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U.S. DEPARTMENT OF ENERGY
FEDERAL ENERGY TECHNOLOGY CENTER

ENCOAL Mild Coal Gasification Project

September 1997

- ***Commercial Plant Feasibility Study***
  DOE/MC/27339-5796, (DE98002005)
- ***Final Design Modifications Report***
  DOE/MC/27339-5797, (DE98002006)
- ***Project Final Report***
  DOE/MC/27339-5798, (DE98002007)

Contents

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ENCOAL and the Clean Coal Technology Program

The Clean Coal Technology Program

The Clean Coal Technology (CCT) Demonstration Program was a government and industry co-funded effort to demonstrate a new generation of innovative coal utilization processes in a series of “showcase” facilities built across the country. These demonstrations are on a scale sufficiently large to demonstrate commercial worthiness and to generate data for design, construction, operation, and technical and economic evaluation of full-scale commercial applications.

The goal of the CCT program is to furnish the U.S. energy marketplace with a number of advanced, more efficient, and environmentally responsible coal-utilizing technologies. These technologies will mitigate the economic and environmental impediments that limit the full utilization of coal.

To achieve this goal, a multi-phased effort consisting of five separate solicitations has been administered by the U.S. Department of Energy (DOE) since 1985. Projects selected through these solicitations have demonstrated technology options with the potential to meet the needs of energy markets and respond to relevant environmental requirements.

The ENCOAL Project

The ENCOAL project, administered by the DOE Federal Energy Technology Center (FETC), was one of two CCT demonstration projects that involve upgrading of low-rank coals. Low-rank western coals, primarily subbituminous and lignite, are generally low in sulfur, making them useful as power-plant fuels in place of high-sulfur eastern coals. However, there are disadvantages to low-rank coals, especially their high moisture content and low heating value.

The ENCOAL Liquid From Coal (LFC®) process involves mild gasification to produce a dry, solid fuel and a liquid hydrocarbon fuel, followed by treatment to decrease particle reactivity and reduce the tendency to self-heat. The multi-step, high-temperature process has been demonstrated for 5 years at a test facility near Gillette, Wyoming. At this plant, which is rated at 1,000 tons/day of coal feed, over 83,000 tons of specification solid-fuel product and 4.9 million gallons of liquid product have been produced.

The ENCOAL project has met its goal of successfully demonstrating the upgrading of low-rank coal to significantly reduce moisture and hence, improve heating value.

The three reports on this CD constitute the final technical report for this CCT project.

For More Information

U.S. DOE Office of Fossil Energy Homepage: www.fe.doe.gov
U.S. DOE FETC Homepage: www.fetc.doe.gov

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Commercial Plant Feasibility Study

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ENCOAL MILD COAL GASIFICATION PROJECT:

COMMERCIAL PLANT FEASIBILITY STUDY

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THE UNITED STATES DEPARTMENT OF ENERGY
UNDER DOE INSTRUMENT NO. DE-FC21-90MC27339

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ENCOAL MILD COAL GASIFICATION PROJECT: COMMERCIAL PLANT FEASIBILITY STUDY

Summary

In order to determine the viability of any Liquids from Coal (LFC) commercial venture, TEK-KOL and its partner, Mitsubishi Heavy Industries (MHI), have put together a technical and economic feasibility study for a commercial-size LFC Plant located at Zeigler Coal Holding Company's North Rochelle Mine site.

This resulting document, the ENCOAL Mild Coal Gasification Plant: Commercial Plant Feasibility Study, includes basic plant design, capital estimates, market assessment for coproducts, operating cost assessments, and overall financial evaluation for a generic Powder River Basin based plant. This document and format closely resembles a typical Phase II study as assembled by the TEK-KOL Partnership to evaluate potential sites for LFC commercial facilities around the world.

Section 1.0 Introduction

The TEK-KOL Partnership (TEK-KOL), a Partnership between SGI International (SGI) and a unit of Zeigler Coal Holding Company (ZCHC), is proposing the development of a commercial-scale LFC plant in the Powder River Basin (PRB) of Wyoming. The LFC Commercial Plant concept consists of three 5,000-metric ton/day parallel modules that will convert 15,000 metric tons/day of low-sulfur, low-ash, low-Btu Powder River Basin coal into Process Derived Fuel (PDF) and Coal Derived Liquid (CDL). PDF is a high-Btu, clean-burning solid fuel or carbon source produced through the LFC mild pyrolysis process. CDL is a low-sulfur hydrocarbon liquid that is a valuable fuel, and its components have value as chemical feedstock. These coproducts possess desirable characteristics and considerable market potential.

TEK-KOL is seeking potential project participants to detail design, construct and operate the Commercial Plant Project.

To demonstrate the LFC technology, ENCOAL Corporation (ENCOAL), a wholly-owned subsidiary of Zeigler Coal Holding Company, designed, constructed and is operating a 1,000-ton/day LFC Plant in Gillette, Wyoming. The Plant has demonstrated the LFC Process and the product values of CDL and PDF. The ENCOAL Plant was designed, constructed and operated for a budget cost of $90 million in cooperation with the U.S. Department of Energy under Round Three of the Clean Coal Technology Program. Operation of the ENCOAL Plant has provided much of the basis for estimating operating cost, design basis, and product market data for the Study. Unlike most coal upgrading projects, full-scale shipment and test burns were made possible by the near-commercial size of the ENCOAL Plant. An ENCOAL project history is included in Section 5.1.

The ENCOAL operating experience was also used for the design basis and capital estimates for the LFC Commercial Plant. In mid-1995, MHI and TEK-KOL engineering staffs initiated a Design and Engineering Cost Estimate for an LFC Commercial Plant located in the Powder River Basin. In February 1996, this arrangement was formalized in an agreement or Memorandum of Understanding signed by MHI and both TEK-KOL partners. The Commercial Plant Feasibility Study (Study) represents a significant engineering effort on behalf of MHI and TEK-KOL. The Study was completed in March 1996, and updated later in the same year. This document reports the results of this Study as of December 1996.

Process Description

The high moisture content of Powder River Basin coal accounts for its low heating value. Powder River Basin coals normally have moisture contents of 25 to 32% with heating value ranging from 8000 Btu/pound to 8700 Btu/pound. The LFC Process first dries the mined coal to very nearly zero moisture. The dried coal is then mildly pyrolyzed, and approximately 60% of the original volatile matter and a portion of the sulfur are removed. Unlike many coal cleaning or coal upgrading processes, these two steps physically and chemically alter the basic coal characteristics. This metamorphosis helps to eliminate many of the problems associated with coal drying. The coal char is then finished in a multiple-step process adding moisture, oxygen and cooling the char to finally produce PDF.

Volatile matter driven off during the pyrolysis process is partially condensed in a multiple-step process that produces the hydrocarbon liquid CDL. The noncondensed or collected hydrocarbon is returned to the process combustors as a heat source for the drying and pyrolyzing steps. Each ton of raw feed North Rochelle coal will produce approximately ½ ton of PDF, ½ barrel of CDL, and will account directly for 70% of the process gas requirements.

TEK-KOL believes that the project will benefit from a number of intrinsic economic advantages:

1. PDF and CDL are clean-burning fuels.

2. PDF has multiple market applications in utilities and steelmaking.

3. The decline of coking ovens in the United States has reduced the supply of coal liquids and increased the potential market for PDF in steelmaking.

