons keep this activity, which employs almost 12% of the working population and allows the recovery of an important local resource.

Opencast mining is a different world.

Even 1 foot seams are mined-out, and selectivity according

to sulphur contents is possible. Land reclaiming can improve the previous landscape and agricultural value.

Productivity allows 10 to 1 ratios, compensating underground losses as a whole.

Coal production at Teruel actually amounts to 4.5 million tons per year, of which 50% comes from opencast mines.

But what really makes possible this production are the coal fired power plants, which create the market: ENDESA's C.T. Teruel of 1050 Mw and UTSA's 175 Mw.

Two main problems have to be faced by these power plants: cost of the fuel that represents over 60% of the electricity generation cost, and the fulfillment of the environmental constraints.

Summing up, Teruel is a poor area with one billion tons of low rank coal reserves. Mining and electricity generation have to be continued as they represent 12% of the employment and 20.5% of the province's income.

This is the challenge that ENDESA has faced at Teruel.

FUEL BLENDING AND ENVIRONMENTAL CONTROL

To start with, the environmental control target was covered by a network of stationary control stations located inside a 20 Km. circle around the power plant. These stations monitor continuously the inmission levels of sulphur and nitrogen oxides and are connected by radio with the plant.

The emissions are reduced by means of a coal blending plant, fed with local coal and high quality imported coal, which supplies the boilers with a constant quality coal avoiding peak sulphur emissions. Besides this, Teruel power plant is connected to the natural gas pipeline.

An action plan is implemented in order to avoid high inmission levels based on the environmental control network, by switching to clean fuel (natural gas) or even reducing load.

COAL PREPARATION STUDIES AND TESTS

Teruel's low rank coal basin was known centuries ago. After WWII there was demand for domestic coal and people tried to increase sales by coming into the coal preparation business. Attempts were made with no success because

of the difficult characteristics of this coal: very unfavorable densimetric curve, high clay soluble content and uniform electro-chemical potential.

In 1983 ENDESA came back looking for a medium term solution for the high sulphur content of the local coal. First studies revealed that 50% of the contained sulphur was organic; as a consequence coal preparation research was headed towards the piritic sulphur decrease.

Because of the high clay and moisture content of the coal we first tried to avoid the use of water, testing as much as possible pneumatic procedures. Laboratory tests carried out deserve the following comments :

- . Shaking tables gave encouraging results
- . Electrostatic separation and froth flotation were unefficient
- . Spirals gave the best results in the fines treatment, among all the systems tested.

After this slightly promising results, ENDESA decided the construction of a Pilot Plant with a capacity of 5 tph , commissioned in May 85. Pneumatic tables, shaking tables, simple and double spirals and jigs for big and small sizes were installed and tested, with the help of several sampling devices and a proper laboratory. A data processing application was developed.

Pilot Plant equipment's imperfection was determined:

- . Pneumatic tables with sizes over 3 millimeters had an imperfection of around.27
- . Shaking tables and spirals had an imperfection of approximately.19 with sizes under 3 millimeters
- . Jigs imperfection were.11 for coarse material and.16 for sizes between 3 and 6 millimeters.

In the meantime several tests were performed on coal samples from the different steps of the process :

- . Coal characterization tests, by means of granulometric and densimetric curves for each granulometric range. Over 1.9 gr/cc ranges had 50% of the sulphur, 35% of the weight and 20% of the calorific value in a total coal balance.
- . Crushing tests for midlings with a density between 1.5 and 1.9 gr/cc. Before crushing midlings amounted 48%; crushed under 6 millimeters it was 42%; down to 3 mm 40%. It was decided to avoid midlings crushing inasmuch as these results did not pay for the crushing expenses.
- . Solubility tests. Raw coal was maintained in water stirring up for two minutes; fines content

was measured before and afterwards: the amount was twice as much after this operation. Characterization tests were repeated after the solubility ones.

This degradation process was really a washing process, as a result of clay solubility. The size of this clay is 95% under 30 microns, amounting around 10% of the total weight. Sulphur content is 7% and gross calorific value 1800 Kcal/kg (dry basis) and it was supposed to be rejected in the process, meaning the main energy loss.

- . Dewatering tests on clean coal, by means of centrifuges, band-filters, and press-filters. This last equipment gave around 25% total moisture with sizes under .1 millimeters and the others around 20% over .1 millimeters.
- . Dewatering tests on clay under 30 microns with band-filters, band-pressure filters and press-filters. The results with first and second equipment were around 50% moisture with a flocculent consumption of 400 g per dry ton; press-filter gave 35% moisture with no flocculent.

Based on Pilot Plant results a feasibility study was developed, with the assistance of Moutan Consulting, including washing process and layout definition, investment cost, operation cost and energy loss estimates. The report was completed early 1986 and final estimates were as follows:

Weight recovery.....	65.5%
Energy loss.....	17%
Total sulphur decrease.	46%
Final moisture.....	20 to 22%

Total cost, energy loss included, was estimated in about \$8 per ton. It was considered that this additional cost could be recovered with a better sale price according to a higher quality coal.

New studies on the rejects are under development. The piritic one with 20% sulphur content might be used for sulphur production; the rest could feed an atmospheric fluidized bed combustion boiler.

CLEAN USE OF COAL

Besides coal preparation a clean use of coal technology is required; it has to be found either for new electricity

generation plants or to refit the present ones at Teruel. To select the most convenient process for this case the following aspects must be considered:

- . Fuel cost in Spain represents about 60% of total electricity generation cost, while investment cost is around 30%. Accordingly generating efficiency is the main factor when evaluating alternative options.
- . Any future power plant must operate with low nitrogen and sulphur oxides emission levels. Nevertheless these levels should be consistent with local circumstances: coal quality, industrialization, population, topography, geography, etc.
- . Selected clean use of coal technology should be available for commercial size units -350 Mw in Spain- by 1995, according to lifetime of present units and demand growth estimates at Spain.

In order to solve Teruel's low rank coal clean use, the following technologies might be considered:

- . Conventional coal combustion with flue gas cleaning.
- . Gasification with combined cycle power generation.
- . Atmospheric fluidized bed combustion, both bubbling and circulating alternatives.
- . Pressurized fluidized bed combustion.

Flue gas cleaning, with desulphurization and denitrification, is at present an available technology. In the Spanish context it is not the most convenient one inasmuch as its generating efficiency is lower than in conventional boilers without gas cleaning.

Gasification with combined cycle, as it is at present was discarded by ENDESA because of high investment cost and low efficiency level. In addition high-ash coals could create problems because of ash melting in the gasification process.

We feel that these technologies will be of interest in Spain after solving some present problems, such as hot cleaning of gas or gas turbine with high combustion temperature (over 1,300° C). We do not expect answers, at a commercial level, before the year 2,000.

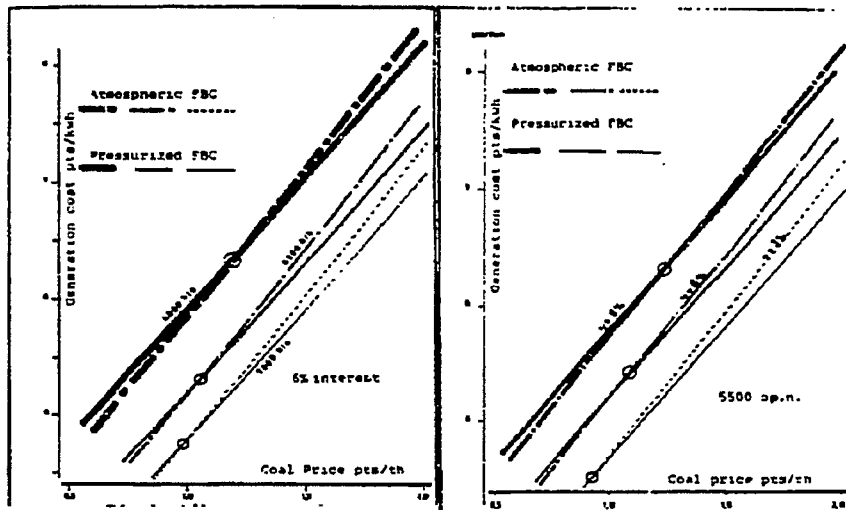
Fluidized bed combustion is considered by ENDESA as the proper technology for the 90s, not only for Teruel's low rank coal but for other Spanish coals. Evaluations on different types of FBC were made: bubbling and circulating atmospheric boilers, as well as pressurized systems, including a combined cycle with gas turbine for expansion of combustion gases.

ENDESA's choice has been the supercharged PFBC, as the most convenient technology to be developed in the next decade, for the following reasons:

- . It is the option with highest generating efficiency and it will probably keep this first place for the next ten years.
- . This technology offers 90% sulphur retention and less than 200 ppm NO_x emissions.
- . High-ash coals might be used, as it was checked up at ASEA PFBC pilot plant during a test period in which 600 t of Teruel's coal were burned.

Nevertheless PFBC technology still have some problems to be solved with bigger demonstration plants experience: high coal and absorbent feeding system reliability; pressure vessel design with good internals maintenance; and gas turbine resistant to the potential erosion of combustion gases carrying small particles. On the other hand escalation to commercial size units has good prospects.

Estimates of total electricity generation cost were made for both AFBC and PFBC 350 Mw units. Results according to coal price in pts/th (at present rate 1 pts/th equivalent to \$ 4,3 per 1,000 B.T.U.) are shown in the following graphs for different yearly working time and interest rates.



In all cases the break even point corresponds with a fuel cost below present Spanish coal price, even Teruel's low rank coal, meaning PFBC will allow better generating cost for higher fuel price and same availability.

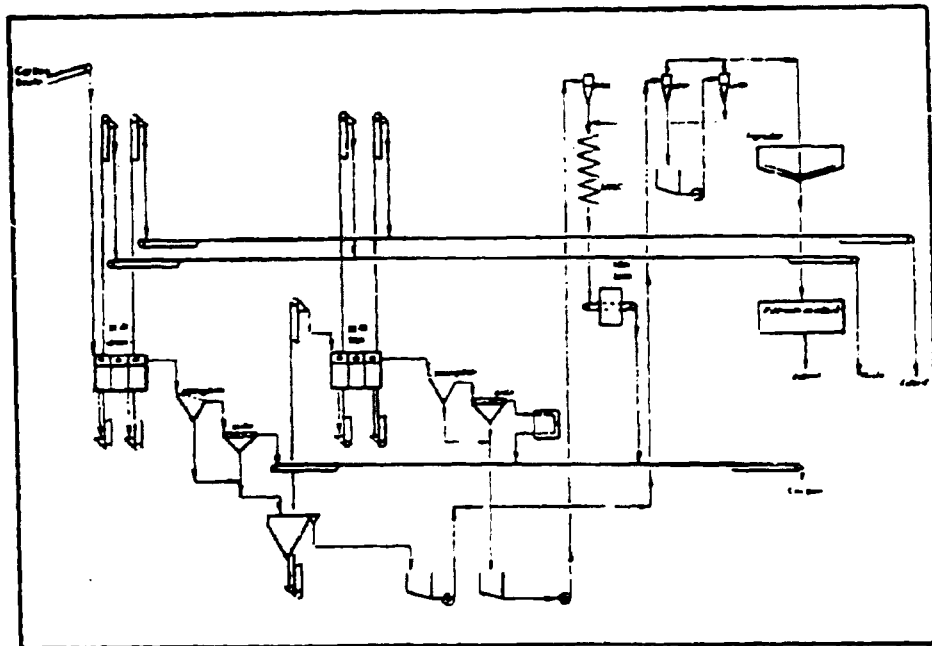
Negotiations ended into an agreement with ASEA PFBC, Malmö , Sweden, for joint development of this technology for high ash coals on a demonstration plant to be built at Escatron, Spain. Main objectives for this plant are: generating efficiency and availability.

COAL PREPARATION PROJECT

In accordance with Pilot Plant results and once the feasibility study was completed, ENDESA decided the construction of an industrial washing plant, 2.5 millions tpy capacity. This project was considered as a medium term solution to improve Teruel's low rank coal quality, as well as a bridge between the present situation and PFBC development programme accomplishment.

Based on the feasibility study process a turn-key contract with IMENOSA-POLYSIUS was signed in July 86. Total plant imperfection, final moisture of coal, delivery capacity and availability of the plant are strongly guaranteed. We expect to have this plant in operation before the end of 87.

Flow sheet is schematically represented in the following sketch:



Coarse coal at a rate of 500 tons per hour, in size 0-60 millimeters, comes into the first 3x5 m² jig-Bawn type, double pulsation-, being split in three:

- 1.- Heaviest part might be called piritic waste. Sulphur production from this material is under study.
- 2.- Second in weight is waste-high ash midlings, with some calorific value and sulphur content similar to clean coal-; its use in a 40 Mw AFBC is being considered.
- 3.- Lighter material, after dewatering and screening at 6 mm splits in two:
 - 3.1.- Over 6mm is already clean coal
 - 3.2.- Under 6mm is classified in two sizes:
 - 3.2.1.- Range 0.3 to 6mm goes to the second jig, being split in three
 - 3.2.1.1.- Heaviest part is piritic waste as 1
 - 3.2.1.2.- Second in weight is waste as 2
 - 3.2.1.3.- Lighter part, after dewatering and screening at 1mm splits again in two:
 - 3.2.1.3.1.- Range 1 to 6mm is centrifugated and goes-out as clean coal
 - 3.2.1.3.2.- Range 0.3 to 1mm goes to first set of cyclons with cut-off 0.15mm to take care of the misplaced and degraded materials.
 - 3.2.2.- Under 0.3mm goes to second set of cyclons with cut-off 0.03mm.

Up to here we have mentioned three types of products with sizes over 1 mm: piritic waste, waste and clean coal. We still have to manage with sizes under 1mm, which contain 20% of Teruel's coarse coal calorific value and are high in water-soluble clay. Let's see this section of the flow-sheet.

First set of cyclons produce underflow over 0.15mm going to spirals and overflow, under 0.15mm, that goes together with material 3.2.2. to second set of cyclons (two stages): underflow over 30 microns goes to spirals; overflow under 30 microns comes into a high-capacity thickener feeding a press-filters battery set. The reason for this last operation is to make sure we can handle the fines, hoping to use them at the AFBC plant under study.

Ranges 0.03 to 0.3mm and 0.15 to 1mm are classified in

three batteries of spirals to give clean coal, which is dewatered in belt filters, waste and midlings which go through a second stage of spirals.

The expected total balance in % is as follows:

From :	Weight (air dried basis)	Surface moisture	Sulphur	Energy
Coarse coal	100	20%	100	100
to :				
clean coal	65.5	20-22%	54	83
Piritic waste	7.5	28%	23	4
waste	17.0	28%	14.5	7
finest waste	10.0	36%	8.5	6

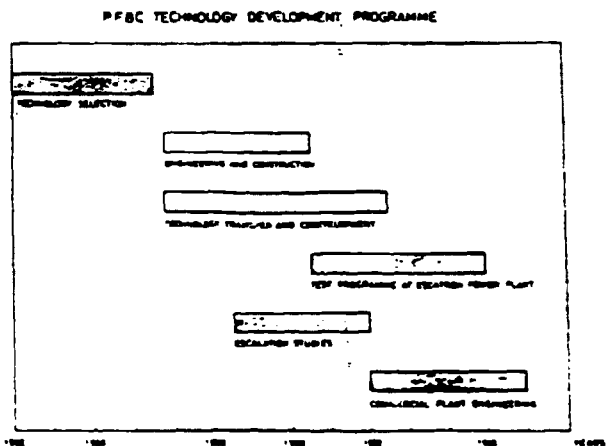
PRESSURIZED FLUIDIZED BED COMBUSTION PROGRAMME

In 1983, by the time ENDESA started coal preparation studies, a clean combustion development programme was established. The target was to have a 350 Mw commercial boiler design by 1995. As it has been already mentioned, supercharged PFBC technology was selected.

Next step will be to design and build an 80 Mw demonstration plant at Escatron, refitting the present power plant and adding a new PFBC boiler. Technology transfer is provided in last year contract with ASEA-PFBC.