A number of factors make PDF an increasingly valuable boiler fuel: PDF has distinct transportation advantages, it is readily available, competitively priced fuel, and it has low sulfur content, low NO_x emissions and low ash fusion temperatures. Proposed electric utility deregulation and potential NO_x emission regulation may make PDF an even more attractive fuel choice in the future. Also, as high costs and environmental problems continue to shut down coke ovens, the steel industry is replacing coke in blast furnaces with Pulverized Coal Injection (PCI). PDF may become a viable injected fuel for these blast furnaces. In the use of Direct Reduction of Iron (DRI) to produce steel, PDF appears to be an excellent alternative source of carbon and fuel.

CDL is a highly aromatic coal liquid that has found some acceptance in the residual fuels market in the United States. Low natural gas prices and an abundance of heavy oils, however, have kept this market depressed during the ENCOAL Plant demonstration period. This has led TEK-KOL to pursue the higher value CDL fractions that are described in this Study.

Detailed project economics and financial analysis can be located in Section 9 of this Study. It is anticipated that the capital investment for the described project scope will be $475 million with an unleveraged rate of return in the 14 to 15% range.

Section 2.0 Mine and Infrastructure Assessment

Introduction and Summary

The North Rochelle Mine is currently being operated on a small scale but is being developed to a full-scale mine by Triton Coal Company. Triton Coal, a subsidiary of Zeigler Coal Holding Company, operates the Buckskin Mine located 10 miles north of Gillette, Wyoming, and is a well-established coal operator.

The North Rochelle mine is located in the Powder River Basin of northeastern Wyoming, currently the largest coal-producing region in the Unites States. North Rochelle is located approximately 60 miles south of Gillette, Wyoming, along the east flank of the Powder River Basin. Its general location is shown in Figure 2.1.

The North Rochelle Mine reserve is classified as a subbituminous coal with a very low sulfur content. Mineable reserves total 172 million tons and extend over the majority of the 1,960-acre federal lease area and adjacent 80-acre feed coal area. To expand this reserve base, Triton has filed a lease-by-application for an adjacent federal lease area that includes 150 million recoverable tons of coal. Minor amounts of coal have been produced from North Rochelle over the last several years to meet due diligence requirements of the federal coal lease. Triton recently announced that full-scale development will begin in 1997 with initial commercial production slated for late 1998.

The equipment planned for the North Rochelle Mine will be adequate to meet the coal production forecast of 15 million tons/year in 1999. Some risk to the LFC plant is involved because at this production rate, the mine will have a life of less than 25 years. This risk can be mitigated by either leasing additional reserves adjacent to North Rochelle or by supplying the plant from several other mines in the immediate area.

Data

Geological Conditions and Coal Resources

The North Rochelle Mine Area is located along the eastern flank of the Powder River Basin. Geologic formations in the Powder River Basin are of sedimentary origin, ranging from the Pre-Cambrian age to the lower Tertiary System and are probably less than 100 million years old. Rocks in the eastern and central portion of the Basin generally strike north-south and have very slight dips, usually less than 3 degrees toward the west.

Mining will disturb sediments ranging from the Paleocene Age Fort Union Formation to Holocene Age colluvium and alluvium. The coal to be mined occurs in the uppermost portion of the Fort Union Formation. The overburden lithologic units present in the mine area consist of alternating shale, sandstone, siltstone and coal of the Wasatch Formation.

The two mineable seams of coal in the area belong to the Tongue River Member of the Fort Union Formation. The Lower Canyon Seam of the Wyodak Bed is identified as the main or "E" seam. The rider seam or "D2" seam is believed to be an extension of the Anderson Seam, the upper seam in the Wyodak Bed. Thin carbonaceous stringers are found in the Wasatch Formation above the coal seams but are of limited extent and poor quality.

The main coal seam is located at a depth of about 110 feet on the southeast side of the mine area, and about 290 feet below the surface on the west side. The average overburden thickness is 207 feet. The main seam varies from 40 to 70 feet thick, and within the mine area it is fairly uniform, averaging 61 feet.

The rider coal seam above the main seam varies from less than 1 foot to over 8 feet in thickness, and is not continuous over the entire mine area. It will be mined in the northern section of the mine area where it averages 7 feet thick and is separated from the main seam by 3 to 10 feet of interburden.

Triton estimates that approximately 172 million tons of coal can be recovered from the mine area. The main seam accounts for the majority of the recoverable coal with 170 million tons. About 2 million tons of the minor seam are recoverable due to sporadic thickness and quality.

Geotechnical

Geotechnical studies were completed in 1982 for the North Rochelle Mine facilities design. This same information forms the basis for foundation design for the LFC Commercial Plant.