Escalation studies are scheduled to start in 1988, once the 80 Mw design is advanced, and these will be perfected later by the results of the demonstration plant, which is scheduled to start up in the middle of 1990.

In 1992 a four year period for engineering and design of the commercial 350 Mw PFBC is programmed. This work should be completed by the time of refitting Teruel power plant units.



Escatron project

Escatron is located about 80 Km east of Zaragoza, by the Ebro river, in an area rich in both limestone and dolomite, not far from Teruel's low rank coal mines. There is an old power plant in this town with only unit No 4 in operation.

The boiler is a 1957 Combustion Engineering model, close to its end; latest inspections of the 62.5 Mw Westinghouse steam turbine -which had some overhauled- indicate 15 more years of possible operation.

Escatron project consists of a new 80 Mw PFBC boiler-together with its gas turbine, as well as coal, absorbent and ash systems-to be matched with the existing steam turbine. The GT35P gas turbine will increase 27% the present plant rating.

Coal analysis for PFBC design is this:

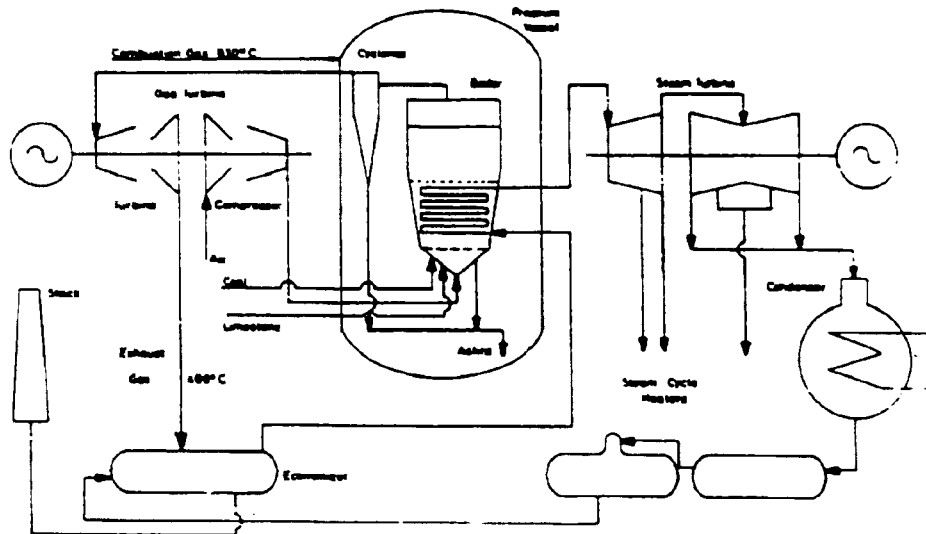
Gross calorific value.....	2898 Kcal/kg
Moisture.....	18.6%
Ash.....	36.1%
Volatile materials.....	22.6%
Fixed carbon.....	22.7%
Carbon.....	28.51%
Hydrogen.....	2.13%
Sulphur.....	6.80%
Nitrogen.....	0.27%
Oxygen.....	7.86%

Design data for PFBC plant are the following:

Coal heat input	218.4	MWt
Coal feed rate	63.4	t/h
Limestone feed rate	25.66	t/h
Stack temperature	183	°C
Steam turbine power(gross)	62.5	MWe
Total power (gross)	79.5	MWe
Gross efficiency(HHV)	36.4	MWe
Net power	76.4	MWe
Net efficiency	34.7	%
Net heat rate	9830	Btu/KWh
Gas turbine entry temperatur.	830	°C
Steam temperature	513	°C
Steam pressure	94	Bar
Steam generation	216.4	t/h
NOx emissions	<150	mg/MJ
Sulphur retention	> 90	%
Ca/ Molar ratio for 90% retention	1,8	
Vessel pressure	11,5	Bar

The flow diagram of the demonstration plant is sketched as follows:

Supercharged PFBC Diagram

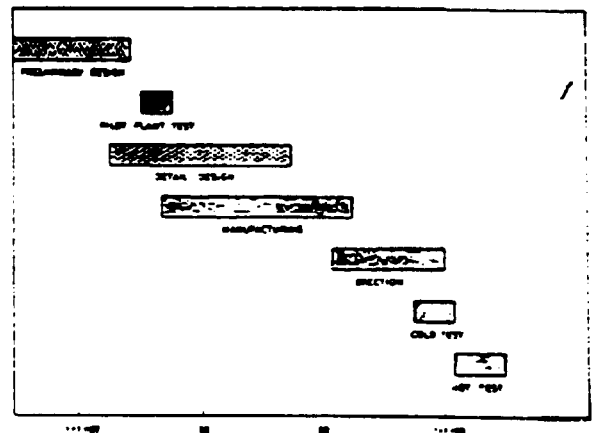


Main feature will be the 13 meter diameter, 20 meter high, cylindrical pressure vessel containing the fluidized bed boiler, gas cleaning cyclons, bed storage vessel and ash cooling systems. Coal and limestone will be blended and injected into the PFBC through a lock-hopper by pneumatic transport. Nine feeding lines will be used for the 30 m² top bed area. Gas turbine pre-cleaning will be by 7 parallel paths, each one with two cyclone stages in series.

A bed temperature of 860°C will be used. Load changes will be produced by altering bed level at essentially constant bed temperature; minimum load will be at 30%.

Up to date this project is on schedule.

ESCATRION PROJECT SCHEDULE



Will Lignite be Used
in the Industrial
Sector of Texas?

Terrence J. Jackson
Sales Manager
The North American Coal Corporation

When I was first asked to speak to you about the industrial market potential for lignite usage in Texas, my initial reaction was less than enthusiastic. People normally want to know specifics like who's going to do it and when? Where and why will they do it, and how much of it will they use? And then how much will it cost me or how much can I get for it?

There have been too many false starts, high expectations and dashed hopes in the Texas lignite business for a sales guy like me to stand in front of a group of knowledgeable people like yourselves in an energy rich producing state like Texas; in the middle of the softest combined market for oil, gas and coal that anyone I know has ever experienced; and expect you to believe me if I were to attempt to forecast the next great lignite bonanza! In the local parlance, I would come off as "all hat and no cattle!"

Today I am going to ask you to reason and speculate with me. What I hope to establish is that lignite is presently a viable industrial fuel in the second largest lignite producing state, North Dakota, but by contrast, it has not been utilized to any great degree in Texas, the largest lignite producing state. The barriers to greater industrial lignite utilization in Texas are primarily economic and to a lesser degree structural rather than technical. And, finally, based upon the dynamic competitive forces constantly at work in the marketplace, I will speculate that certain types of industrial consumers have higher potential to eventually utilize lignite than others, with the corollary that economic benefit to the producers and consumers of lignite will erase the structural barriers to its utilization.

Do you realize that in 1985 Texas and North Dakota produced 99.3% of the lignite tonnage in the United States. The country produced 878.5mm tons of coal of all types and rank. 72.4mm tons or 8.2% of total production was lignite. Texas produced 62.2% while North Dakota produced 37.1% of the lignite

in the reference year 1985. Now I know that this is 1987, but since the Energy Information Administration had not yet published its 1986 figures when I wrote this speech in March, we will all just have to live with the 1985 figures as our point of comparative reference.

The North Dakota Lignite Council provided me with some interesting information for 1986. Lignite production dropped to 25.5mm tons in 1986 from an all time high of 26.6mm tons in 1985. In 1986 2.1mm tons or 8% of total production was shipped out of state. 85% was used at the mine-mouth.

76% was used for electrical generation, 22% for coal gasification and the remaining 2% was used for charcoal briquetting, heating needs, agricultural processing and as an additive in oil well drilling mud.

But by contrast, in excess of 99% of the lignite produced in Texas was consumed to generate electricity. As I understand it, the balance was used to make activated charcoal in East Texas and a small amount was gasified by the Butler Brick Company in Elgin.

In the case of the brick company, they never really set out to mine the lignite. It just happened to reside on top of the clay that they were mining to make bricks. They probably figured "what the heck. We might as well use it since its already mined and that's cheaper than storing it or disposing of it!"

We see two lignite producing states and can easily observe that both use the majority of their lignite to generate power. But North Dakota uses 24% of its production for purposes other than the generation of electricity as compared to less than 1% in Texas.

The key differences are these. Given the economic fuel choices of the industrial sectors of the two states, Texas industry has had economically attractive alternatives to using lignite in industrial boilers. In Texas the lignite producing sector is not nearly as flexible as in North Dakota. That is, production is, by and large, captive; the coal reserves are dedicated to a specific utility consumer; and the distribution network from operations is a closed loop to a consuming power plant. Half the mines are captive in North Dakota as well, but lignite is commercially available to the industrial consuming sector with delivery by truck and railcar from both captive and non-captive mines.

In short, the necessary ingredients for utilizing lignite in the industrial sector are:

1. A producing sector free to sell the lignite;
2. A workable distribution network to deliver the lignite;
3. The technology to utilize the lignite; and
4. The competitive economic fit so that there is benefit to both the producer and the consumer of the lignite.

I think most of you would agree that if you wanted to buy a train load of lignite in Texas today, it would be difficult to arrange the purchase at an affordable price if at all. If you wanted 100 tons per day for 6 months, it would be equally difficult. You can jury-rig a system to load trucks or trains and the roads and railroads can take the material to market, but the lignite mining sector in Texas, was not established to service large scale non-captive commercial markets.

If the captive producer were free to sell lignite and geared to load trucks or trains, the combustion and conversion technology is just not in place today to use the lignite in Texas as it is in North Dakota, if it were delivered free of charge. The technology exists, it just is not in place. If the six largest energy consuming sectors in Texas as classified by SIC code were to instantaneously convert to lignite the equivalent usage would be in excess of 100 million annual tons of 6000 BTU lignite. That's a lot of lignite, but again we've stepped out of the real world and into fantasy land. Try convincing an existing gas or oil fired boiler that lignite is just another hydrocarbon energy form. It just isn't an interchangeable hydrocarbon energy form. There are numerous equipment manufacturers out there who would love to sell you the technology, off the shelf, to use lignite. But why would the rational manager consider recommending the expenditure of capital today to convert an existing facility or to construct a new combustion system when the one that he has in place works well and its fuel is both available and inexpensive? The time may come when that recommendation is lauded, but tonight's not the night, folks!

So Where's the Potential

Texans traditionally have been very practical thinkers. Like Mid-westerners they normally assume that "if it works, don't fix it." To date, for energy consumers, the market has worked. Sure, in the early '80's, people were incredibly nervous about the price and availability of natural gas. At that time it was naturally assumed that the price of natural gas would increase to \$6-\$8/mcf by 1985. Forget oil, it would go even higher. Right? Wrong! It didn't happen. But, what did happen.?

After the first energy crisis, in 1973, companies other than Texas Utilities started to acquire the mineral rights to lignite. Texas Utilities is to be complimented for the leadership role which they assumed in both mining and utilizing

lignite. They produce and consume more lignite than the entire state of North Dakota. Texas Utilities is the fourth largest coal mining company in the country, but they are a captive, non-commercial mining company. They mine for Alcoa, a self-generator of power. But regulatory considerations preclude the sale of production from their large captive utility mines to the industrial sector.

Had the price of gas continued to rise to the \$6-\$8 mcf area in 1985, you would have seen lignite based synthetic energy projects in Texas sponsored by Dow, Exxon and Phillips on captive reserves. The projects didn't materialize but those companies and many others, including my employer North American Coal, have retained the rights to mine Texas lignite. The existence of 17.4 billion tons of reserves in East Texas in the Wilcox, Sabine Uplift and Jackson Yegua trends combined with the presence of mining companies with the rights to mine the lignite points to first type of customer with the potential to utilize lignite in the industrial sector: the larger industrial consumer who can site a new production facility in close proximity to the lignite.

The Competitive Balance

If there are any Western coal producers in the audience, I don't wish to oversimplify the competitive nature of the solid fuel market. But the larger the market, the more competitive the Western rail carriers seem to be with their rail rates.

Before the bottom fell out of the price of gas and oil, utilities were continually trying to decide between Powder River Basin coal and lignite for conventional pulverized coal units with scrubbers. But for the first time, a Texas utility is before the PUC justifying the choice of lignite over Western coal despite a higher first cost for the lignite. The rationale is simple, really. Rail rates escalate, and there is a larger exposure to inflation based on diesel fuel as a component of delivered price; the same is true for the industrial consumer.

Overcapacity is a reality in the Powder River Basin, but it won't last forever. Without adding capacity, supply and demand in the region is forecast to come into balance by the mid to late '90's. And at some point, even with two originating carriers, the railroads will not move another ton of coal for the same revenue dollar. They will need more locomotives, rail cars, track and maintenance shops to continue to expand without limit in the region.

In the near term, its a moot point since no one seems to be building and siting anyway. But the beauty of the market today is that with the emergence of fluidized bed combustion technology the consumer has the flexibility to use either Western coal, lignite or both. Oil and gas, too, for that matter. But if the industrial consumer has a fluidized bed unit, and is located within a reasonable distance of lignite it would be foolish not to at least consider it as an option and to continually re-evaluate it for no other purpose than to keep his fuel supplier and rail carrier honest. That's the beauty of competition. Lignite doesn't have to bat 1.000 against Western coal; .300 gets you into the Hall of Fame.

The fluidized bed unit comes in a range of sizes and is a relatively benign combustion technique from an environmental standpoint. The small energy consumer can purchase a small unit, fire it with gas, any type of coal, and, yes, lignite if it becomes available economically. If, for example, Texas New Mexico Power Company's units are built at Calvert, we will see the first example in Texas of a mine in production without a total reserve dedication to a single customer. The very existence of fluidized bed technology allows other mining companies to consider developing smaller mines, say in the 100,000 to 500,000 annual ton range, in lower ratio and of lesser quality than they would for the large central generating stations of the utility market. If you are interested, see me after this session!

The Frontier

There is significant research activity in the field of utilization technology that has been discussed at this conference which again points us to the conclusion that in the future there will be numerous options available to fully tap the potential of lignite in the industrial sector. I don't wish to slight anyone in the field, but I am going to single out one process as an example of a different approach to solving the industrial generation problem in this region with broad application and high potential to spur lignite utilization by the industrial sector once it is proven and economical.

You may or may not know that Dow Chemical Company has installed a low-rank coal gasifier at its Plaquemine, Louisiana complex. Dow consumes huge quantities of natural gas, both as a boiler fuel and as a product feed. The long term exposure to rising prices for natural gas and their two pronged exposure to its effects has led them to develop a process to convert low rank coal to gas which can be used in existing gas turbines. A secondary objective of Dow is to market a commercial technology which allows the utility or industrial company with gas turbines in place to use the existing unit with slight modifications and to run it with synthetic gas derived from coal. They have initiated their efforts with Synthetic Fuels Corporation support and they are gasifying Western coal today; but, the system was designed to utilize lignite. In the ten years of scheduled operation, it is Dow's goal to prove the technology on all low rank coals especially lignite.

I like their approach for two reasons: 1) it has broad application in this region with serious implications to the lignite industry; and 2) it reduces the resistance to change in the powerhouse.

There is no question that anyone who runs a powerhouse prefers a liquid or gaseous fuel to a solid fuel. Lignite has been referred to a "high grade dirt", but there is plenty of it in Texas. And the economic benefits of using it have great potential to insure a safe energy future for Texas.

Economic Impact

The North Dakota State University Department of Agricultural Economics added that:

1. For every dollar spent by the North Dakota lignite industry, another \$1.99, or a total of \$2.99, is generated into the economy.
2. In state expenditures by the North Dakota lignite industry totaled more than \$400 million in 1985.
3. The \$400 million of direct lignite industry expenditures produced, through recirculation of dollars in the North Dakota economy, a total gross business volume of \$1.2 billion for 1985. This includes personal income of \$424 million and retail sales of \$286 million.
4. For every permanent job in the lignite industry, another five jobs are required to provide goods and services. For every \$1 million in expenditures by the lignite industry, approximately 10 direct and 50 secondary employment opportunities are provided for North Dakotans.*

Conclusion

The effects are different from state to state, but most of you will agree that greater lignite utilization and development has a role to play in the future of Texas. As producers of products each of you knows, as I do, that runaway inflation in the primary energy markets is disastrous to American business. Each of us is a primary consumer of electricity in our homes, of gasoline to run our cars. Some of us heat our homes and cook our food with natural gas, and, hopefully, we use products manufactured right here in the U.S.A.