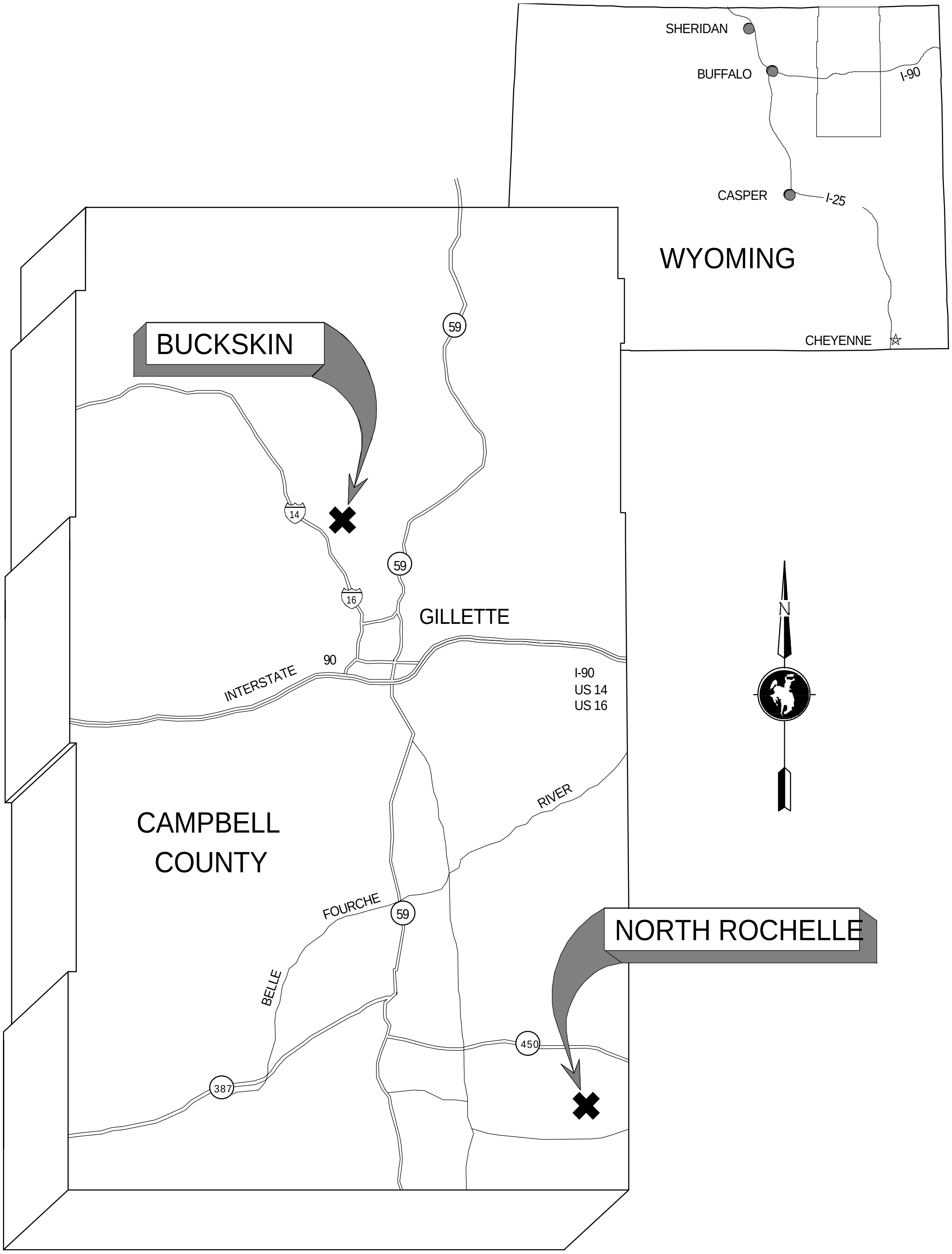
Coal Quality

The weighted average as-received quality for the recoverable reserves is outlined below.

	As-Received Basis
% Moisture	27.00
% Volatile Matter	31.60
% Fixed Carbon	36.70
% Ash	4.70
% Sulfur	0.23
Btu/pound	8,750

Because of its very low sulfur content, the North Rochelle coal is classified informally as a "super-compliance" coal.

Figure 2.1: North Rochelle Mine Location



Section 3.0 Coal Sampling and Testing

Summary

In order to determine the suitability of a candidate coal for LFC upgrading, the coal is subjected to the same three-step evaluation process that was use to determine the applicability of the LFC technology to Buckskin Mine coal. Because the ENCOAL Plant has been extremely successful in processing this type of subbituminous coal, the evaluation process is considered to be a very reliable predictor.

Successful completion of the evaluation process has determined that Powder River Basin coal is a good candidate for upgrading using the LFC technology. Additionally, because of the similarities between North Rochelle and Buckskin coals, there is a very high level of confidence in the ability to apply experience gained at the ENCOAL Plant to the processing of Powder River Basin coal in an LFC facility. Also, based on the effectiveness of the three-step laboratory evaluation process and the success of the ENCOAL Plant, a full-scale plant test of candidate coals similar to Buckskin coal is not required.

Introduction

Not all low-rank subbituminous and lignite coals are suitable for upgrading utilizing the LFC technology. In order to identify suitable candidates, a sequential evaluation process is employed.

In the first step, the candidate coal's physical and chemical properties are compared to technical screening criteria. Good agreement with the screening criteria strongly suggests success will be achieved in the next phase of testing. Table 3.1 details these criteria. The significance of these criteria and the respective values are as follows:

- High moisture content adds more value by upgrading.
- Low ash content is required because the ash remains in the solid product, PDF.
- The lower the fuel ratio, the greater the amount of volatile mater available for recovery as CDL.
- The H/C ratio needs to be high in order to ensure volatile matter will evolve with a high percentage of recoverable hydrocarbon vapor and not oxygen based gases (i.e., carbon dioxide and carbon monoxide).
- Free swelling is an important consideration concerning coal handling and processing in the drying and pyrolyzing stages of the LFC process.

The second step in the evaluation process is referred to as the Phase I Technical Feasibility Study. This employs small-sample testing of the candidate coal in a thermogravimetric analyzer (TGA), where the sample is subjected to mild gasification conditions. Fourier Transform Infrared (FTIR) spectroscopy is used to analyze the gases generated during the testing. Combining FTIR results with proximate and ultimate data for the as-received coal and the residual solid product (char) facilitates generation of a mass balance suitable for preliminary LFC plant design. Successful completion of this step demonstrates the technical feasibility of using the LFC process for upgrading the candidate coal.

A Phase II Study is the third step in the evaluation process and is intended to demonstrate the viability of a commercial-scale LFC project. This step employs large-scale sample testing in a Sample Preparation Unit (SPU) equipped with a CDL recovery system and FTIR analytical capability for gas analysis. The SPU provides the necessary quantities of liquid CDL and solid PDF for a detailed product analysis: in turn, this analysis provides data for an accurate mass balance and for product marketing assessments. In addition to a budgetary plant design and marketing study, the Phase II Study also includes operating cost analysis, plant site and infrastructure assessment, and financial analysis.

Data Section

In leu of large-scale sample testing in the SPU, an alternate coal test was conducted at the ENCOAL plant to provide the necessary data for the Phase II Study. In October and November 1995, nearly 5,000 tons of North Rochelle Mine coal was transported via truck to the Buckskin Mine for processing in the ENCOAL plant. After screening to 2 x ⅛ inch size, approximately 2,500 tons of coal was processed between November 21st and November 26th, 1995. A summary of parameters for the North Rochelle coal tested at CT&E and the resultant PDF qualities are outlined in Tables 3.2 and 3.3, and values for Buckskin PDF are shown for comparison. As can be seen from this information, the North Rochelle coal processed increased in heating value from 8,600 Btu/lb to over 11,300 Btu/lb. The PDF produced was lower in quality than anticipated when the average coal reserve feedstock quality values are considered. This lower product quality may be explained, however, by examining the coal feedstock quality used for the ENCOAL plant test. The North Rochelle coal processed was higher in ash and therefore lower in Btu value than the composite average of the reserve. Therefore, the resultant PDF was also higher in ash and lower in Btu than anticipated. TEK-KOL believes that the PDF quality would have been enhanced if a representative sample of the total reserve coal was processed. However, by correlating between the coal quality processed and the actual average coal reserve quality, an 11,400 Btu/lb, and a 6-8% ash PDF may be inferred. This corrected PDF quality is used as the basis for this study.

CDL quality is shown in Table 3.4. In general, the North Rochelle CDL exhibits characteristics very similar to Buckskin CDL which has proven to be a valuable fuel, and contains components with chemical feedstock potential.

Conclusions

Evaluation of the testing data shows that, with the exceptions of lower moisture, sulfur, and ash contents, North Rochelle coal is quite similar to the Buckskin coal in meeting key criteria. Based on the similarity between the two coals and the success of the ENCOAL Plant in processing Buckskin coal, it can be concluded that:

- North Rochelle coal is a good candidate for upgrading using the LFC technology.
- There is a very high level of confidence regarding application of experience gained at the ENCOAL Plant to the processing of North Rochelle coal utilizing the LFC technology.
- The three-step process of evaluation to determine if a candidate coal is suitable for upgrading by the LFC process is effective.