Our high standard of living as a country is directly dependent upon efficiency, productivity and competition especially in the primary energy markets. We live in a global economy and when we can't compete we will lose our markets and, close our facilities. For some of us, we might face the prospect of unemployment and a reduced life style for the first time in our professional careers.

Well, enough hyperbole! None of us, either energy producers nor consumers, is going to concede our futures to off-shore competitors. I will concede that the energy markets are soft for now, but I won't concede that they will always stay that way.

I will concede a portion of the Texas energy future to Western coal, synthetic fuels and even natural gas and oil. But, I won't concede it all. Nor will I or any other representative of the lignite industry in Texas withdraw from the competition in the market. Competition is the basis of our success as a nation. So to come full circle in my speculation, the answer to the question "will lignite be utilized in the industrial sector of Texas?" is really very simple: of course it will, when it is competitive.

Thank you.

*(footnote: Lignite Facts 1985-1986, published by The
North Dakota Lignite Council. Suite 410, Norwest Bank
Bldg. P. O. Box 2277 Bismarck, N.D. 58502)

KELLOGG'S KRW IGCC
POWER GENERATION
PROCESS

By
M. J. Van Sickels

The M. W. Kellogg Company
3 Greenway Plaza
Houston, Texas 77046

Presented To

FOURTEENTH BIENNIAL LIGNITE SYMPOSIUM
ON THE TECHNOLOGY AND UTILIZATION
OF LOW RANK COALS

20 May 1987

Dallas, Texas

ABSTRACT

KELLOGG'S KRW IGCC POWER GENERATION PROCESS

BY M. J. VAN SICKELS

The M. W. Kellogg Company has been developing its KRW pressurized, fluid bed coal gasification/hot gas cleanup technology which, when combined with a combined cycle system, results in an advanced integrated gasification combined cycle (IGCC) power plant. This plant will have superior heat rates, lower costs, and minimal environmental impact.

The process has been developed in the KRW pilot plant and has been successfully tested on all types of U.S. coals and lignites. The test work at the KRW pilot plant is a cost shared effort between Kellogg and the U.S. Department of Energy.

The first commercial scale demonstration of Kellogg's KRW IGCC process will be in the Kellogg sponsored Appalachian Project. This nominal 60 MW power production facility has been selected by the U.S. DOE to receive financial assistance under its Clean Coal Technology Program. It will be located near the Quemahoning Reservoir in western Pennsylvania. Initial operation is scheduled to begin in 1990.

I. Introduction

The M. W. Kellogg Company has been developing its KRW pressurized fluid bed coal gasification/hot gas cleanup technology. When integrated with a combined cycle system, this gasification/hot gas cleanup technology results in an advanced integrated gasification combined cycle (IGCC) power generation process which has a superior heat rate, lower costs and minimal environmental impact compared to competing coal based technologies. These characteristics provide the incentive for Kellogg to commercialize the technology.

The development of the technology, which employs a single-stage pressurized, fluidized-bed reactor, was begun by the Westinghouse Electric Corporation during the early 1970's. Successful early work led to the construction of a 24-TPD process development unit (PDU) at Waltz Mill, Pennsylvania. The PDU has been operational and in use for testing since 1975. Also located at Waltz Mill is a commercial scale cold-flow model of the gasifier reactor for use in scaleup design and in operator training. The initial development of the technology was jointly sponsored by Westinghouse, the U.S. Department of Energy (DOE), and Gas Research Institute.

Early in 1984, Kellogg acquired from Westinghouse an 80% equity in both the technology and its synfuels operating division at Waltz Mill. This group, known as KRW Energy Systems Inc. (KRW), is now a part of Kellogg.

By the early 1980's the major process configurations relating to the basic gasification system had been well established and proven. As a result, this permitted development efforts to be directed towards continued improvement in processing efficiency, reduction in overall product cost, and simplification of the overall system.

In late 1984, a hot gas cleanup study and test program was initiated with the specific goal of providing the electric utility industry with an advanced technology for IGCC electric power generation.

The specific objectives of Kellogg's Waltz Mill pilot plant program are (1) to demonstrate operability of two complimentary hot gas sulfur removal systems,

gasifier "in-bed" desulfurization and "external bed" desulfurization; (2) to demonstrate hot particulate collection/removal technology; and (3) to characterize levels of particulate, ammonia, alkali and sulfur emissions in the product gas. This program is a cost-shared effort between Kellogg and DOE.

An initial in-bed desulfurization test was completed in late 1984 and this mode of testing continued through 1985. The external desulfurization tests were started in 1986 and are continuing through this year. The in-bed desulfurization testing has evaluated calcium based sulfur sorbents and the external bed desulfurization utilizes a zinc ferrite sorbent. In-bed tests have been combined with the external bed step to evaluate a combined or "integrated" desulfurization operation. All major development work is targeted for completion by the end of this calendar year.

The purpose of this paper is to describe the technology, to show that Kellogg's KRW IGCC process offers economic incentive to utilities for power generation, and to discuss Kellogg's commercialization efforts via the Appalachian Project.

II. Kellogg's KRW Gasification Process

The KRW pilot plant, in more than 11,000 hours of hot operation, has demonstrated the KRW process to be a technically feasible and economically attractive method to meet energy needs with minimal environmental impact.

Further, the pilot plant has successfully tested all types of U.S. coals and lignites, as shown in Figure 1, as well as a number of foreign coals. The range of the feedstocks tested is shown in Figure 2.

Kellogg's KRW coal gasification process is designed for efficient operation. It converts a high percentage of the carbon in coal to gas, requires relatively little water or steam to moderate the reactions, and consumes less oxygen than gasifiers operating at higher temperatures. In addition, an advanced design char-ash separator, integrated into the bottom of the gasifier vessel, contributes to high carbon efficiency by reducing the carbon content in the by-product ash.

The KRW gasification process is simple and is designed to provide for reliable operation. The gasifier can be operated in either an air or oxygen-blown mode to produce low BTU or medium BTU product gas. Also, the gasifier can be operated with oxygen enriched air to provide for intermediate BTU heating value product gas. A large carbon inventory in the bed provides operating flexibility, yet allows adequate response to load demand changes. A refractory lined gasifier vessel with no internal moving parts simplifies system operation while providing significant reliability benefits. Moderate operating temperatures and gas velocities extend refractory life and minimize material selection concerns, thus improving system availability.

The KRW fluidized-bed gasifier operates at temperatures ranging from 1550 to 1900^oF. Figure 3 depicts a schematic of the gasifier vessel showing the various functional zones and Figure 4 is a process flow schematic for a gasifier train using conventional cold gas cleanup.

As the carbon in the char particles react, the ash concentration in these particles increases. This coal ash undergoes partial melting and sintering in the hotter combustion jet because of the lower melting eutectics present in the ash. These lower melting eutectics act as "glue" to allow particles which are high in ash content to adhere to each other and agglomerate into larger particles. These low carbon containing ash agglomerates are separated from the gasifier bed char in a fluidized-bed separator located in the bottom section of the gasifier. In the char/ash separator zone, the agglomerates are defluidized from the bed and collected at the base of the gasifier vessel. The agglomerates are cooled by recycle gas introduced at the bottom of the separation zone and removed from the gasifier by means of rotary feeder and depressurizing lockhoppers.

A freeboard zone, located at the top of the gasifier vessel, is used to separate entrained solids from the product gas. The product gas, containing some small char particles (fines) exits at the top of the gasifier. The fines that are elutriated from the gasifier are recovered with an external cyclone and recycled directly back to the gasifier by means of a dipleg. The lower end of the dipleg feeds these fines directly into the gasifier bed for further reaction and consumption.

The product gas exiting the cyclone can be processed in a variety of ways depending on the end use application for the gas. Some of these applications are shown in Figure 5.

When compared to other technologies such as fixed bed or entrained gasifier systems, the following advantages of Kellogg's KRW process become apparent:

- o Processes all ranks of coal:
 - No pretreatment of caking coals
 - Superior for highly reactive coals
- o Moderate temperature operation:
 - Maximum yield of methane
 - Reduced oxygen consumption
 - Modest steam consumption
 - Conventional materials and components
 - No ash clinker formation
 - Long refractory life
 - No tar and oil formation
 - No restrictions in processing coals with high ash fusion temperatures
- o Air or oxygen blown operation, depending on product requirements
- o No carbonaceous liquids are produced
 - Effluent water is easily cleaned by conventional methods
- o Ash is discharged in disposable form:
 - Agglomerates do not require dust control measures
 - Agglomerates are inert to leaching, so groundwater pollution is avoided
- o Safety:
 - Large inventory of carbon inside gasifier avoids oxygen breakthrough
 - Gasifier has a large time constant which allows reasonable time for response to upsets without danger of major damage or failure
 - Operation is interruptable
 - Loss of flow of any major reactant will not result in immediate damage
 - Gasifier operation is easily resumed after a short-term outage

III. Hot Gas Cleanup

As noted earlier, a hot gas cleanup study and test program was initiated in 1984 at Waltz Mill focusing on developing both in-bed and external bed desulfurization systems, demonstration of hot particulate collection technology, and characterization of levels of particulates, ammonia, and alkali.

- In-Bed Desulfurization

The in-bed desulfurization modifications to the KRW fluid-bed gasification process results in a sulfur sorbent (dolomite or limestone) being loaded in a lockhopper, pressurized, and injected into the gasifier either by pneumatic transport or by gravity feed. The sorbent mixes with the coal char in the gasifier fluidized-bed and hydrogen sulfide gas produced during the coal gasification process and reacts with the calcium oxide or calcium carbonate forming calcium sulfide. The calcium sorbent (sulfided material and unreacted oxide or carbonate) is removed with the ash agglomerates as previously described. The sulfided calcium material is then oxidized with air with the combustion energy used to generate steam. Approximately 90% of the sulfur present in the coal can be captured in this step alone, sufficient to meet current NSPS standards.

- External Bed Desulfurization

In the external bed desulfurization system, particulate free and slightly cooled product gas is passed through a fixed bed of zinc ferrite sorbent to further reduce the hydrogen sulfide content. A commercial plant would normally have two or more fixed beds of zinc ferrite sorbents. One bed would be on-line to desulfurize product gas while the other beds would be in various modes of regeneration. The zinc ferrite sorbent provides capability of removing virtually all of the sulfur compounds at 1000-1200°F. Thus a hot clean fuel gas is produced that is well below environmental emission and turbine limits.

The external bed sorbent is regenerated using a mixture of steam and air and the sulfur values are removed as sulfur dioxide. The regeneration tail gas from the external zinc ferrite desulfurizer

will be recycled to the KRW gasifier where the sulfur dioxide in the tail gas will be removed by the calcium sorbent in the gasifier bed. This eliminates the need for an additional system to capture these sulfur compounds and reduce them to elemental sulfur. The combination of in-bed and external-bed desulfurization is a feature which significantly simplifies and reduces the cost of the sulfur removal/recovery process. This combination can meet any new emission standards approaching total cleanup.

- Kellogg's KRW IGCC Power Generation Concept

Kellogg's KRW IGCC power generation concept incorporates the latest features and advantages of our hot gas cleanup development work.

A block flow diagram of KRW-based IGCC technology is given in Figure 6. Kellogg's KRW air-blown pressurized fluidized bed gasification technology economically processes all coal types. It operates at 1600-1900^oF, a temperature range high enough to avoid formation of extremely carcinogenic tars and oils and low enough to avoid materials and safety problems. Effective in-bed desulfurization is favored in this temperature range and is accomplished simply by feeding limestone or dolomite to the gasifier with the coal.

Projected commercial hot gas cleanup performance is summarized in Table 1. Desulfurization is 85-95 percent, depending on the coal type, and resultant stack emissions meet New Source Performance Standards. The spent sorbent is roasted in air to produce a residue that meets landfill requirements.

When an external desulfurization system using a regenerable zinc ferrite sorbent is added, sulfur levels in the coal gas are reduced to 5-10 ppm. High efficiency cyclones and ceramic filters reduce particulates and alkali metals and vanadium to very low levels.

The clean coal gas from the gasifier island is delivered at 1000-1200^oF to the power island, increasing system efficiency by reducing fuel requirements. A heat recovery generator on the hot gas turbine exhaust produces steam that is used for

power generation and for the gasifier. The system is further integrated by the gasifier air requirement being supplied from the gas turbine's air compressor.

As illustrated in Figure 7, integration of Kellogg's KRW gasifier island/hot gas cleanup technology with a combined cycle system results in a simple IGCC power plant system when compared to competing technologies using cold gas cleanup. This appeals to electric utilities because it:

- o Uses air-blown gasification avoiding the need for expensive air separation plants.
- o Delivers hot fuel gas to the gas turbine without gas cooling to ambient temperatures for removal of sulfur and other contaminants followed by subsequent reheating. System heat rate is improved and acid gas removal, sulfur recovery and tail gas treatment systems are avoided.
- o Integrates steam produced in the gasification island with the power island, thereby increasing electrical output.
- o Avoids production and treatment of water condensate associated with other IGCC systems.
- o Avoids a chemical plant or refinery image.

Further, an additional benefit to the electric power industry utilizing IGCC systems will be the opportunity to add new capacity in smaller increments and on a much shorter time schedule. The installation of a "standard" module will reduce risk (technology and environmentally siting) and also reduce capital requirements (cost of working capital due to lower overall plant costs and shorter construction schedule time).

While the advantages listed above are available to IGCC in general, KRW's technology offers economic incentive to the utility. The Cool Water project was a technological, execution and operation success. However, entrained flow type gasifiers must utilize oxygen and cannot capitalize on in-bed desulfurization. Projected future plants have a similar installed cost to pulverized coal fired boilers with scrubbers, while Kellogg's KRW IGCC technology with hot gas cleanup shows as much as 30% savings.

- Appalachian Demonstration Project

Commercial scale demonstration of Kellogg's KRW IGCC technology is a necessary precursor to utility acceptance. This demonstration will be accomplished by the Appalachian Project, which is scheduled to begin operation in 1990.

The Kellogg sponsored Appalachian Project is a nominal 60 MW IGCC power production facility which has been selected by the U.S. Department of Energy (DOE) to receive financial assistance under its Clean Coal Technology Program. The Project will be located about 70 miles southeast of Pittsburgh, PA near the Quemahoning Reservoir. It will require about 200 acres of property in an Industrial Park for which Kellogg is securing an option to purchase. The site is in a region which has an abundance of coal, water, limestone and skilled labor. The area itself has been fully characterized for environmental purposes due to an earlier project which was under consideration by the U.S. Synthetic Fuels Corporation.

The major features of the facility, as shown in Figure 8, are:

- o Kellogg's KRW fluidized bed gasification system including hot gas cleanup technology
- o A power generation block comprised of a gas turbine, heat recovery steam and electric generation equipment
- o Associated offsite facilities including coal handling equipment, utility and waste disposal systems

The gasification system will be a scaled-up version of the KRW pilot plant Kellogg has been operating under contract to the DOE at Waltz Mill. The proposed plant will use crushed and sized coal and limestone which will be fed to a Kellogg-designed KRW gasifier along with air and steam.

The low BTU gas, produced at about 1850°F and 270 psig, undergoes further cleanup external to the gasifier, first in a system of cyclones and a filter which removes essentially all entrained

particulates and alkali metal contaminants and, second, in a zinc ferrite desulfurizer which removes the remaining sulfur species to a level of 5 ppm. The resulting fuel gas is, for practical purposes, free of pollutants or contaminants which could compromise the operation of the power plant or degrade the environment.

In the power island, the clean low BTU gas will be fed to a combustion turbine generator designed to accept the gas delivered at 1000^oF and combust it in a multi-fuel combustor. Steam is produced from heat recovered from the turbine exhaust and from the gasification island heat recovery system, in order to generate additional electric power in a non-reheat steam turbine generator. Of the 60 MW net output, approximately 35 MW is produced by the combustion turbine and 25 MW by a steam turbine.