Table 3.1: Technical Screening Criteria Comparison

	MOISTURE CONTENT (wt %)	ASH CONTENT (wt %)	FUEL RATIO[2]	H/C MOLAR RATIO[3]	O/C MOLAR RATIO[4]	FREE SWELLING INDEX[5]
Technical Screening Criteria	20-34	≤5	<1.4	≥0.80	≤0.20	≤2
N. Rochelle Criteria Testing Results[7]	25.9	4.7	1.17	0.81	0.20	<2
Buckskin Criteria Testing Results	29.1	5.3	1.14	0.83	0.18	<2
ENCOAL Plant Data[1]	28.9	4.8	1.07	0.86	0.18	NT

NOTES:
1) As-Received Test Data are for the period of 1/22/94 - 4/7/95.
2) Weight Ratio of Fixed Carbon to Volatile Matter (Ultimate Analysis)
3) Molar Ratio of Hydrogen to Total Carbon (Ultimate Analysis)
4) Molar Ratio of Oxygen to Total Carbon (Ultimate Analysis)
5) NT: Not Tested
6) NA: Not Available
7) Data are for 97% of Recoverable Reserves

Table 3.2: Run of Mine Coal Qualities

	Buckskin ***(Average of '95-May '97)***	**North Rochelle** ***(November 1995 Test)***
Proximate		
Moisture (wt%)	28.0	28.0
Ash (wt%)	5.5	5.6
Volatile (wt%)	32.0	31.0
Fixed Carbon (wt%)	34.5	35.4
Ultimate		
Moisture (wt%)	28.0	28.0
Carbon (wt%)	49.5	49.2
Hydrogen (wt%)	3.5	3.4
Nitrogen (wt%)	0.8	0.7
Sulfur (wt%)	0.4	0.2
Ash (wt%)	5.5	5.6
Oxygen (wt %)	12.3	12.9
Thermal Energy Btu/lb (Kcal/kg)	8,350 (4,639)	8,600 (4,778)

Table 3.3: PDF Quality Comparison

	Buckskin ***(1995 Average)***	**North Rochelle** ***(November 1995 Test)***
Proximate		
Moisture (wt%)	8.90	8.10
Ash (wt%)	8.90	7.50
Volatile (wt%)	24.50	22.30
Fixed Carbon (wt%)	57.34	61.80
Sulfur (wt%)	0.36	0.30
Thermal Energy Btu/lb (Kcal/kg)	11,100 (19,980)	11,300 (20,340)
Ash Mineral Analysis	Same as Coal	Same as Coal
Ash Fusion Temperature	2220^{o}F (1216^{o}C)	2250^{o}F (1232^{o}C)
Hardgrove Grindability Index	47	46

Table 3.4: CDL Quality Comparison

	Buckskin ***(1995 Average)***	**North Rochelle** ***(November 1995 Test)***
API Gravity (^{o})	2.3	3.0
% Sulfur	0.6	0.3
% Nitrogen	0.7	1.6
% Oxygen	10.8	8.0
Viscosity @ 122^{o}F or 50^{o}C cSt	240	350
Pour Point ^{o}F (^{o}C)	80 (27)	75 (24)
Flash Point ^{o}F (^{o}C)	218 (103)	220 (104)
Heating Value: Mbtu/gal (Kcal/kg)	140 (2051)	138 (2022)
% Water	0.6	0.5
% Solids	2 - 4	3.8
% Ash	0.2 - 0.4	0.6

Section 4.0 Market Assessment of PDF and CDL

Introduction

The LFC Process is unique compared to other low-rank coal upgrading processes in that it produces two marketable products, PDF and CDL. PDF and CDL are truly coproducts because the viability of a future commercial LFC plant will depend on getting substantial revenue from each product stream. Recent marketing efforts have focused on identifying and developing the highest value markets for each product. Results of these efforts made it possible to estimate that existing market prices will net back revenues in the range of $18 to $20 per ton and barrel for PDF and CDL respectively.

Summary

PDF can compete in two domestic U.S. markets: the electric utility market and the noncoking coal metallurgical market. The electric utility industry offers the opportunity to participate in a large volume but strongly price-competitive market. TEK-KOL, through studies completed by Resource Data International (RDI), estimates that market volume for PDF will total 78 million tons/year by 2000 and will increase to 148 million tons/year by 2005.

The application of PDF to noncoking metallurgical coal applications shows great promise for increasing net back values. PDF offers a very competitive alternative for pulverized coal injection and, because of its high fixed carbon content, has competitive advantage in direct iron reduction processes.

Based on available markets and pricing, TEK-KOL marketers project that 80% of the PDF production from a three-module LFC Commercial plant could be sold into the utility market, and the remaining 20% can be moved into the metallurgical market.

CDL from the ENCOAL Plant has been sold to date in the residual fuel oil market as an industrial boiler fuel, but has more potential when fractionated into four separate products. Considerable work has been completed in determining CDL 's composition, and value-added markets have been identified for potential CDL-derived products. A process has been developed to separate CDL into four component fractions:

- crude cresylic acid,
- petroleum refinery feedstock, similar to a petroleum gas oil,
- oxygenated middle distillate usable as an industrial fuel, and
- pitch suitable for blend stock into anode binder products.

Each of these markets is well defined, and discussions with potential customers have proven the viability of these CDL -derived products.

Data
PDF Markets

The U.S. electric utility market is clearly the largest market for PDF, but a relatively small but growing market for noncoking metallurgical coals appears to provide the best opportunity for higher net back values for PDF. Both of these markets are discussed in further detail in the following sections.

In general, however, the wide acceptance of PDF into the broad utility, metallurgical, or industrial marketplace depends on PDF's meeting three important product handling and utilization criteria:

1. The potential for PDF to self-ignite must be equal to or less than the potential for the parent coal to self-ignite.

2. The dustiness of PDF must be less than the dustiness of Powder River Basin coal.

3. PDF flame stability and other combustion characteristics must remain constant as the volatile content of PDF is reduced.

Laboratory combustion tests and large-scale commercial test burns have demonstrated that PDF meets all three criteria. It has been proven that PDF will burn very well, and that PDF is anywhere from less dusty than, to as dusty as run-of-mine (ROM) Powder River Basin coal. ENCOAL has also shown that it can produce stable PDF through a ground-spreading technique, and commercial shipments of PDF stabilized using that method showed no tendency toward self-heating. A faster mechanical stabilization process has recently been proven in trials run at the ENCOAL Plant, and a commercial-sized version is incorporated into the design of the LFC Commercial Plant.

Detailed descriptions of laboratory combustion tests and commercial test burn results are incorporated in other reports published by the DOE.[1] [2] [3]

U.S. Utility Markets
Overview

To better define the potential market for PDF, Resource Data International (RDI) was engaged to perform a competitive market study. That study, completed September 8, 1995, addressed the U.S. utility market in detail and arrived at a number of significant conclusions:

1. Fifty-three power plants operated by 34 utilities were identified as the "best potential" market for PDF on the basis of meeting the following criteria:

   - These utilities had boilers requiring low-ash fusion coal (primarily cyclone and wet bottom boilers).

- The boilers required high-Btu fuel.

- The utilities wanted to switch to low-sulfur coal to meet Phase I and Phase II CAAA compliance levels.

- Transportation economics were favorable.

These 53 plants represent a potential annual market of 65 million tons by the year 2000 and 81 million tons by the year 2005.

2. Additionally, 37 power plants were identified as a "challenging" market for PDF because they burn coal with different specifications than those of PDF. Given price incentives and PDF 's other advantages, however, the utilities may adopt PDF as a fuel. Appropriate strategies will target this huge potential market: these 37 plants represent a 13 million-ton/year market by the year 2000 and 67 million tons/year by the year 2005.