A projected performance summary of the plant is shown in Table 2.

The facility incorporates major features that will be found in future Kellogg KRW IGCC power plants and will accomplish the following:

- o Demonstrate commercial scale operation of the air-blown KRW gasifier island and ability of in-bed desulfurization to meet or better New Source Performance Standards.
- o Confirm the accuracy of gasification system design models.
- o Demonstrate economic multi-cycle regeneration ability of the zinc ferrite desulfurizer.
- o Demonstrate commercial operation of the particulate removal system.
- o Demonstrate ability of the power island to operate on hot coal gas.
- o Demonstrate commercial base load operation of the IGCC-H power plant.
- o Demonstrate ability of the system for turndown, load follow and part power operation, including controls.

- o Develop detailed system operating data and performance mapping.
- o Provide data regarding environmental performance including atmospheric emissions, water use, and solid waste characteristics.
- o Provide a record of operating costs, maintenance costs and system availability.

Summary and Conclusions

Kellogg's KRW IGCC process is one of the most promising new technologies for electric power generation. It is capable of efficiently operating on the complete range of U.S. coals and lignite feeds.

The technology has been extensively tested in Kellogg's KRW pilot plant. The process will be commercially demonstrated in the Appalachian Project and will provide an attractive, cost-effective option for electric power generation in the 1990's.

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FIGURE 1

The KRW Gasifier has Processed All Types of U.S. Coals

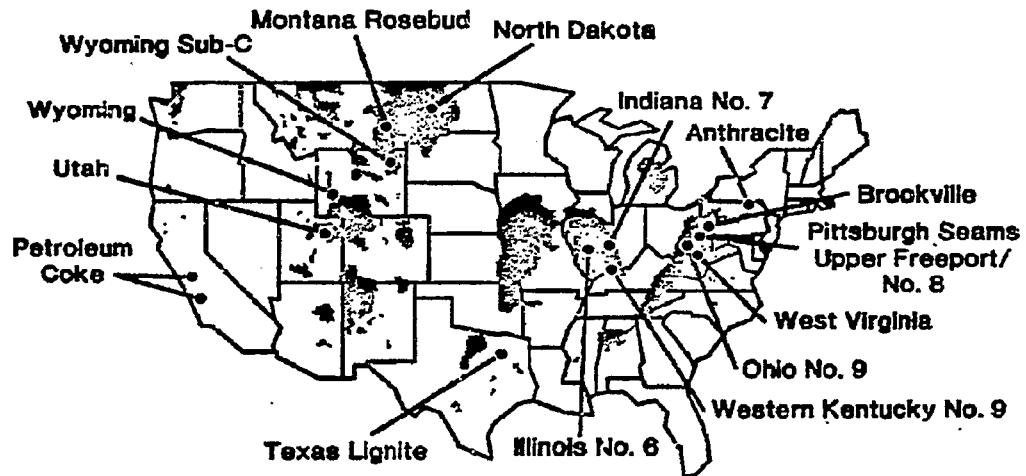


FIGURE 2

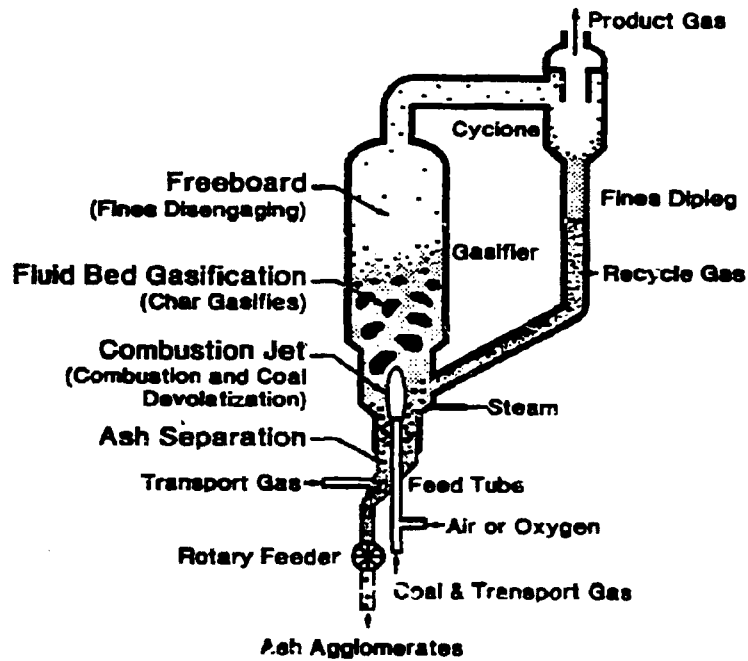
Range of Feedstock Properties

	Bituminous	Sub-Bituminous	Lignites	Cokes	Non U.S.A.
Ash, %	7-12	5	11-23	0.2-14	16-45
Moisture, %	2-7	18-22	14-16	0.9-10	2-4
Caking Index, FBI	2-9	0	0	0	0-0.5
Reactivity	4-9	60-71	28-44	1-2	5-49
Sulfur, %	1-4	0.4-0.8	0.8-0.9	1-2.5	0.5-0.9
Total Carbon, %	65-74	74	45-52	80-90	49-82
Ash Fusion Temperature, °F	2,300-3,000	2,320-2,410	2,140-2,500	2,530-2,610	2,530-2,600
Volatile Matter, %	16-38	33-44	32-38	2-10	23-25

*Processed in the KRW POC.

FIGURE 3

KRW Single-Stage Coal Gasifier



- Features**
- Pressurized Operation
 - Carbon Steel Vessel
 - Long Lived Insulation
 - High Efficiency
 - High Carbon Recovery

FIGURE 4

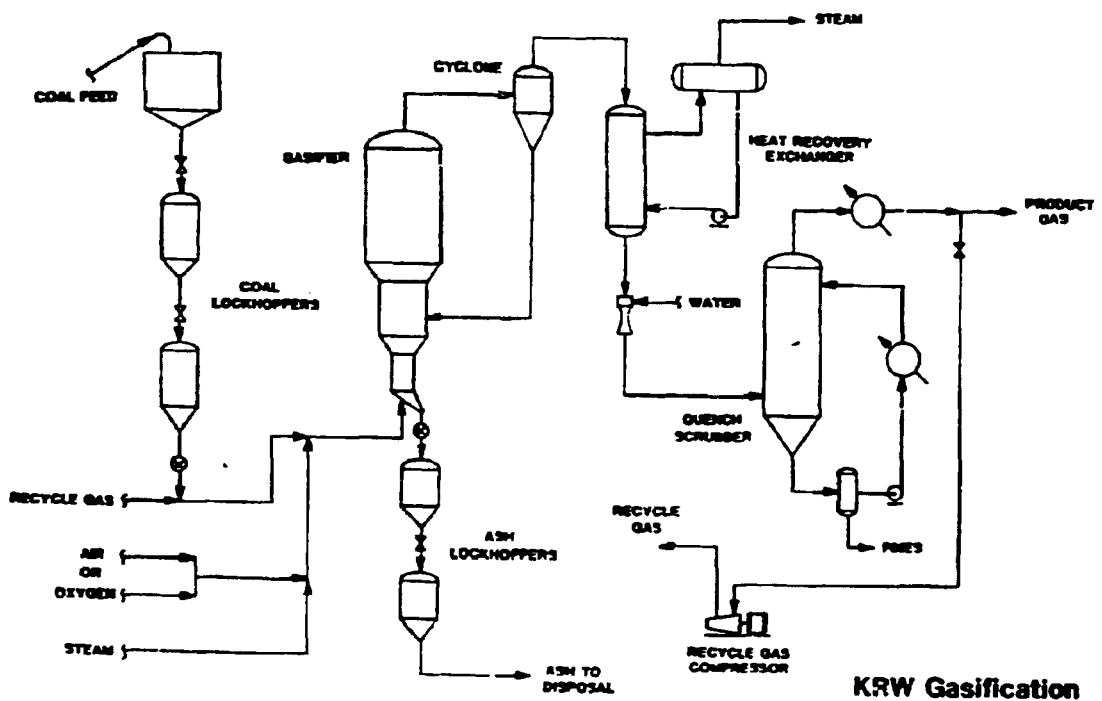


FIGURE 5

The KRW Gasifier Has Broad Applicability to the Synfuels Industry

	<u>Medium Btu Gas</u>	<u>Low Btu Gas</u>
Electric Power		
Combined Cycle	✓	✓
Fuel Cells	✓	✓
Fuel Gas	✓	✓
SNG	✓	
Indirect Liquefaction		
Methanol	✓	
Gasoline	✓	
Diesel	✓	
Ammonia	✓	
Hydrogen	✓	

FIGURE 6
KELLOGG'S KRW IGCC POWER PLANT

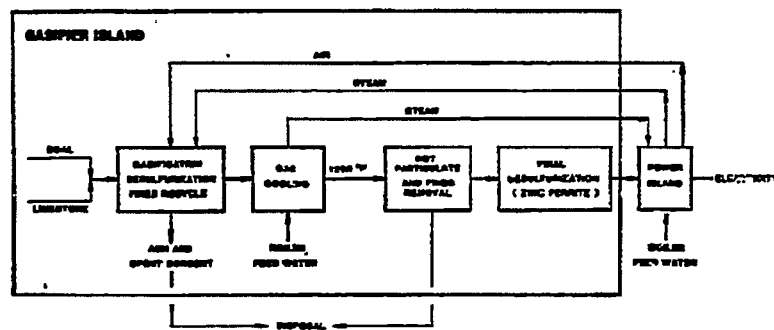


FIGURE 7

IGCC Equipment Comparison Cold vs. Hot Gas Cleanup

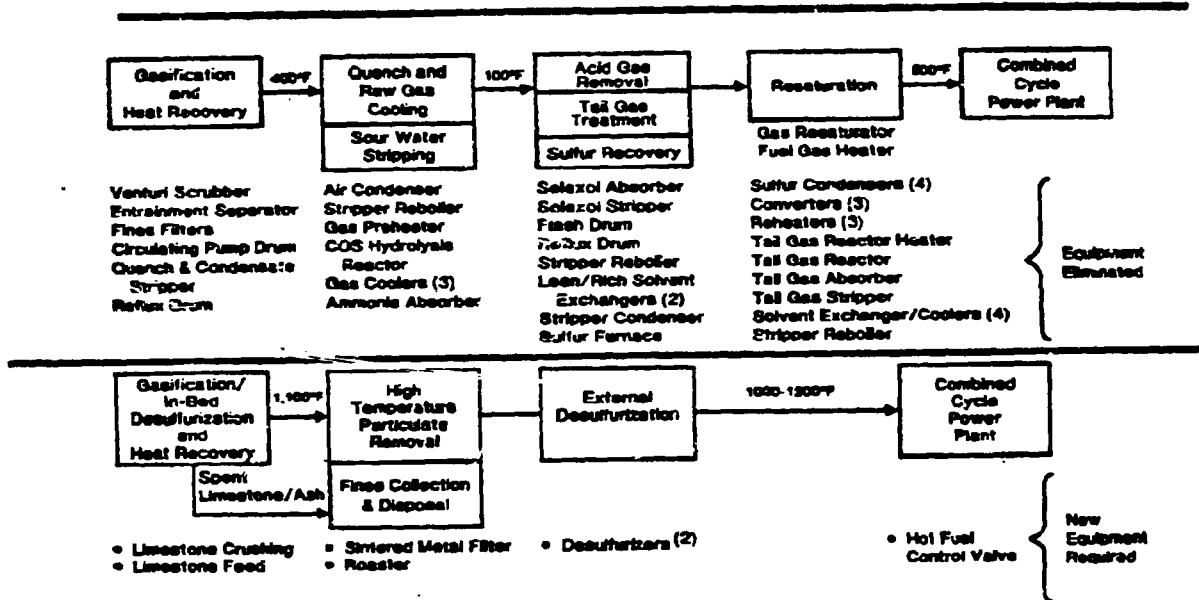


FIGURE 8

Appalachian Project IGCC Schematic

- Gasifier Island - KRW Air Blown Gasifier With Hot Gas Clean-Up
- Power Island - Combined Cycle With Gas Turbine

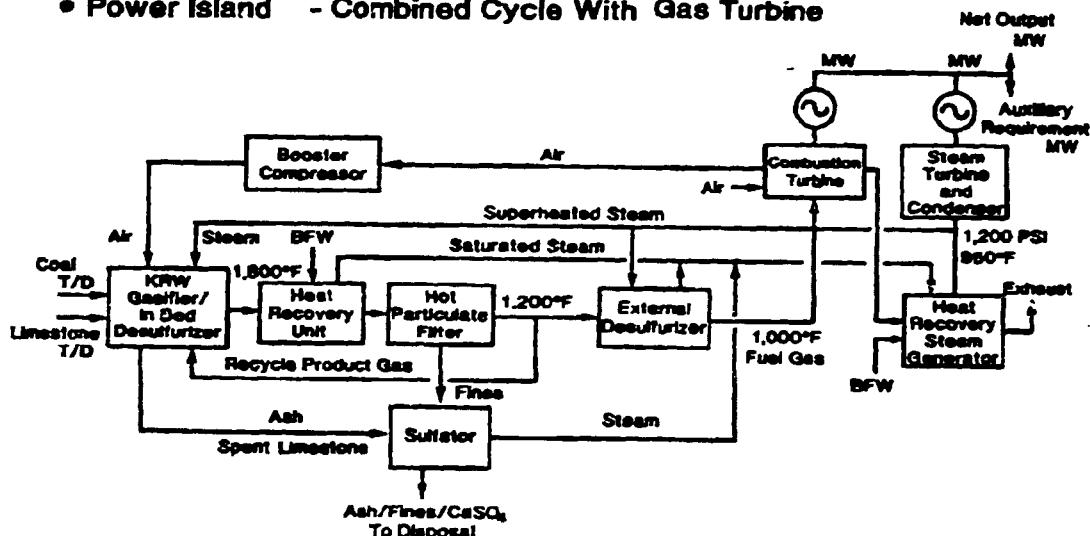


TABLE I

HOT GAS CLEANUP PERFORMANCE

<u>Hot Gas Cleanup</u>	<u>Pilot Plant Result</u>	<u>Requirement/ (Basis)</u>
In-Bed Desulfurization	95% (Pittsburgh Coal) 85% (Wyoming Coal)	90%/(A) 85%/(A)
External Desulfurization	5-7 ppm Sulfur in fuel gas	-
<u>Other Emissions:</u>		
Particulate	Nil	0.03 lb/10 ⁶ /(A)
NO _x	0.2 lb/10 ⁶ Btu	0.60 lb/10 ⁶ /(A)
Alkali	20.0 ppb	1.00 ppm/(B)
Lead	0.004 ppm	1.00 ppm/(B)
Calcium	1.5 ppm	10.00 ppm/(B)
Vanadium	0.007 ppm	0.50 ppm/(B)

(A) NSPS - New Source Performance Standards of U.S.
Environmental Protection Agency

(B) Gas Turbine manufacturers

TABLE 2

Appalachian Project Plant Performance Summary

Coal to Gasifier	485 T/D
Limestone to Gasifier	111 T/D
Steam to Gasifier	167 T/D
Air to Gasifier	1521 T/D
Fuel Gas to Combustion Turbine	2205 T/D
Net Gasifier Steam	1165 T/D
Ash/Spent Limestone Product	180 T/D
Combustion Turbine Power	35.7 MW
Steam Turbine Power	25.4 MW
Auxiliary Power Required	3.6 MW
Net Power Output	57.5 MW
Heat Rate (HHV)	8790 Btu/KW-Hr.

ABSTRACT

Class "C" Fly Ash Markets

Author

L. E. "Tex" Leber
Nebraska Ash Company
P.O. Box 80268
Lincoln, Nebraska 68501

Our company is in the business of marketing Power Plant Ash predominately in Nebraska. We have four sources under contract, all producing a Class "C" Fly Ash.

This paper will describe the various uses we have for Fly Ash in our market area. Some of the uses which will be covered are a partial cement replacement in portland cement concrete, filler in asphaltic concrete, and soil stabilization. Portland cement products which will be covered are Concrete Paving, Ready Mixed Concrete, Prestressed Concrete, Concrete Block, and Concrete Pipe. The various soil stabilization uses which will be discussed are the drying of highway subgrades and building construction sites, temporary grain storage pads, stabilization of high P. I. soils, and pozzolanic base and armor coat for upgrading gravel roads. In 1986 a 2 mile pozzolanic base roadway was constructed in central Nebraska. The procedures and test data are available and will be included in this paper.

CLASS "C" FLY ASH MARKETS

L. E. "TEX" LEBER
NEBRASKA ASH COMPANY
LINCOLN, NEBRASKA

Our company was formed in the mid 70's for the primary purpose of marketing Power Plant Ash in Nebraska and its surrounding states. We currently have contracts with the following utilities to conduct the current marketing, and storage of their remaining ash products for future marketing:

Omaha Public Power District
Omaha, Nebraska

North Omaha Station - Omaha, NE
Nebraska City Station - Nebraska City, NE

Nebraska Public Power District
Columbus, Nebraska

Gerald Gentleman Station - Sutherland, NE

City of Grand Island
Grand Island, Nebraska

Platte Generating Station - Grand Island, NE

The fuel source for the four stations in which we are involved, is a sub-bituminous coal mined from the "Powder River Basin" near Gillette, Wyoming. All of the Fly Ash produced at these plants is Class "C" with Calcium Oxide contents varying from 23% to 28%. We are currently shipping approximately 90,000 tons annually for our current outside markets and internal utilization; and storing approximately 150,000 tons annually for future utilization.

To date our largest volume market has been as a partial cement replacement in portland cement concrete. Fly Ash is currently being utilized in the following concrete products:

1. The State of Nebraska Highway Department allows a 15% replacement of cement on nearly all of its concrete purchases. The only exception being a class of concrete used for patching of pavement where an extremely high-early strength gain is required. In addition to the actual purchases of Fly Ash, which are substantial, having this specification is very beneficial to our marketing efforts as it encourages other specifying agencies along with individuals to also allow for the use of Fly Ash in their concrete usage.

2. Ready Mixed Concrete plants throughout Nebraska are replacing from 15% to 25% of the cement in concrete used for flatwork, structural concrete, walls, footings, and concrete for pumping. The replacement amount varies depending on many things, such as strength requirements, type of aggregate, temperature, specifications, end use of product, and many other variables. In most all instances a concrete mix containing Fly Ash can be designed to meet the requirements for the specific project.

3. The Prestressed and Precast concrete industry use Fly Ash in their concrete mixes because of the improved workability and high strength requirements. In many of the concrete pieces there are areas congested with reinforcement which make it very difficult to obtain complete consolidation of the concrete. Fly Ash in the concrete mix greatly improves its flowability so that proper consolidation and filling of forms does occur. It is also a known fact that Fly Ash is essential in a concrete mix requiring high compressive strength. With the Aggregates in our area a concrete mix will peak at about 5000 psi and additional cement increases the strength very little, but if Fly Ash is added to the mix the strength will increase by approximately 20%.

4. The Concrete Masonry and Concrete Pipe industries use Fly Ash to improve the surface texture of their product and to make it more impervious to water. Due to the rounded particle shape of Fly Ash the concrete flows into the forms more freely and creates a denser concrete with sharper edges and a more uniform surface. In addition to the improved finished product, the Concrete Masonry industry has found that machine times in producing the masonry units are improved and mold wear is reduced from the more flowable concrete mixture. For some high pressure concrete pipe the only way to meet the critical specifications is thru the use of Fly Ash to form a concrete pipe which will not leak under the high pressure testing.

The State of Nebraska requires that Fly Ash be utilized as the filler in Asphaltic Concrete used on high density roads. Fly Ash is allowed in all of their mixes and required for mixes used on roads which carry a high volume of heavy truck traffic. The Fly Ash filler creates a mix which has a higher density and improved stability, making the finished mat more resistant to rutting and pushing under traffic load. Fly Ash filler also lowers the required amount of asphaltic oil in the mixture by approximately 15% which is a very important benefit due to the high cost of petroleum products.

A relatively new market in our geographical area is the use of Fly Ash for soil stabilization. In the last several years we have used Fly Ash to dry wet subgrades for highway construction, dry building construction sites, build temporary grain storage pads, stabilize high PI soils, and upgraded a gravel county road to a pozzolanic base and armor coated roadway. The drying of highway subgrades and building construction sites is a simple matter of adding only enough Fly Ash to make the soil stable and easy to compact with no concern given to compressive strength.

When temporary grain storage pads are being constructed compressive strength and durability are both a concern as there will be rather heavy trucks on the pad from time to time plus the freezing and thawing of the product during the winter months. The owners generally involve an Engineer in these projects to design the mix and conduct on site inspection during construction. Our most dramatic stabilization project to date has been the construction of a 2 mile pozzolanic base and armor coat roadway in Custer County near Anselmo, Nebraska. The procedures and test results of this project are as follows:

Project: Custer County Road Stabilization

Location: County Road two miles South of Anselmo, Nebraska

In early September of 1986 a two mile section of gravel road was stabilized with Fly Ash and Portland Cement. The objective of this project was to upgrade a gravel roadway into a hard surfaced road which was capable of handling farm to market traffic including a substantial amount of grain and stock trucks.

The Fly Ash utilized for this project was a reclaimed Class C Fly Ash, which contained approximately 15% moisture and was pulverized with a Bomag Recycler. The Fly Ash was delivered to the jobsite in dump trucks and placed in a windrow on the shoulder of the roadway. The Portland Cement was delivered in pneumatic tankers. Prior to spreading the cement, the Fly Ash was evenly spread, with a motorgrader, over the 22 ft. wide roadway. The pneumatic tankers were equipped with a gate under each hopper so that the cement dropped on to the spread Fly Ash and by making three passes on the 22 ft. roadway the cement was evenly spread over the Fly Ash. Water was then added, if necessary, to obtain the correct moisture for the mixed product.

A Bomag Recycler was used to mix all ingredients together in a single pass, each pass being about 6.5 ft. wide. Immediately after mixing, a vibratory padfoot roller began compacting the road bed materials, to obtain a high density final product including the subbase directly under the road mixed materials. The padfoot roller made a minimum of two passes and then a vibratory steel drum roller was used for final compaction. Along with the steel drum roller a motorgrader was utilized to shape and smooth the roadway. A final pass of the steel drum roller with the vibrator shut off left a very smooth tight surface which was kept moist until an immulsified oil sealer was sprayed on the surface to retain the moisture for curing purposes. After the entire project was stabilized, an armor coat wear surface was placed to protect the Pozzolanic Base from wear and moisture penetration.

The following companies were involved in the completion of this experimental project:

Custer County Highway Department
Broken Bow, Nebraska

Nebraska Public Power District
Columbus, Nebraska

Fehrs Tractor & Equipment Co.
Omaha, Nebraska

Nebraska Ash Company
Lincoln, Nebraska

MIX DESIGN

<u>Material</u>	<u>Lb./Ft.³ Dry</u>	<u>% of Mix</u>
Reclaimed Fly Ash	22.17	18.6
Type I Portland Cement	3.23	2.7
Sand-Gravel	19.50	16.4
Road Bed Material	74.14	62.3

Maximum Dry Density: 119.04 #/ft.³

Optimum Moisture: 9.2%

AVERAGE FIELD TEST RESULTS

<u>Date</u>	<u>Location</u>	<u>Density Lb./Ft.³ Dry</u>	<u>% Moisture</u>	<u>% Compaction</u>	<u>Compressive Strength P.S.I.</u>	
					<u>7 day</u>	<u>28 day</u>
9-09-86	Sta. 1 thru 21	123.7	7.5	104	959	---
9-11-86	Sta. 21 thru 33	119.3	7.6	100	---	---
9-12-86	Sta. 33 thru 57	123.1	7.4	103.5	500	1334
9-16-86	Sta. 57 thru 95	<u>121.3</u>	<u>8.7</u>	<u>102</u>	<u>830</u>	<u>1746</u>
Average		121.9	7.8	102	763	1540

IDENTIFYING AND CORRELATING OVERBURDEN STRATA WHICH MAY REQUIRE
SELECTIVE HANDLING OPERATIONS

I. INTERPRETING HIGH QUALITY GEOPHYSICAL LOGS

By

D. G. Purdy, CPAg/SS
Senior Agronomist/Soil Scientist
North American Coal Corporation

Omer Jenkins, Ph.D.
Professor of Statistics
Texas A & M University

John J. Jedlicka
Senior Geologist
North American Coal Corporation

Abstract

The North American Coal Corporation conducted an investigation focusing on the application of classification, correlation, and calibration techniques for the purpose of interpreting the signatures of high quality geophysical logs. The objectives of this study were to:

1. Evaluate the potential of using high quality geophysical logs to identify and correlate important chemical and physical properties of overburden materials within a 5- to 10-year mining block; and
2. To investigate methods to spatially characterize overburden properties important to the soil reconstruction process, using high quality geophysical logs as the final basis for identification and correlation.

The data for the study were obtained from (1) digitized geophysical logs, (2) chemical and physical laboratory data of selected testing intervals, and (3) strata classification by depositional environment as interpreted by a professional geologist. The geophysical logs interpreted during this study included a natural gamma log, a density log, a resistivity log, and a caliper diameter log.

The results of the statistical analyses of these data using analysis of variance (ANOVA), discriminant function analysis, and correlation analysis show that geophysical log signatures can be effectively grouped and interpreted.

Introductory Discussion

An objective, reliable and low cost approach for spatially correlating chemical and physical properties of overburden sediments would find many practical applications in the Texas lignite industry. A few apparent applications would include:

1. Correlating reclamation study data collected from small field study areas to larger mine blocks.
2. Correlating overburden data obtained from continuous cores to project size areas.
3. Correlating and mapping suitable and unsuitable overburden properties for:
 - i. evaluating the potential of randomly mixed or selective overburden handling operations, and/or
 - ii. designing selective overburden handling systems.

The current approach for spatially characterizing overburden sediments usually fit into one of the following categories:

1. Expensive methods which rely on sampling overburden on high density centers and costly laboratory analyses of numerous testing intervals; or
2. Inexpensive methods making use of a minimum number of overburden cores and laboratory analyses, which may result in broad generalizations about chemical and physical properties of overburden sediments; or
3. Defaulting to selective handling of native topsoil and conceivably subsoil materials, in lieu of sufficient overburden characterization data.

Clearly, these approaches have their disadvantages of high costs or increased project risk, or both.

An investigation directed towards developing a reliable and lower cost approach to spatially characterize overburden properties important to the soil reconstruction process, was undertaken by The North American Coal Corporation (NACCO) in 1985. The objective of the investigation

was to evaluate the hypothesis that high quality geophysical logs can be used, as the final basis, to identify and correlate overburden properties which can positively or negatively affect the productivity of a reconstructed soil.

The initial results of the investigation have produced good results with the potential for promising applications in the area of soil reconstruction design and reclamation planning.

Conceptual Background

The development of and the understanding of the hypothesis requires an understanding of:

1. Where the sediments came from e.g. the drainage basin;
2. How the sediments were transported e.g. the fluvial system;
3. How the sediments were deposited e.g. the fluvial-deltaic system;
4. Classification systems;
5. Geophysical wire-line logging systems;
6. Soil formation, particularly the functions of parent material and weathering;
7. Existing chemical and physical properties of undisturbed soils as they relate to soil productivity and capability; and
8. Chemical and physical properties of overburden sediments as they relate to the drainage basin properties, particle size distribution and mineralogy.

Geology of East Texas

Economically recoverable lignite seams occur in the early Tertiary Wilcox Group in the coastal plain of east Texas. Within these strata (sediments), lignite is a component facies of fluvial-deltaic and barrier-bar/strand plain depositional systems that prograded into the Gulf Coast Basin. (Ayers and Kaiser, 1986)

The Fluvial-Deltaic System

The following discussion of fluvial-deltaic systems is from Deltas Processes of Deposition and Models for Exploration, Second Edition (J. M. Coleman, 1981). Figure 1 presents a generalized overview of sediments deposited by a typical fluvial-deltaic system.

The delta plain and ultimately the coastal plain of east Texas can be subdivided into basic physiographic zones. Every delta consists of a subaqueous and subaerial component even though the relative areas of these may

vary considerably. The subaerial delta is that portion of the delta plain above the low tide limit. The upper portion of the subaerial delta, commonly referred to as the upper deltaic plain, is normally the older portion of the subaerial delta and exists above significant tidal or marine influence. It is essentially the seaward continuation of the alluvial valley and is dominated by fluvial depositional processes. The lower portion of the deltaic plain lies within the realm of river-marine interaction and extends landward from the low-tide mark to the limit of tidal influence. The lower plain is most extensive where tidal range is large and seaward gradients of the fluvial channel and delta are low.

The subaqueous delta is that portion of the delta plain which lies below the low-tide water level. It is the foundation on which progradation of the subaerial delta must proceed. Most commonly the subaqueous delta is characterized by a seaward fining of sediments, sand, and coarser clastics being deposited near the river mouth and finer-grained sediments settling further offshore from suspension in the water column. The seaward-most portion of the subaqueous delta is normally referred to as prodelta deposits and is composed of the finest material deposited from suspension. The prodelta clays grade landward and upward into the coarser silts and sands of the delta front. Immediately at the mouths of the active distributaries are found the coarsest sand deposits, commonly referred to as the distributary mouth bar deposits.

The processes which occur in the active delta are important, for it is these processes which determine the development and distribution of the various facies relationships displayed by modern deltas. In most instances, the active delta consists of one or more river mouth systems which are the dissemination points for sediments which contribute to delta progradation. When a stream discharges into a receiving basin, its momentum is dissipated by the interaction of the river water with the ambient seawater; the result is the deceleration of the affluent, a consequent loss of sediment transporting ability and deposition. Commonly, there is a progressive seaward decrease in the concentration and grain size of sediments transported by the affluent. Most rapid deposition and deposition of the coarsest materials takes place a short distance from the river mouth, a sand body commonly referred to as a distributary mouth bar. Seaward of this region, the percentage of sand diminishes rapidly and a zone of interfingering generally unconsolidated sands, silts, and clays is commonly found. This zone is commonly referred to as the delta front deposits. Beyond or seaward of the delta front, only fine silts and clays remain in suspension and are deposited out of suspension on the continental shelf. These sediments are commonly referred to as prodelta clays. With time, and as the delta builds or progrades seaward, the coarser sand deposits are progressively laid

down over the finer-grained sediments, resulting in the classical coarsening-upward sequence common to all delta deposits.

The sediments marginal to, and between the distributary channels, comprise the largest percentage of the total subaerial delta. Immediately adjacent to the active channels, the most common depositional forms are probably natural levees, overbank splays, and associated minor channel systems. Further from the channel in the interdistributary regions, a wide variety of depositional environments can be found. Rapid distributary progradation coupled with rapid subsidence and low wave energy results frequently in the formation of shallow-water interdistributary bays. If subsidence is slow and depositional rates high, the interdistributary areas may be complete infilled with marsh and mangrove deposits.

An orderly repetition of depositional events and shifting sites of sedimentation result in numerous interfingering and overlapping regressive deltaic sequences separated by shallow water marine deposits or transgressive sands. The initiation, growth, and abandonment of the various delta lobes result in cyclic alternations of detrital and nondetrital deposits. The detrital lens or the regressive phase is characterized by a high percentage of relatively coarse clastics, sands and silts, abrupt facies changes, and rapid accumulation and burial rates. The bounding sediments, which tend to be generally richer in organic constituents and chemical precipitants, show a slower depositional rate and tend to be tabular accumulations with considerable lateral continuity. The cyclic concept provides a framework for organizing the complex environmental relationships and facies distributions.

Environments of Deposition

The environments of deposition associated with the regressive or progradation phase of deltas are extremely complex and highly variable. In most river deltas there is a constant sediment supply of a given grain-size distribution and composition during the period of progradation. The various processes active in each subenvironment of the delta distributaries result in selective concentration and distribution of the sediment.