The expected net back value of PDF into the "best potential" and "challenging" markets is estimated to be in the $18 to $20 per ton range (in constant 1996 dollars for an 11,400 Btu/lb product) for the great majority of the utilities analyzed. The PDF net back values estimated by RDI were based upon evaluating PDF against the most competitive high-Btu coal source to a specific power plant, which were generally coals form the Uinta Basin of Colorado and the Green River and Hams Fork Basins of Wyoming; to a lesser extent, low-fusion Pocahontas #3 coal and other Eastern bituminous coals.

A number of factors could have a significant positive impact on the size and value of the utility market for PDF. These factors, some of which were touched on in the RDI study, are discussed below and were not reflected in the utility market revenue estimates used for this project economics.

Positive PDF Burning Characteristics - NO_x Emission Reduction

Recent research indicates an important environmental advantage that PDF could bring to the utility market: laboratory and test burn data suggest that combustion of PDF could result in lower NO_x emissions than would result from the combustion of other bituminous coals.

A laboratory combustion test of PDF and an Australian bituminous coal performed by Electric Power Development Company (EPDC) in Japan in 1994 appeared to indicate NO_x emissions levels that were roughly proportional to the nitrogen contained in the coal. PDF, which had 40% less nitrogen than the Australian coal, produced 40% lower NO_x emissions. Another significant finding of this laboratory combustion work was that the same percent reduction of NO_x emissions was maintained as the amount of overfired air was increased. (The use of overfired air is a NO_x reduction technique). Additionally, while increasing the amount of overfired air typically results in less complete combustion of the coal (as evidenced by the higher percentage of unburned carbon in the ash of the Australian coal), there was only a very minor increase in unburned carbon in the PDF ash at high levels of overfired air.

A 1995 test burn of PDF at Muscatine Power & Light's Unit 8 indicated NO_x emission levels for PDF /Powder River Basin blends equal to or less than straight-run Powder River Basin coal, and a 1996 test burn at Indiana-Kentucky Electric Cooperative's Clifty Creek Station demonstrated NO_x reduction in what may represent the most significant test to date. At this utility, PDF was blended with Ohio high-sulfur coal and burned in the Babcock & Wilcox open-path, slag-tap boiler with full instrumentation. In addition to increasing the unit's capacity relative to the base blend, burning the PDF blend resulted in at least a 20% NO_x reduction. A third party analysis confirmed these results.[3]

Conventional wisdom would expect PDF to produce higher flame NO_x emissions than Powder River Basin coal because PDF burns at higher flame temperatures than Powder River Basin coal, and higher flame temperatures generally produce higher NO_x emissions. However, observation and data from test burns and the Shell Development Company laboratory show increases in flame stability. A more stable flame produces uniform temperatures and reduces localized "hot spots," possibly contributing to reduced overall flame NO_x generation.

These data are not conclusive, but are indicative of PDF's potential to reduce NO_x emissions. Many factors beyond the nitrogen content of the coal may impact NO_x generation in a boiler, including boiler type and size, boiler load, burner design and flame characteristics of coal. However, combustion of PDF/coal blends in a low-NO_x burner at Black Hills Power in December 1996 still showed no increase in NO_x production, so additional full-scale test burns of PDF in utility boilers will be required to more definitively assess PDF's potential in reducing NO_x emissions.

The potential economic impact of Title IV of the 1990 Clean Air Act Amendments (CAAA) on the utility industry is enormous, and PDF, a fuel that can help reduce NO_x emissions, may become a major preferred fuel source. While regulations under Title I of the CAAA, which have been finalized, are less severe than the regulations expected under Title IV, some plants may have trouble meeting Title I compliance with simple burner technology. These plants could present marketing opportunities for PDF. No attempt was made to quantify the positive impact on expected PDF net back values resulting from the utility industry placing a value on a fuel that could reduce NO_x emissions.

As environmental regulations become stricter, especially those regarding NO_x, the desirability of PDF may increase. In fact, the potential for reduced NO_x emissions increases the likelihood that PDF will become a preferred fuel in all utility markets.

Metallurgical Market Opportunity

The markets for PDF have opened up for metallurgical use in the steel industry, where a demand for coke substitutes is building up world wide. In steel making, in addition to the usual drive for higher efficiencies, environmental constraints on coke production and the lower limits on permissible stack emissions are strongly motivating development of new technologies. Techniques to replace coke in the blast furnace, new iron ore reduction techniques and new steel making technologies have emerged to replace the traditional blast furnaces and coke oven batteries.

Coke in the blast furnace has three main functions: as a reductant, a heat source, and as a porous structure to support the burden inside the blast furnace. Pulverized coal injection (PCI) and granular coal injection (GCI) are techniques that replace the coking coal in the blast furnace. Either method can only assume the coke's roles as reductant and heat source, so injection rates are limited by the remaining need for coke to provide the porosity and support the burden. Regardless of this limitation and the concurrent increases in the efficiency of coke production and blast furnace operation, PCI injection rates of 250Kg/ton-hot-metal (thm) have been realized on blast furnaces with coke rates between 200-250 Kg/thm. PDF's characteristics make it an ideal replacement for the coke and limited testing has been conducted utilizing CDL as a blast furnace injectant. The reduction in coke production also provides an additional market for CDL as a replacement for coal tars produced during the coking process.

Another answer to the decline of coke production lies in direct reduction techniques, some of which are already commercial, and other technologies, using direct smelting techniques, have passed the pilot plant stages. Both offer opportunities for PDF marketing. These emerging technologies, which include COREX, HIsmelt, AISI direct steel making, Fastmet, the DIOS process, and the Romelt process are coal-based methods to produce clean iron units. For these new technologies a different set of coal requirements have emerged, centered on the volatile content and the elemental structure of coal. The new criteria do not require strength, but favor low to medium volatile content, low sulfur, and low atomic ratios of oxygen, hydrogen, and carbon. The LFC process removes volatiles, sulfur, hydrogen, and oxygen from coal and enhances carbon content of the solid product. Therefore, the coal properties that are important for the production of direct reduced iron (DRI), specifically a high fixed carbon content, a low sulfur content, and a high reactivity, make PDF attractive as a reductant for the conversion of iron ore to DRI.

Three tests were performed in the United States and Japan to assess the acceptability of PDF in the metallurgical markets. For simplicity the results of these tests will be explained briefly:

1. Petrographic studies were performed by both Mitsui Mining Company and Coal Petrographic Associates. Both studies determined the reflectivity of PDF to be 1.3, a value that is typical of bituminous coals. Typical reflectivity of subbituminous coal is 0.5 to 0.6. This is evidence that the LFC process transforms some of the characteristics of subbituminous coal into those of bituminous coal, and the PDF displays positive characteristics of both subbituminous and bituminous coals.

2. A grinding test was performed by Williams Patent Crusher and Pulverizer Company. Results indicate mill performance with PDF increased by over 60% (under two separate operating conditions) compared to Appalachian high volatile coal that is used for the comparative standard.

3. Flowability tests performed by Jenike and Johanson indicated that PDF is suitable for dense phase pneumatic conveying and does not have cohesive, compressibility or permeability characteristics that would require special equipment for pneumatic conveying.