Subenvironments associated with the subaqueous delta consist of: (a) shelf, (b) prodelta, (c) delta front, (d) distributary mouth bar, and (e) subaqueous natural levees. The subenvironments associated with the subaerial environment consist of: (a) channel deposits, (b) natural levee or overbank splays, (c) interdistributary bays, (d) marshes, and (e) crevasse splays of bay fills.

Shelf Environment

Shelf deposits generally are grouped into three major types of sedimentary accumulations. The first type of shelf facies is a product of extremely slow accumulation of fine sands

generally removed from areas of active progradation. Cores taken in this type of shelf facies are typically composed of apparently homogeneous clay, shelly clay or silty clay. Shells and shell fragments are scattered throughout the deposits. Contact between the stratifications is normally sharp and well-defined. Parallel and lenticular laminations are relatively rare due to the intense activity of burrowing organisms, one of the most characteristic aspects of these deposits. Individual laminae of silt and fine sand, when present, are normally distinctive, having sharp basal boundaries. Occasionally the silt layers are graded, normally from coarse at the base to fine at the top. The lithology as well as the structural assemblage generally indicates a slow deposition under marine conditions.

The second type of shelf facies results when the offshore region adjacent to the deltas receives little or no clastic accumulations. Organic debris, precipitates, and reworked material become the dominant lithology.

A third type of shelf facies consists of sediments deposited on the shelves via numerous subaqueous mass movement processes. These deposits characteristically display little or no internal bedding. Often sand bodies slumped from higher positions on the delta front are incorporated in these massive shelf deposits.

Prodelta Environment

The prodelta facies is characteristically a blanket of clays deposited from suspension having high lateral continuity and low lithologic variation. Deposition is entirely from suspension and parallel laminae are by far the most common primary structure. In many instances the prodelta deposits will normally appear as structureless massive clays. Because of the higher rates of deposition associated with the prodelta deposits these deposits will normally escape intense burrowing by marine organisms. Faunal species are normally high, especially foraminiferal tests, indicating an open marine environment; both number and species are high. The shallower water portions of the prodelta deposits tend to show laminae that are thicker and grain size is normally coarser.

Delta Front Environment

Progressing upward or landward within the deltaic sequence, the deltaic front, referred to as the delta platform or distributary bar, overlies the prodelta facies. Increase in sedimentation rates and coarseness of the sediments distinguishes these deposits from the prodelta clays. Lithology generally can be characterized as laminated silts and clays with thin sand layers. The delta front generally shows lower lateral continuity than the prodelta environment.

Dilutions of salinity by river water along with the nutrient-laden currents derived from the river make this a highly favorable environment for burrowing organisms.

Distributary Mouth Bar Environment

The distributary mouth bar is an area of shoaling associated with the seaward terminus of a distributary mouth. Accumulation rate is extremely high, probably higher than in any other environment associated with the delta. The deposits of the distributary mouth bar consist primarily of the coarsest clastic material available in the delta system.

The coarser sediments, the sands, settle rapidly from suspension and almost all of the sand is deposited near the vicinity of the distributary mouths. Because of variations in turbulence at the river mouth and different process intensities between low river stage and high river stage, silts and clays will also be deposited in this environment. Thus in many instances, the distributary mouth bar can contain and incorporate silts and clay beds. However, reworking by marine processes results in cleaning and sorting of the sediments by marine processes. As a result, the distributary mouth bars consist commonly of clean, well-sorted sands delivered by the river to its mouth. Both suspended load and bottom sediments become progressively finer with increased distance from the distributary mouths. As the sediment load is constantly diminishing and being spread in an ever increasing area, the rate of clastic deposition gradually decreases seaward from the distributary mouths.

Subaqueous Natural Levee Environment

Submarine ridges bordering the channel form in response to reduced current velocity as the channel broadens and shoals. As deposition continues, natural subaqueous levees develop beneath the lateral boundaries of the expanded effluent where velocity gradients are steepest. The bulk of the subaqueous levee facies is composed of very fine sand and silt with occasional thin laminae of plant debris or clay.

Subaerial Natural Levee Environment

The areas of slightly higher elevation bordering and confining the channel are called subaerial natural levees or overbank splays. These ridges form in response to differences in river stage. Deposition is solely the result of overbank flow. Highest elevations and broadest widths are found where the river stage fluctuation is greatest. Often the subaerial natural levee deposits will be capped by a tightly cemented zone of iron oxides and iron carbonates that form in conjunction with the highly bioturbated zones.

Distributary Channel Environment

A distributary channel accommodates and directs a portion of the sediment from the parent river system to the receiving basin. In most instances within the lower delta, the distributary channels are rather stable and do not show a tendency to migrate laterally.

Regardless of the size, processes within the channel environment are essentially similar. In the upstream part of the channel, current flow is confined by banks to a general downstream direction. Beyond the mouth, however, the channel flares and currents frequently move in varying directions. Deprived of an active influx of sediment and water, the lower portions of the channel are commonly filled with poorly sorted sands and silts containing an abundance of transported organic debris. As the waters in the channels become more stagnated and lower current velocities are maintained, the finger-grained materials begin to infill the channel proper. With time and continuing subsidence, the channel often is entirely filled with fine-grained and poorly sorted sediments. Fine-grained organic debris and logs commonly form the upper part of the channel fill. Borings through a typical channel indicate that the lower portion of the sedimentary fill consists of poorly sorted sands and silts commonly showing an abundance of organic trash along the bedding planes. In the central portion of the channel fill, highly bioturbated silts, silty clays and clays characterize the fill sequence. In the uppermost portion of the channel fill, fine-grained organic debris, primarily peats, with abundant woody horizons are common; consequently, the final stage of filling is normally characterized by a high abundance of peat.

Interdistributary Bay Environment

The interdistributary bay environment may be completely surrounded by marsh or distributary levees but which are more often partially open to the sea or connected to it by small tidal channels. Because these bays are generally bypassed by active coarse clastic sedimentation, the deposits are composed primarily of fine-grained sediments that are brought into the bays during periods of high flood or abnormal high tides associated with the passage of storms.

Bay Fill Environment

One of the major facies associated with many deltas is the large aerial extent of the bay fill that break off of the main distributaries and infill the numerous interdistributary bays. These sequences form the major land areas of the subaerial delta and form as crevasse deposits in shallow bays between or adjacent to major distributaries and extend themselves seaward through a system of radial bifurcating channels. Each bay fill forms initially as a break in the major distributary natural levee during flood stage, gradually increases in flow through successive floods, reaches a peak of maximum deposition, wanes, and becomes inactive. As a result of subsidence, the crevasse system is inundated by marine waters reverting to a bay environment, thus completing its sedimentary cycle. Although individual bay fills are relatively thin, continuing subsidence and a repeating of similar processes result in stacking one bay fill on top of another, thus building up quite a thick sequence of subaerial delta deposits.

With the development of systematic channel patterns the delta front advances into the bay resulting in the deposition of a sheet of relatively coarse detritus thickening locally in the vicinity of the channels. Seaward of the active river mouths is an area of fine-grained accumulation or prodelta clays. These clays mark the first introduction of detritus into the bay and are distinguished from the underlying shallow marine clays by alternate repetition of sedimentary structures related to seasonal floods. The size distribution within this environment grades from fine to coarse, both upwards in the section and horizontally from the distal ends of the system towards the point source.

Once active sedimentation ceases in the bay fill, subsidence and coastal retreat become the dominant process. For a time, marsh growth can keep pace with subsidence, but eventually large bays tend to develop and the shoreline retreats rapidly. The regressive sequence is capped by bounding transgressive sediments including shallow marine bay clays and marsh deposits. These deposits contain a higher percentage of elements characteristic of the basin. The initiation, growth, and abandonment of the various bay fills result in cyclic alternations of detrital and nondetrital deposits.

The most common vertical sequence along the distal ends of the bay fill is represented by shallow marine bay deposits which grade upward into silty clays representative of the seaward-most portion of the prograded bay fill. This silty clay deposit is normally capped by a thin peat deposit. The peats in this vicinity are generally thin, but tend to show wide lateral continuity and thus the entire cycle consists only of silty clays and peats that alternate in an orderly fashion.

The lowermost sequence in the complete bay fill cycle represents the organic clays and silty clays which represent the initial fine-grained fill of the bay. The sandy deposits represent those facies associated with the actively prograding distributaries and consist primarily of delta front and distributary mouth bar deposits. Overlying the distributary mouth bar are the natural levee deposits and the calcareous clays of the small interdistributary bays and overbank deposits. The final lithologic unit is the peat deposits that tend to cap the regressive sequence and thus a complete cycle is recorded.

Marsh Environment

Marshes are low tracts of periodically-inundated land supporting non-woody plants such as grasses, reeds and rushes. The marsh surface normally approximates the mean high tide level. Within the delta this level is only a fraction of a meter higher than mean sea level. Within the active deltas, marshes generally range from fresh to brackish. Most marsh deposits result from an abundant organic accumulations which accumulated under relatively stagnant chemically reducing environments. Occasionally overtopping of the newer banks by

major floods will introduce fine clastic clays into an otherwise rich organic region. The end result is production of laterally continuous peat deposits.

Very commonly, peat or lignite deposits will be overlaid by a sand deposit. The contact between the lignite and the sand is usually sharp. With the exception of this sand, the entire section consists predominantly of marine clays and prodelta deposits with a final capping of interdistributary bay deposits which can accumulate to considerable thicknesses because of the lack of deposition except by overbank flooding.

Classification Systems

Systems for classifying units into groups of more uniform characteristics is not new to soil scientists and geologists. Classification systems, when properly organized, can improve property uniformity of the materials grouped and generally reduces sample variability. This investigation suggests that: (1) a classification system can group sediments having common sediment load transport and depositional processes; that (2) these processes influence sediment properties which can be evaluated in terms of their affect on soil productivity and capability; and (3) sample variability will be controlled by grouping. Therefore, group properties will be more uniform among samples within each group and the properties between groups will be different.

Assuming that sediment classification is possible, a reliable and low cost method that can accurately group sediments into a classification system is needed. A potentially useful tool to meet this requirement may be the geophysical log.

Other considerations for using geophysical logs as the basis to classify sediments are:

1. The surface mining industry frequently obtains geophysical logs of drill hole locations during lignite exploration and development programs. Usually, the drilling density is a function of the mining status of a project and generally increases as a project moves toward production. This promotes the possibility that if accurate and reproducible overburden data were determinable from geophysical logs, overburden characterization would improve (as a function of drilling density) while costs could be reduced.
2. Major advances to improve data accuracy and data reproducibility have been incorporated into many geophysical logging systems. These improved systems have incorporated better logging tools and computerized and digitized recorders into the systems, thereby significantly reducing errors (variability) in the geophysical logs produced.

3. Findings from a review of related research investigations show a strong potential for the quantitative assessments of overburden properties using high quality geophysical logs.

An 1978 investigation conducted by D.J. Dollhopf, et al. showed that the use of natural gamma logs in combination with mechanical analyses data provided a means for consistent delineation of rock types within the research area. This investigation also demonstrated that statistical relationships existed between overburden lithology and chemical properties of the overburden material. Data presented in 1985 at the Texas Reclamation Workshop by W. D. Hall and L. Garrett showed that overburden characterization of stratigraphic units can be mapped by using geophysical logs as the basis for correlation; provided that the logs were carefully run and of consistent quality, and that accurate laboratory data from each logged site were available to characterize stratigraphic units exhibiting characteristic log signatures.

Geophysical Logging

Both M. H. Rider (1986) and J. H. Doventon (1986) provide detailed explanations of geophysical logging and logging tools. An explanation of the theory of geophysical logging is beyond the scope of this paper. However, the type of information and the accuracy of the data obtained by various logging methods is not.

A common geophysical log used by the lignite mining industry consists of four readings: (1) a caliper diameter log, (2) a natural-gamma log (3) a density log, and (4) a resistivity log. Other logs, e.g. the spontaneous potential log and the neutron log, though not always used, may provide the means to even better define lithology and the occurrence of iron disulfide deposits or other heavy metal deposits, etc.

Caliper Logs

Caliper tools measure hole size and shape. The simple mechanical caliper measures a vertical profile of hole diameter. An extremely important use for the caliper is in the quality control of logs. When caving is serious, the quality of all logs is impaired. Therefore, it is essential to consult the caliper log before consulting other logs.

Gamma and Spectral Gamma Logs

The gamma log is a record of a formation's radioactivity. The radiation emanates from naturally-occurring uranium, thorium and potassium. The simple gamma log gives the radioactivity of the three elements combined, while the spectral gamma log shows the amount of each individual element contributing to this radioactivity. The gamma log is principally used to quantitatively calculate shale volume.

The gamma log value of shale formations is often variable, depending on the various amounts of clay minerals, carbonate and organic matter present.

As a first indicator of lithology, the gamma log is extremely useful as it suggests where shale may be expected. Moreover, the higher the gamma value, the higher the percentage of shale. However, that lithology indicated by the gamma log must be confirmed by other logs.

Quartz, the principal component of the coarse-grained detrital rocks, shows no radioactivity. Sandstones consequently usually show low gamma values. However, associated detrital minerals are radioactive. The most common of these are feldspars, micas, heavy minerals and lithic fragments. The first two groups contain potassium, the third thorium, and the last contains shale. These all can cause high to moderate gamma values for sands.

Some marine sands contain glauconite and, if the concentrations are sufficiently high, render the sands radioactive. Certain minerals can be identified on the gamma log by their abnormal contribution to the radioactivity level. Usually high gamma values often occur as narrow, isolated peaks.

An interesting and fairly comprehensive scheme for facies identification in detrital sediments (sand-shale) has been developed using gamma log signatures. The basis for the scheme is the relationship between grain size and shale content. A coarse-grained sand will have a very low shale content, a medium-grained sand some shale, and a fine-grained sand may be very shaly. The changes in grain size will be followed by changes in the gamma value. Empirically, if the gamma log shows a typical signature it can be taken as indicating grain-size changes. However, a lack of shape is not evidence for lack of grain-size change since it cannot be interpreted.

Although it has many advantages for correlation, the gamma ray log also has disadvantages. The fine detail on the logs is merely statistical variation. A comparison between any log and a repeat section shows to what extent this has an effect. Fine peaks therefore cannot be used for correlation. The second disadvantage is that the gamma log cannot be calibrated.

A certain amount of literature exists on the possibility of identifying individual clay minerals using the spectral gamma log. Local variations, complexity of clay-mineral mixtures and many other contributory variables allow no convincingly clear picture as yet for clay-mineral identification. The use of the spectral gamma log for this purpose is still in the future.

Gamma log profiles may be applied in an analogous manner to the spontaneous potential log for the interpretation of depositional environments of both sandstone-shale and carbonate-shale sequences. In common with the spontaneous potential log, the gamma records the nature of

upper and lower contacts as sharp or gradational, and gives indications of shale content variation. The gamma log should be used in conjunction with more orthodox geological data in order for it to be a realistic aid in environmental interpretation.

The Density Log

The density log is a continuous record of a formation's bulk density. This is the overall density of a rock, including solid matrix and the fluid enclosed in the pores.

Quantitatively, the density log is used to calculate porosity. Qualitatively, it is a useful lithology indicator and (1) can be used to identify certain minerals, (2) can help to assess organic matter content, and (3) may help to identify overpressure and fracture porosity. Bulk density variations in sandstone generally indicate porosity changes. In sands without shale, grain density can give some idea of sand composition. Changes in grain density in sands are generally gradual and of a moderate order. Abrupt changes, especially in otherwise homogeneous beds, often indicate diagenetic or secondary changes. A similar phenomenon may also occur with secondary pyrite cement.

Density becomes a criterion for lithological identification when it is either abnormally high or abnormally low. Coals, for example, are identified by very low densities, between 1.2g/cm^3 and 1.8g/cm^3 , and pyrite, conversely, by very high densities, between 4.8g/cm^3 and 5.1g/cm^3 . The extreme values for these minerals may not be reached under natural conditions, but abnormally high and abnormally low peaks are still easily visible. The presence of organic matter in shales lowers their density. The normal average matrix density of a mixture of clay minerals is about 2.7g/cm^3 , while organic matter has densities between 0.70g/cm^3 - 1.80g/cm^3 . The presence of organic matter therefore has a marked effect on shale bulk density. The organic-matter effect on the density log can be quantified and the log used to derive the amount of organic matter in a shale. The relationship between density and organic matter percentage however should be normalized.

The densities of the more common lithologies are rarely diagnostic since there is too much overlap and too much spread caused by differences in composition and texture. Although the density log is itself a poor indicator of lithology, combined with the neutron log it becomes excellent. In fact the neutron-density log combination is probably the best qualitative indicator of general lithology.

Resistivity (Conductivity) Logs

The resistivity log is a measurement of a formation's resistivity, that is its resistance to the passage of an electric current. Conductivity logs measure a formation's conductivity or its ability to conduct an electric current but this value is generally converted directly to resistivity. A formation's resistivity is

one of its typical geophysical characteristics and as such can contribute information on lithology, texture, facies, overpressure and source rock characteristics. The log is used frequently for correlation.

Clays conduct electricity in two ways, through pore water and through the clay itself. Clay consists of stacked silicate layers which are negatively charged. Clay can be described as a negative framework surrounded by current-conducting ions (the double layer). The capacity of clays to conduct electricity varies between clay species and seems to depend on the surface area of the clay which is a function of mineralogy. An independent expression related to the surface area is cation exchange capacity. Geologically this is of interest, since montmorillonite has a far greater specific surface area than the other clays and is therefore more conductive.

The resistivity of a rock is intimately related to texture. The simplest relationship between resistivity and texture is that demonstrated by an increase in resistivity as porosity decreases, other factors being equal. As the porosity increases, the resistivity will decrease logarithmically, and the shallow and deep devices will show separation. The resistivity-texture relationship can in fact display considerable subtlety, as the following example shows.

It is the domination of shale as a subsurface lithology which enables the resistivity logs to have no characteristic resistivity limits for shale. The values depend on many variables, such as compaction, porosity, mineral content, quartz content, etc. But in any restricted zone, shale characteristics will tend to be constant, so that the resistivity log, although it does not allow a first indication of lithology, can subsequently confirm it. High resistivities will also be associated with tight limestones, sandstones, or dolomites. Usually low resistivities may also be indicative. A low resistivity can be associated with electronic (metallic) conductivity as opposed to ionic conductivity. This is the case for mineral concentrations attributed to secondary hematite or pyrite.

Although the resistivity logs do not allow the direct identification of lithology, they are nonetheless very sensitive lithology indicators. The increase in resistivity corresponds to an increase in the silt (quartz) content. Even slight, subcyclic events are visible on the logs. Within sands themselves, it is suggested that different resistivity values may be correlated with differences in grain size. A coarser-grained sand will generally have a low irreducible water saturation and hence higher resistivity, the fine-grained sand with higher irreducible water will show lower resistivity. A clean, fining-upwards sandstone should show a regular upwards decrease in resistivity. Additionally, organic matter is generally highly resistive to electric current and when present in shale can cause an increase in the shale resistivity.

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East Texas Soils

Soils in east Texas are characteristically old and highly weathered soils. Properties common to Texas soils are: (1) very sandy topsoils which can be drought prone, (2) root-penetration and root-function restricting subsoils, (3) low organic matter content, (4) low cation exchange capacity, and (5) low nutrient supplying capacity. Without going into another detailed discussion on soil science, suffice it to say that most east Texas soils are old (10,000 + years), highly weathered, acid, soils with high needs for management inputs to achieve customary yield goals. Also consider that the original parent materials for these soils were fluvial-deltaic sediments exposed to surface weathering and other soil formation processes e.g. time, topography, vegetation, and climate.

Statistical Verification

Statistical procedures were used to: (1) test the effectiveness of the classification system, (2) semi-calibrate chemical and physical properties of the geophysical log signatures characteristics of each group, and (3) test the objectivity and reliability of the approach. Statistical procedures used were discriminate function analysis, analysis of variance, T-test for mean differences and correlation analysis.

All statistical analyses were performed using the Statistical Analysis System (SAS) software package release 82.4.

Investigative Methods

An investigative area of approximately 12,000 acres was selected for this study. The investigative area is situated in the Wilcox Geologic Formation in east Texas. The investigative area is characteristic of much of the geology and soils in east Texas.

The information and data collected to support this investigation included: (1) the selection of an appropriate sediment classification system; (2) selecting and locating continuous coring and geophysical logging sites within the investigative area; (3) obtaining detailed laboratory data from testing intervals for each continuous core; and (4) selecting statistical methods for (i) analyzing laboratory data and classification data, and for (ii) quantifying (semi-calibrating) geophysical log signatures.

The classification system chosen to group sedimentary materials, based on geophysical log signature interpretation, was the system used by geologists from the Texas Bureau of Economic Geology in support to a Texas A&M study on overburden characterization. The system incorporated the following classification groups:

1. Bay Center
2. Bay Fill
3. Bottomload and Mixed Load Channel
4. Channel
5. Flood Basin
6. Marsh

Each of these classification groups encompass unique sediment load transport and depositional processes and associated postdepositional environments. It is believed through the classification of unconsolidated sediments to one of these six groups that much of the sample variability associated with these sediments will be adequately controlled. By controlling variability and by grouping materials exhibiting similar lithologic and stratigraphic characteristics, it is believed that efficient quantification of overburden properties is possible.

A total of eight sites were identified for the collection of both continuous core samples and geophysical logs. These eight continuous coring sites were located to sample the broadest range of overburden and interburden characteristics within the area of investigation. This specification of the study was met by carefully siting continuous coring locations to encompass the complex stratigraphy and topography of the investigative area. Previously collected geotechnical data and environmental coring data were used to assist in the selection of these sites. The continuous cores were collected to a total depth of 100 feet below the deepest economically recoverable lignite seam. Immediately following collection of each continuous core, a high quality geophysical log, consisting of a gamma log, a density log, a resistivity log, and a caliper-diameter log was obtained. These data were immediately transferred to the logging system's on-site computer, digitized and stored on magnetic tape.

All of the sample material from the eight continuous cores were transported to a Texas Railroad Commission (RRC) approved laboratory for laboratory analysis. Laboratory testing intervals were selected based upon lithologic and stratigraphic characteristics, specific to each continuous core, without the aid of reviewing the geophysical logs. The laboratory procedures selected were procedures recommended by the RRC and/or procedures considered to be diagnostic of important reclamation properties.

The first step in data analysis involved the timely completion of the laboratory analysis of the selected testing intervals. The second step involved interpreting the geophysical logs for unique and repeating log signatures and assigning stratigraphic facies of the continuous cores to a classification group. The classification was performed by a project geologist experienced with interpreting geophysical logs. The geologist's effort was accomplished without the benefit of reviewing any laboratory data. The classification data generated by the geologist were coded and entered into the computer. The classification data were entered

into the computer. The classification data were entered into a SAS file, such that each identified laboratory testing interval was assigned to a classification group identified by the geologist.

The third step involved a discriminant function analysis of the classification data generated by the geologist. The data set for the discriminant analysis involved classification groups having ten or more observations. The discriminant analysis procedure was used to test for property similarity within the sample group based upon the geologist's classification model. The data used in the discriminant analysis were sieve size data, pyritic-sulfur data, and electrical conductivity data.

An analysis of variance of the classification groups means was planned. However, this step depended on the successful results of the discriminant analysis of the classification of the sediments investigated. The use of Analysis of Variance of the classification grouping would test for the unbiased capability to uniformly group sediments of similar properties. If positive results were obtained, then statistical support for organizing sediments into common groups having common chemical and physical properties using geophysical log signatures would be recognized.

Comparisons of classification group means for significant differences were planned if the analysis of variance F-test indicated that significant differences existed between group means. The project's statistician recommended that an adjusted T-test be used to make the comparisons based upon the sample size of the means tested. Basically, the adjustment involved using alpha testing levels at the two- and five-percent levels in order to declare significance differences at the ten- and twenty-percent levels. (It is acknowledged that a twenty-percent testing level is higher than normally used, but it is felt that this is a reasonable level considering this stage of investigation.)

Correlation analysis was also performed on select laboratory data. Correlation analysis was used to determine if a field procedure could be used to identify the occurrence of less easily measured properties. To this extent, three pH measurements, pH (1:1 water), pH (1 normal KCl), pH (SMP Buffer), were correlated to total iron disulfide (FeS_2) concentrations of the testing intervals.

Discussion of Results

The geophysical log of each core site and the geologist's classification results are presented in Figures 2 through 9. A review of the geologist's data shows a tendency for consistency and sensitivity to major changes in the log signatures. However, a close examination of the geologist's classification reveals a tendency to lump the subtler changes in the log signatures and not split these signature changes. As examples refer to: (1) Figure 2 between the 10- to 50-foot depth interval, and

(2) Figure 3 between the 35- to 70-foot interval.

The results of the discriminant function analysis are presented in Table 1. The data in Table 1 show that the discriminant analysis testing function (the first approximation) agreed with the geologist's groupings for 75 of the 119 observations in the data set. The results of this analysis show that the computer analysis of the classification groupings is in agreement with the geologist's groupings for 63 percent of observations.

An evaluation of the 31 dissenting observations involved: (1) a review of the classification probability levels assigned by the discriminant function to the dissenting observations, and (2) coding the computer's groupings next to the geologist's groupings, both placed adjacent to the log signature of each core. This first evaluation showed that the regrouping probability for 16, or 51.6 percent, of the 31 dissenting observations exceeded the 90 percent probability level and that regrouping of 24, or 77.4 percent, (includes the 16 previously noted observations) of the 31 dissenting observations exceeded the 80 percent probability level.

The second evaluation of the geologist's classification data involved coding the computer groupings of the 119 observations onto the geophysical logs next to the geologist's groupings. The results of this effort are also presented in Figures 2 through 9. This side-by-side comparison allows for an evaluation of both the geologist's and the computer-generated groupings. The side-by-side review of the geologist's groupings and the computer groupings tend to support, in most cases, the regrouping refinement of the computer's discriminant function. Examples of this are again evident in: (1) Figure 2 between the 10- to 50-foot depth interval, and (2) Figure 3 between the 35- to 70-foot depth interval. Overall the discriminant function analysis of the testing intervals tended to be immediately more sensitive to the log signatures in terms of subtler and thinner log signature changes.

Refining the sample groupings, based upon the visual examination of the log signatures, brings the correct number of sample intervals assigned to the appropriate classification group to 88 out of 119 or 74 percent.

Both the statistical and visual examination of the classification data generated by the geologist supports the capability to identify overburden materials having qualitatively definable group characteristics. However, it is possible that improvement in technique, supported by laboratory data, could have increased the precision of the classification further. This indicates that more detailed knowledge of the relationship of the signature to quantified data may be useful to further improve the precision of sediment classification and signature quantification using geophysical log signatures.

As previously mentioned, the success of the classification grouping of sediments is impor

tant to the investigation. However, the classification groups also must exhibit expected properties of materials transported and deposited by the processes, which the classification system is trying to characterize.

The analysis of variance results are presented in Table 2. The analysis of variance was performed using the classification groups determined by the discriminant analysis data. The results of the analysis of variance of the sand, clay, acid-base balance, pH (1:1 water), pH (SMP Buffer), and iron disulfides (FeS₂) data show that highly significant differences exist between the classification group means.

In order to examine the group properties in terms of expected characteristics, the laboratory data were examined using the SAS Univariate Procedure. The data were examined as a whole body before classification and as independent groups using the discriminant analysis classifications. Table 3 presents selected sediment characteristic properties for the investigative area important to soil reconstruction planning. It is evident from the magnitude of the separation of the chemical and physical properties of groups means that the characteristics of the sediments, when evaluated on whole or as independent groups, are different and fit with the expected characteristics. The high energy processes have high sand contents, high pH levels, and low clay contents. Conversely, the lower energy processes are opposite the high energy processes.

The mean differences between classification groups were evaluated using an adjusted T-test. The stated alpha levels are 10 percent and 20 percent but are actually the two and five percent levels. The formula used to generate the calculated T value is:

$$(1) \quad T(\text{calc}) = \frac{X_1 - X_2}{\sqrt{\text{MSE} \times \left(\frac{1}{\text{obs}_1} + \frac{1}{\text{obs}_2} \right)}}$$

The final step in this investigation was to statistically test for mean differences between the classification groups. The T-test results for sand, clay, acid-base balance, and pH (SMP Buffer) are presented in Tables 4 through 7.

Quantification of the sand and clay contents of the sediment classification groups is the final necessary step towards spatially characterizing sedimentary materials associated with lignite deposits.

The T-test results for mean differences between sand and clay contents are presented in Tables 4 and 7. These tables demonstrate that significant differences between classification group means can be quantitatively determined. Several mean differences were not determined to be significantly different by this T-test, e.g., in Table 4 - Bay Fill vs. Channel, in

Table 5 - Bottom Load and Mixed Load Channel vs. Channel, Bay Fill vs. Channel. The reason that the T-test could not detect significant differences between these group means are attributed to the few observations occurring in the channel classification group.

The T-test results for mean comparisons for acid-base are presented in Table 6. These data also show that significant differences between classification groups can be quantitatively determined. These data show that the flood basin group exhibits the highest content of acid producing material. The capability to differentiate these materials through the classification system is beneficial to soil reconstruction planning. The data presented in Table 6 also indicates that significant differences would probably be detected between other classification groups, e.g., mean comparisons with calculated T-values greater than and equal to 1.4 but less than 2.02, had more observations for these groups been available.

The most interesting mean comparison result of the T-test analysis is associated with the pH (SMP Buffer) data (Table 7). These T-tests show that the sediments classified into the flood basin group are significantly different from all other classification groups with the exception of the marsh group. The analytical importance of pH (SMP Buffer) data is this procedure may be useful for distinguishing acid-producing materials from other sedimentary materials in the field during exploration drilling programs. An additional evaluation of this potentially low-cost method for identifying and quantifying acid-producing sediments involved correlation analysis.

Statistical correlations for pH (SMP Buffer), pH (1 normal KCl), pH (1:1 water), to percent iron disulfide contents of the testing intervals were performed. The correlation coefficients for pH (SMP Buffer), pH (1 normal KCl), pH (1:1 water) were respectively 0.86, 0.69, and 0.67. The high correlation coefficient of 0.86 for the correlation of pH (SMP Buffer) to iron disulfide concentration indicates that this procedure may provide a low-cost, field-adaptable method to isolate potentially high iron disulfide contents of sedimentary material during lignite exploration and development drilling activities.

Summary

The findings of this investigation and the approach developed to characterize overburden properties provides evidence that a low-cost and reliable approach to quantify and spatially correlate lignite-bearing sediments maybe possible. However, more investigative effort is still required in order to develop the approach to the level of quantitative sensitivity necessary. It is believed that both refinement and improvement of the approach, along with increasing the size of the database of classification group properties, will ultimately lead to the acceptance and use of this method.

Table 1
Discriminant Analysis of Overburden Core Data

FROM CLASS GROUP	Number of Observations and Percent Classified into CLASS GROUP					TOTAL
	BAYCTR	ZAYFILL	BOLDCHN	FLDBASN	MXLDCHN	
BAYCTR	14	0	0	0	0	14
Probability	100.00	0.00	0.00	0.00	0.00	100.00
BAYFILL	4	9	5	1	0	19
Probability	21.05	47.37	26.32	5.26	0.00	100.00
BOLDCHN	1	0	15	0	0	16
Probability	6.25	0.00	93.75	0.00	0.00	100.00
FLDBASN	12	1	2	27	3	49
Probability	26.67	2.22	4.44	60.00	6.67	100.00
MXLDCHN	0	0	13	2	10	25
Probability	0.00	0.00	52.00	8.00	40.00	100.00
TOTAL OBS	31	10	35	30	13	119
PERCENT	26.05	8.40	29.41	25.21	10.92	100.00

Note: It was these data that suggested combining observations of the BOLDCHN and MXLDCHN.