Further research into uses of PDF in metallurgical markets is ongoing. In 1996, a contract was issued to test PDF in DRI production. The DRI has been processed and analyzed, showing that they achieved 96% metallization and contained 0.08 to 0.15% sulfur. These results confirm that PDF can be used as a good reductant for DRI. ENCOAL is proceeding with the next step of testing to determine the feasibility of utilizing PDF as the reductant for a targeted iron ore and DRI process.

Beyond the testing that ENCOAL has contracted to determine the acceptability of PDF in the metallurgical market, companies in Japan and Austria have also conducted testing that indicate PDF displays a high degree of thermal stability and is acceptable as a slurried feedstock for coal gasification.

Table 4.1 is a summary of the North American blast furnaces with existing and planned PCI/GCI systems. Currently this market amounts to approximately 4 million tons/year and will grow as the planned projects materialize. To date, discussions with PCI customers have been concentrated with those with installations in Northern Indiana, along Lake Michigan, because those plants have the most favorable logistics for PDF originating in Wyoming. In particular, assessment of competing Eastern bituminous coals has indicated that net backs in the range of $26 to $30 per ton for PDF product are attainable. Twenty percent of the production of a three-module LFC plant is reflected in the economics of this study using this price range.

Transportation Issues

The most significant transportation issue that would affect the marketing of PDF is creating access to more than one railroad. For this Commercial Plant Study, this issue is solved by the plant siting choice. The chosen commercial plant site provides access to both the Burlington Northern Santa Fe, and the Union Pacific railroads. Access to two railroads assures access to the most competitive transportation rates out of the Powder River Basin.

Table 4.1:
Existing North American PCI/GCI Blast Furnaces *(December 1996)*

Company and Plant Location	Operation Start Date	Capacity (thm/day)	Annual Coal Needs (Mtpy)	
			@200 lb/thm	@400 lb/thm
Bethlehem Steel Burns Harbor, IN	1995	2x7000	490	980
U.S. Steel Gary, IN	1993	3x2700 1x9000	595	1190
Inland Steel Indiana Harbor, IN	1993	1x2500 1x3000 1x10000	543	1085
Armco Steel Ashland, KY	1973	1x3500	123	245
USS/Kobe Lorain, OH	1994	2x3800	266	532
Stelco Hamilton, Ont	1996	2x7000	490	980
National Steel Detroit, MI	late 1996	1x7000	245	490

CDL Markets

When the ENCOAL LFC Plant was designed and built, it was envisioned that crude CDL could be readily sold into the industrial residual fuel oil market or be sold as a chemical feedstock. Because of these expectations, and to keep the ENCOAL Plant simple, the facilities for upgrading CDL were not incorporated into the ENCOAL Plant design.

The industrial residual fuel oil market has not delivered the expected opportunity for CDL. Instead, the four CDL-derived products have been found to offer the most substantial market possibilities, and both the three-module and the single-module commercial plants described in this Study incorporate some simple processes to produce four marketable product streams from CDL. Other markets for crude CDL, such as the refinery feedstock market, could be developed, but are not likely to produce net backs as high as those from the four distillation products.

Most of the physical characteristics of CDL such as pour point, heating value, flash point, viscosity, and API gravity are in the range of acceptability for many residual oil markets. Table 4.2 compares North Rochelle Mine CDL specifications with typical #6 oil specifications. The low sulfur content of CDL makes it desirable in blends with high-sulfur residual fuels that are more prevalent (and carry a lower value in the market place). The two major impediments to CDL gaining wide acceptability as an industrial boiler fuel are its odor and its lack of compatibility when blended with the most readily available residual fuel oils.

Other markets for crude CDL that are currently being investigated include petroleum refinery feed stock, marine transportation, and coal tar replacement.

Table 4.2: Typical CDL Quality

	North Rochelle CDL	**Low Sulfur No. 6 Oil**
Gravity (° API)	3.0	5.0
Sulfur (wt %)	0.3	0.8
Nitrogen (wt %)	1.6	0.3
Oxygen (wt %)	8.0	0.6
Viscosity @ 122°F or 50°C (cSt)	350	420
Pour Point °F (°C)	77 (25)	50 (10)
Flash Point °F (°C)	220 (104)	150 (66)
Mbtu/gal (Kcal/kg)	138 (2022)	150 (2198)

CDL Upgrading

In the summer of 1995, Dakota Gasification Company was engaged to perform a laboratory investigation of the composition of the crude CDL produced by ENCOAL. That study indicated the presence of many high value chemical constituents in CDL that are potentially extractable. On the basis of that study, M.W. Kellogg was engaged to design a process to separate crude CDL into four intermediate products that would be useful feedstocks for various chemical and refining processes:

1. Crude cresylic acid - suitable for shipment to cresylic acid refiners for separation into phenol, cresols and xylenols. The production from the Commercial plant is anticipated to be approximately 50% cresylics and 50% neutral oils. Based upon

discussions with the leading North American manufacturer of cresylic acid products, the delivered value of the cresylic acid portion has been estimated at $66.62/bbl. The delivered value of the neutral oils has been conservatively estimated at $16.00/bbl. Calculating the weight averaged delivered value and subtracting out the cost of caustic extraction and transportation gives a net back value in the range of $19 to $21 per barrel for the crude cresylic CDL product.

2. Pitch - usable as a binder in anode manufacturing. Other uses include roofing pitches and road sealants. According to discussions with anode pitch manufacturers, CDL pitch product is not suitable on its own without blending. CDL pitch has been tested by several pitch manufacturers and delivered value estimates of $42.00 to $51.55/bbl have been obtained. For the purposes of this Study, the lower value minus transportation cost has been used.

3. Refinery Feedstock (low oxygen middle distillate) - a satisfactory replacement gas oil feed to catalytic cracking units in petroleum refineries, resulting in the production of transportation fuels. Discussions with several Wyoming region refining companies have resulted in an estimated product value of $16.00/bbl delivered to Billings, MT.

4. Oxygenated Middle Distillate - planned to be used as an industrial fuel. Several companies have expressed interest in this fraction due to its high catechol content; however, detailed assessment is currently being examined. For the purposes of this Study, a conservative net back value of $5.50/bbl has been assumed for this product.

The crude cresylic acid and the pitch represent important new raw material sources for their respective industries because of the decline of traditional feedstock sources derived from coke oven liquids, in turn resulting from the reduction in metallurgical coke capacity and production.

Conclusions

Based upon market research studies, TEK-KOL believes that 80% of the PDF production from a three-module LFC Commercial plant could be sold into the utility market. The opportunity represented by PDF metallurgical markets represents at least 20% of the plant capacity. For the purposes of this study, average PDF net-back revenues in the range of $18 to $20 per ton were used.

CDL continues to be of interest in the fuel oil markets, but a far more attractive option is to separate it into the four higher value products outlined above on 10%, 30%, 35%, and 25% ratios respectively. Well-defined markets exist for each of the above products, and discussions continue with potential customers have indicated that the CDL fractions may be suitable for their needs. The weight averaged net back value of CDL utilized for this Study is in the $18 to $20 per barrel range.

Section 5.0 Engineering
5.1 Introduction and Overview

Summary

The LFC Commercial Plant design is based on three major components: design information from the ENCOAL project, the ENCOAL Plant's most recent data and operating results, and test runs of coal from the North Rochelle Mine as discussed in Section 3.0. The North Rochelle Mine, the prospective mine site, is about 15 miles southeast of Wright, Wyoming, or 60 miles southeast of the existing ENCOAL plant.

The engineering work for this Phase II Study was performed by TEK-KOL or Mitsubishi Heavy Industries through agreements with the TEK-KOL Partnership. The first step in engineering was to prepare a document that would make it possible to estimate costs. This design basis document covers the geological, geotechnical, climatological, capacity, engineering and utility requirements for the LFC Commercial Plant project. It also establishes the codes and standards that will be followed and sets forth the underlying assumptions and process performance.

Introduction

As it exists today, the LFC Technology is well developed and demonstrated through the joint efforts of the TEK-KOL partners, SGI International and Bluegrass Coal Development Company. Bench-scale and pilot-plant testing of the LFC Process began in the early 1980's. By 1987, when ENCOAL's then-parent Shell Mining Company became involved, SGI had worked with three successively larger process demonstration units (PDU)s at three different equipment manufacturers' research and development facilities. The TEK-KOL Partnership was formed in mid-1987, and SGI and Shell Mining Company continued process testing and development at Salem Furnace Company where the latest PDU was in operation.

In 1987 and 1988, the Salem PDU was used to perform a substantial amount of pilot-plant testing of the LFC Process and laboratory testing of PDF and CDL. It was at the Salem PDU that the process evolved from a batch to a semi-continuous operation, and several alternative liquid recovery schemes were tested. The pilot-plant tests showed that the process was viable, predictable and controllable and could produce PDF and CDL to desired specifications. Based on the success of the PDU testing and product market assessments, Shell Mining Company decided to proceed with the 1,000-ton/day ENCOAL Plant.

Not a pilot plant or a "throw-away," the ENCOAL Plant was designed to commercial standards and is intended to operate for at least 10 years. The Plant, designed, constructed and operated in cooperation with the U.S. Department of Energy, uses commercially available equipment as much as possible, and state-of-the-art computer control systems. Best available control technology for all environmental controls minimizes releases, and a simplified flowsheet makes two products matched to existing markets. The intent in designing the Plant was to demonstrate the core process without making the project overly complicated or expensive.

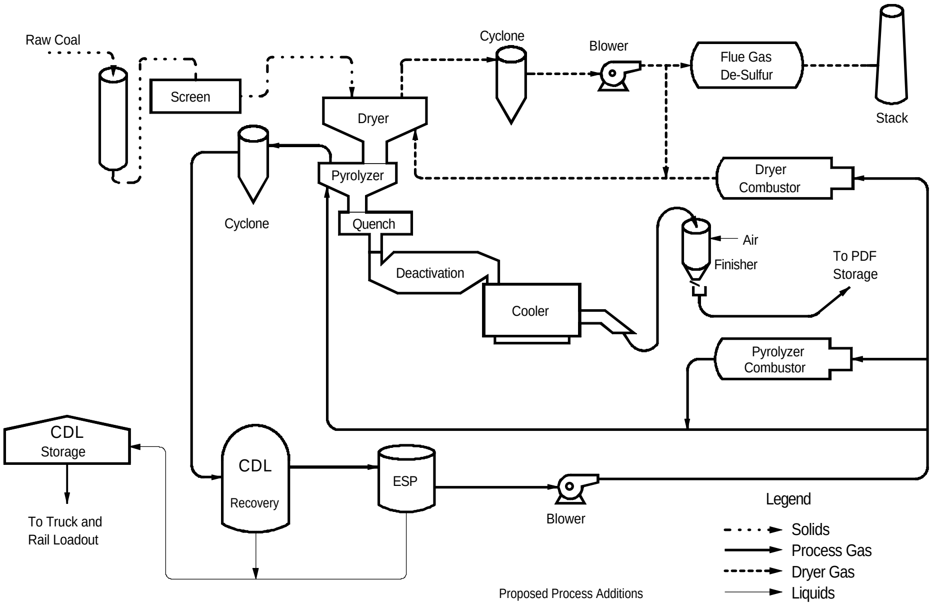
Operation of the ENCOAL Plant over the last 4½ years revealed that numerous equipment and process modifications were necessary to produce PDF and CDL efficiently, continuously and within specifications. Most of the early changes were related to equipment reliability, plant availability, plant operability and maintenance. By 1993, as the Plant was operated for extended periods, process shortcomings appeared. Deactivation of PDF was not possible in the original plant configuration, and an additional processing loop was added. In 1994-95, combustor controls were changed, and a process water clean-up system and an oily solids disposal facility were added.[4]

Most recently, the testing of a PDF finishing step was completed. This testing successfully demonstrated that stabilized PDF can be made continuously in commercially available equipment, and this equipment will be added to the ENCOAL Plant in 1997. This valuable information and experience has been incorporated into the design of the LFC Commercial Plant.

Process Description

Figure 5.1.1 is a simplified flow diagram of ENCOAL's application of the LFC Technology. The process involves heating coal under carefully controlled conditions. Nominal 3- by 0-inch ROM coal is conveyed from the Buckskin Mine to a storage silo. The coal from this silo is screened to remove oversize and undersize materials. The 2 x ⅛ inch coal is fed into a rotary grate dryer where it is heated by a hot gas stream. The residence time and temperature of the inlet gas have been selected to reduce the moisture content of the coal without initiating chemical changes. The solid bulk temperature is controlled so that no significant amounts of methane, carbon monoxide or carbon dioxide are released from the coal.

Figure 5.1.1: ENCOAL Plant Simplified Process Flow Diagram



The solids from the dryer are then fed to the pyrolyzer; there a hot recycle gas stream increases the temperature to about 1,000°F on another rotary grate. The rate of heating and the residence time of the solids are carefully controlled because these parameters affect the properties of both solid and liquid products. During processing in the pyrolyzer, all remaining water is removed, and a chemical reaction occurs, releasing volatile gaseous material. Solids exiting the pyrolyzer are quickly quenched to stop the pyrolysis reaction, then transferred to a small surge bin in the vibrating fluidized bed (VFB) deactivation loop shown in Figure 5.1.2.

In the VFB loop, the partially cooled, pyrolyzed solids contact a gas stream containing a controlled amount of oxygen. A reaction, termed oxidative deactivation, occurs at active surface sites in the particles, reducing the tendency to spontaneously ignite. The heat generated by this reaction is absorbed by the fluidizing gas stream. This gas stream then circulates through a cyclone, which removes entrained solids, passes through a heat exchanger and is returned by a blower to the VFB. Oxygen content in the loop is maintained by introducing the proper amount of air through a control valve. Excess gas in the loop is purged to the dryer combustor for incineration.

Following the VFB, the solids are cooled to near atmospheric temperature in an indirect rotary cooler. A controlled amount of water is added in the rotary cooler to rehydrate the PDF to near its ASTM equilibrium moisture content. This is also an important step in the stabilization of the PDF. Additional contact with oxygen at fairly low temperatures is the final step in stabilization, and a finishing step at this point in the process will be added as shown in Figure 5.1.3. The cooled PDF is then transferred to a storage bin. Because the solids have little or no free surface moisture and are likely to be dusty, a patented dust suppressant is added as PDF leaves the product surge bin. Patents have been issued on both the deactivation and rehydration steps.