Table 2

Analysis of Variance Results of the Classification Groups

Variable	Degrees of Freedom		Mean Square		F Value	PR > F	CV	Mean
	Model	Error	Model	Error				
Sand Pct.	5	119	8995.0	491.3	18.7	0.0001	47.2	46.4
Clay Pct.	5	119	2465.2	197.5	12.5	0.0001	52.9	26.5
Acid-Base Balance (1)	5	119	4821.1	763.9	6.3	0.0001	349.7	7.9
pH (1:1 water)	5	142	8.7	2.6	3.29	0.008	27.4	5.9
pH (SMP Buffer)	5	119	5.4	1.1	4.91	0.004	15.7	6.7
Iron Dissulfide (FeS ₂) (1)	5	142	767.0	104.4	7.35	0.001	127.4	8.0

(1) Units in Tons CaCO₃ of neutralization potential/1,000 tons of sediment.

Table 3

Classification Group Means

Classification Group	Total OBS	Classification Group Means			pH (SMP)	pH (Water) (1:1)
		Sand	Clay	Acid-Base (1) Balance		
All Observations	(2)	46.4	26.5	7.9	6.7	5.9
Channel	2	91.5	4.5	98.4	8.02	8.8
Bayfill	14	69.7	13.2	0.9	6.78	6.4
Bottom Load and Mixed Load Channel	43	63.7	17.8	7.0	7.07	5.0
Mash	3	35.4	34.8	7.4	7.01	5.6
Bay Center	27	30.0	35.4	19.3	6.80	6.4
Flood Basin	36	27.5	36.0	-1.93	6.01	5.3

(1) Units in Tons CaCO₃ of neutralization potential/1,000 tons of sediment. A possible value indicates excess neutralization capacity.

(2) Varies with testing parameters.

Table 4
T-test Results for Variable Sand

Classification Group	Obs	Mean Percentage	Classification Group					
			Channel	Bayfill	BLMXL Channel ⁽¹⁾	Marsh	Bay Center	Flood Basin
Channel	2	91.55	-	1.31	1.76	2.92 **	3.82 **	4.02 **
Bay Fill	14	69.72	1.31 ⁽²⁾	-	0.89	2.46 **	5.49 **	6.12 **
Bottom Load and Mixed Load Channel	43	63.68	1.76	0.89	-	2.16 *	6.24 **	7.31 **
Marsh	3	35.40	2.83 **	2.46 **	2.16 *	-	0.41	0.60
Bay Center	27	30.05	3.82 **	5.49 **	6.24 **	0.41	-	0.46
Flood Basin	36	27.48	4.02 **	6.12 **	7.31 **	0.60	0.46	-

(1) BLMXL = Bottom load and mixed load channel.

(2) Calculated T value

* Indicates significant difference at the 20 percent alpha level (experimentwise)

** Indicates significant difference at the 10 percent alpha level (experimentwise)

Table 5
T-test Results for Variable Clay

Classification Group	Obs	Mean Percentage	Classification Group					
			Flood Basin	Bay Center	Marsh	BLMXL Channel ⁽¹⁾	Bayfill	Channel
Flood Basin	36	36.03	-	0.16	0.15	5.74 **	5.16 *	3.08 **
Bay Center	27	35.44	0.16 ⁽²⁾	-	0.08	5.11 **	4.81 **	3.00 **
Marsh	3	34.80	0.15	0.08	-	2.02 *	2.42 **	2.36 **
Bottom Load and Mixed Load Channel	43	17.81	5.74 **	5.11 **	2.02 *	-	1.08	1.31
Bayfill	14	13.17	4.36 **	4.81 **	2.42 **	1.08	-	0.81
Channel	2	4.55	3.08 **	3.00 **	2.36 **	1.31	0.81	-

(1) BLMXL = Bottom load and mixed load channel.

(2) Calculated T value

* Indicates significant difference at the 20 percent alpha level (experimentwise)

** Indicates significant difference at the 10 percent alpha level (experimentwise)

Table 6
T-test Results for Variable Acid Base Balance

Classification Group	Obs	Mean Percentage	Classification Group					
			Channel	Bay Center	Marsh	BLMXL Channel(1)	Bayfill	Flood Basin
Channel	2	98.32	-	3.90 **	3.61 **	4.57 **	4.67 **	5.12 **
Bay Center	27	19.34	3.90 ** (2)	-	0.71	1.81	2.02 *	3.04 **
Marsh	3	7.41	3.61 **	0.71	-	0.02	0.36	0.56
Bottom Load and Mixed Load Channel	43	7.04	4.57 **	1.81	1.81	-	0.72	1.44
Bayfill	14	0.94	4.67 **	2.02 *	0.36	0.72	-	0.33
Flood Basin	36	-1.93	5.12 **	3.04 **	0.56	1.44	0.33	-

(1) BLMXL = Bottom load and mixed load channel.

(2) Calculated T value

* Indicates significant difference at the 20 percent alpha level (experimentwise)

** Indicates significant difference at the 10 percent alpha level (experimentwise)

Table 7
T-test Results for Variable pH (SMP)

Classification Group	Obs	Mean Percentage	Classification Group					
			Channel	BLMXL Channel(1)	Marsh	Bay Center	Bayfill	Flood Basin
Channel	2	8.02	-	1.26	1.07	1.61	1.58	6.93 **
Bottom Load and Mixed Load Channel	43	7.07	1.26 (2)	-	0.10	1.00	0.90	4.41 **
Marsh	3	7.01	1.07	1.26	-	0.31	0.34	1.58
Bay Center	27	6.80	1.61	1.10	0.31	-	0.09	2.96 **
Bayfill	14	6.78	1.58	0.90	0.34	0.09	-	2.33 *
Flood Basin	36	6.01	6.93 **	4.41 **	1.58	2.96 **	2.33 *	-

(1) BLMXL = Bottom load and mixed load channel.

(2) Calculated T value

* Indicates significant difference at the 20 percent level (experimentwise)

** Indicates significant difference at the 10 percent level (experimentwise)

Deltas: Processes and Models

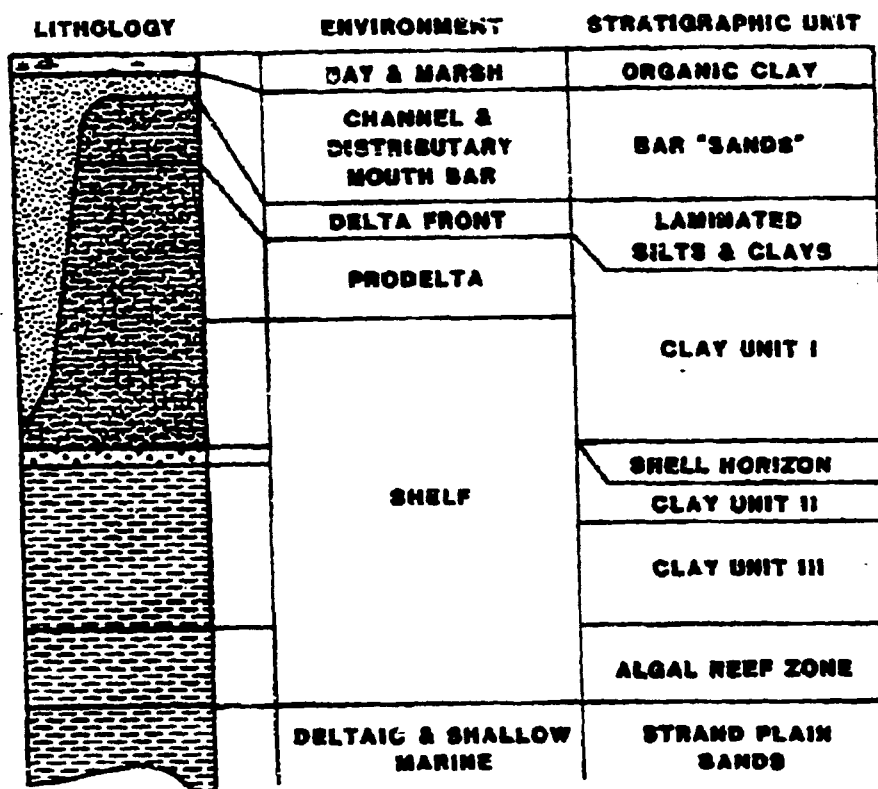


FIGURE 1

FIGURE 2

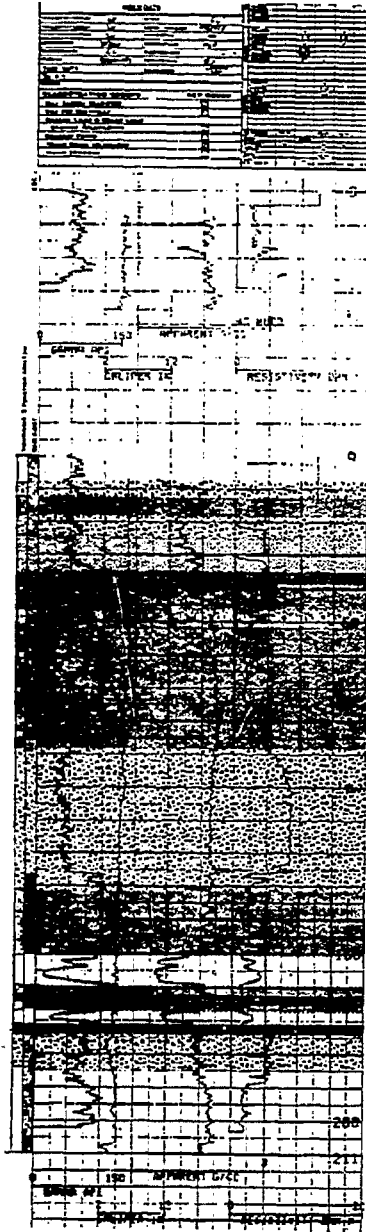
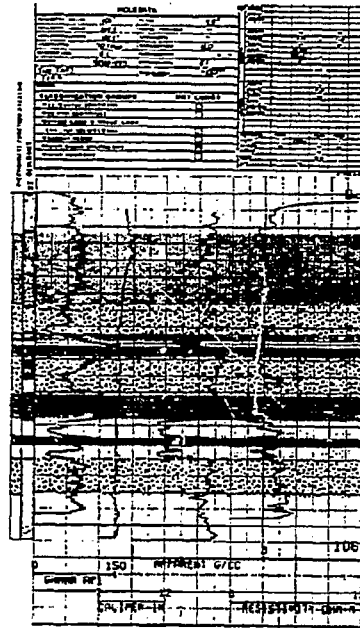


FIGURE 3



CLASSIFICATION GROUPS

KEY CODES

Bay Center (BAYCTR)



Bay Fill (BAYFILL)



Bottom Load & Mixed Load Channel (BLMXLCHN)



Channel (CHN)



Flood Basin (FLDBASN)



Marsh (MARSH)



Sample Not Collected



FIGURE 4

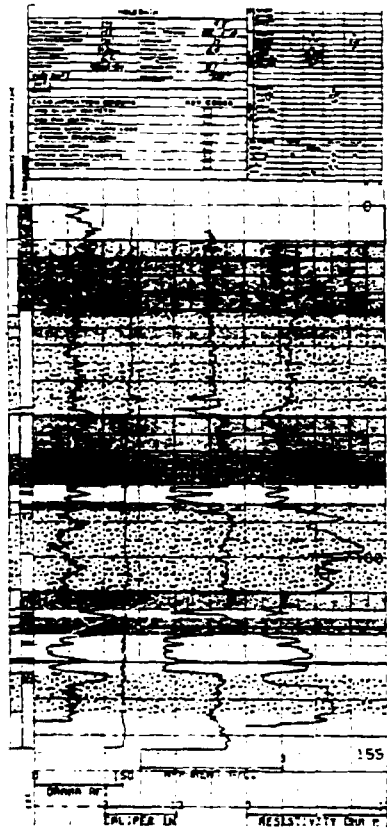


FIGURE 5

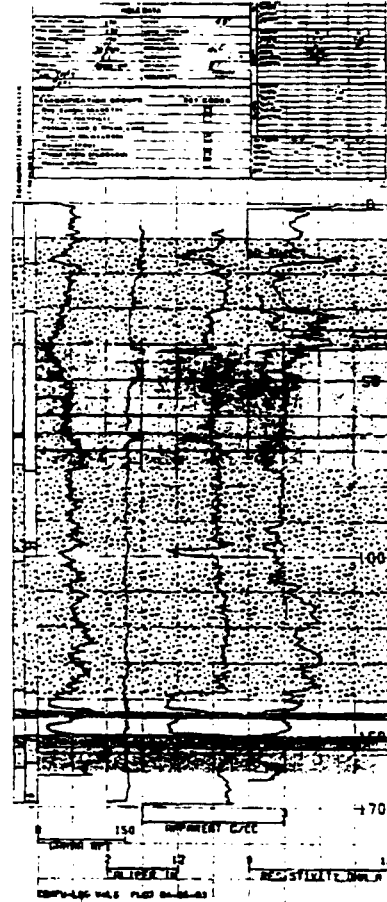
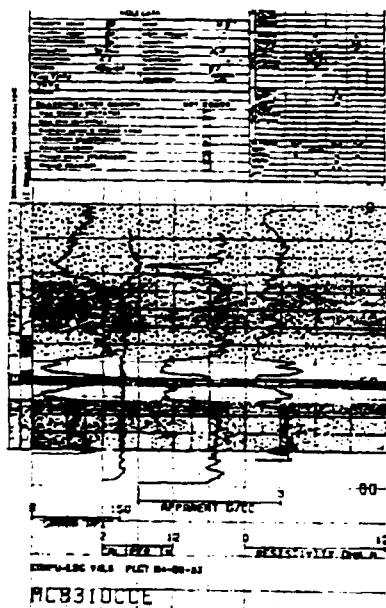


FIGURE 6



CLASSIFICATION GROUPS

KEY CODES

Bay Center (BAYCTR)



Bay Fill (BAYFILL)



Bottom Load & Mixed Load Channel (BLMXLCHN)



Channel (CHN)



Flood Basin (FLDBASN)



Marsh (MARSH)



Sample Not Collected



FIGURE 7

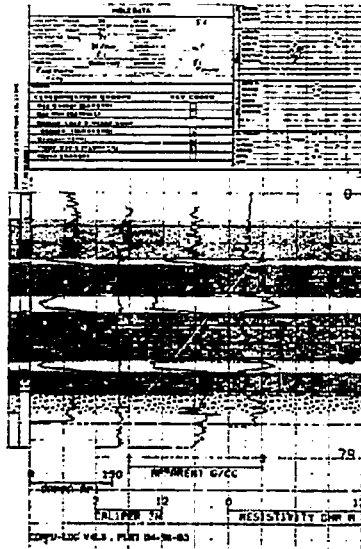


FIGURE 8

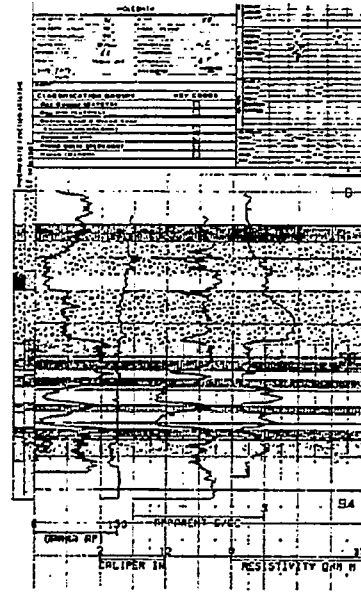
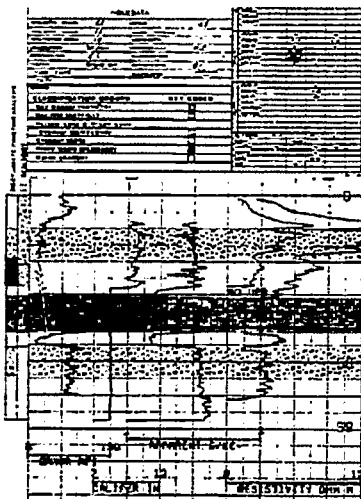


FIGURE 9



CLASSIFICATION GROUPS

KEY CODES

Bay Center (BAYCTR)



Bay Fill (BAYFILL)



Bottom Load & Mixed Load Channel (BLMXLCHN)



Channel (CHN)



Flood Basin (FLDBASH)



Marsh (MARSH)



Sample Not Collected



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