Figure 5.1.2: PDF Deactivation (VFB) Loop Simplified Flow Diagram

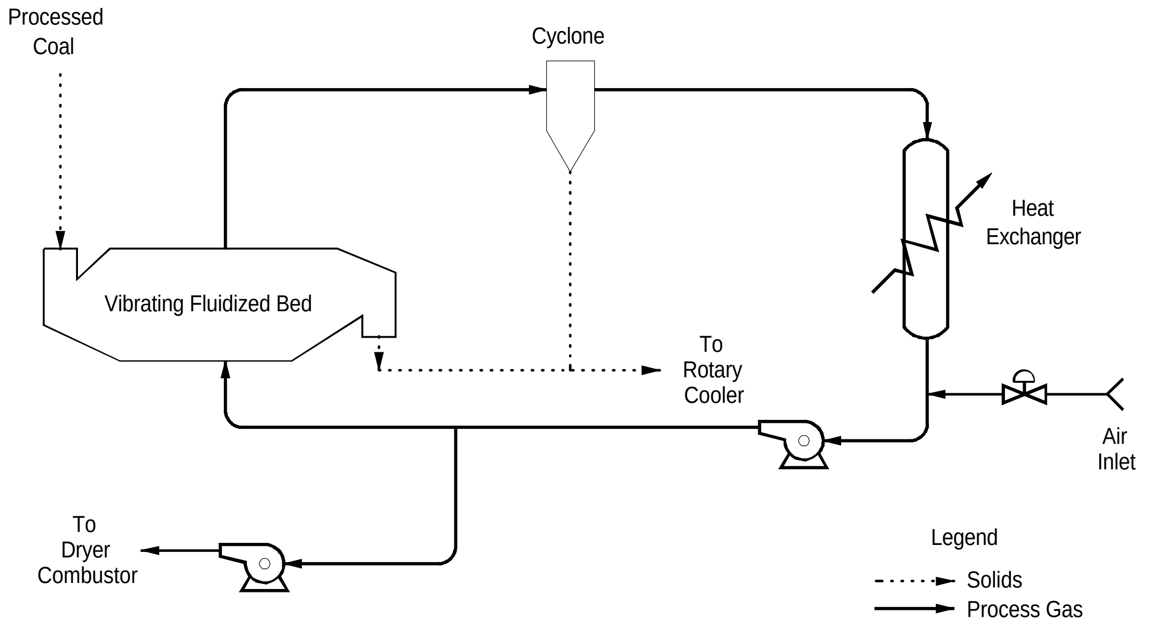
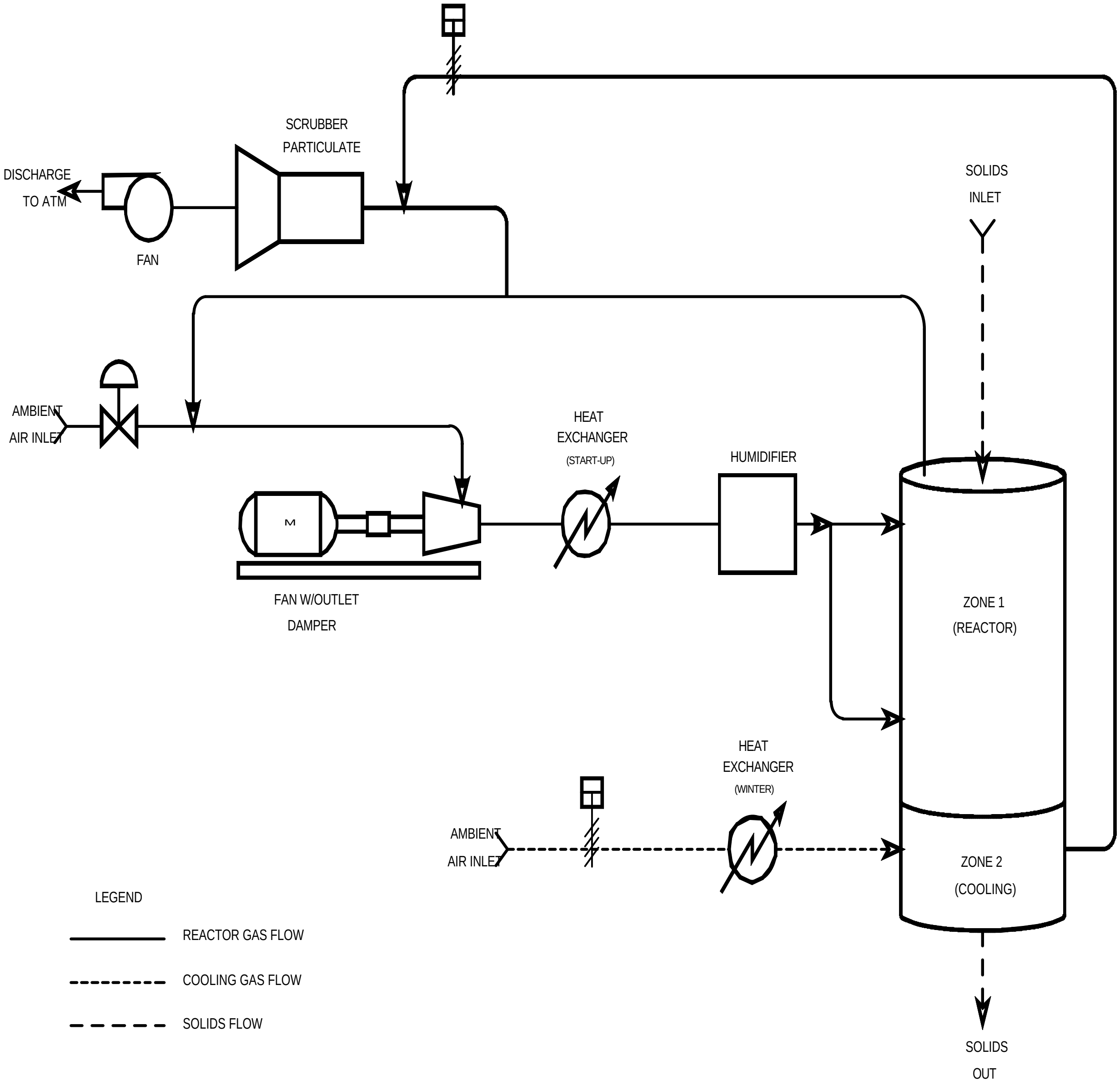


Figure 5.1.3: PDF Finishing Loop Simplified Process Flow Diagram



The hot gas produced in the pyrolyzer is sent through a cyclone for particulate removal. The gas is then cooled in a quench column to stop any additional pyrolysis reactions and to condense the desired liquids. Only the CDL is condensed in this step; the condensation of water is avoided. Electrostatic precipitators recover any remaining liquid droplets and mists from the gas leaving the condensation unit.

Almost half the residual gas from the liquid recovery unit is recycled directly to the pyrolyzer. Some of the remainder is burned in the pyrolyzer combustor and then blended with the recycled gas to provide heat for the mild gasification reaction. The remaining gas is burned in the dryer combustor, converting sulfur compounds to sulfur oxides. Nitrogen oxide emissions are controlled through appropriate combustor design. The hot flue gas from the dryer combustor is blended with the recycled gas from the dryer to provide the heat and gas flow necessary for drying.

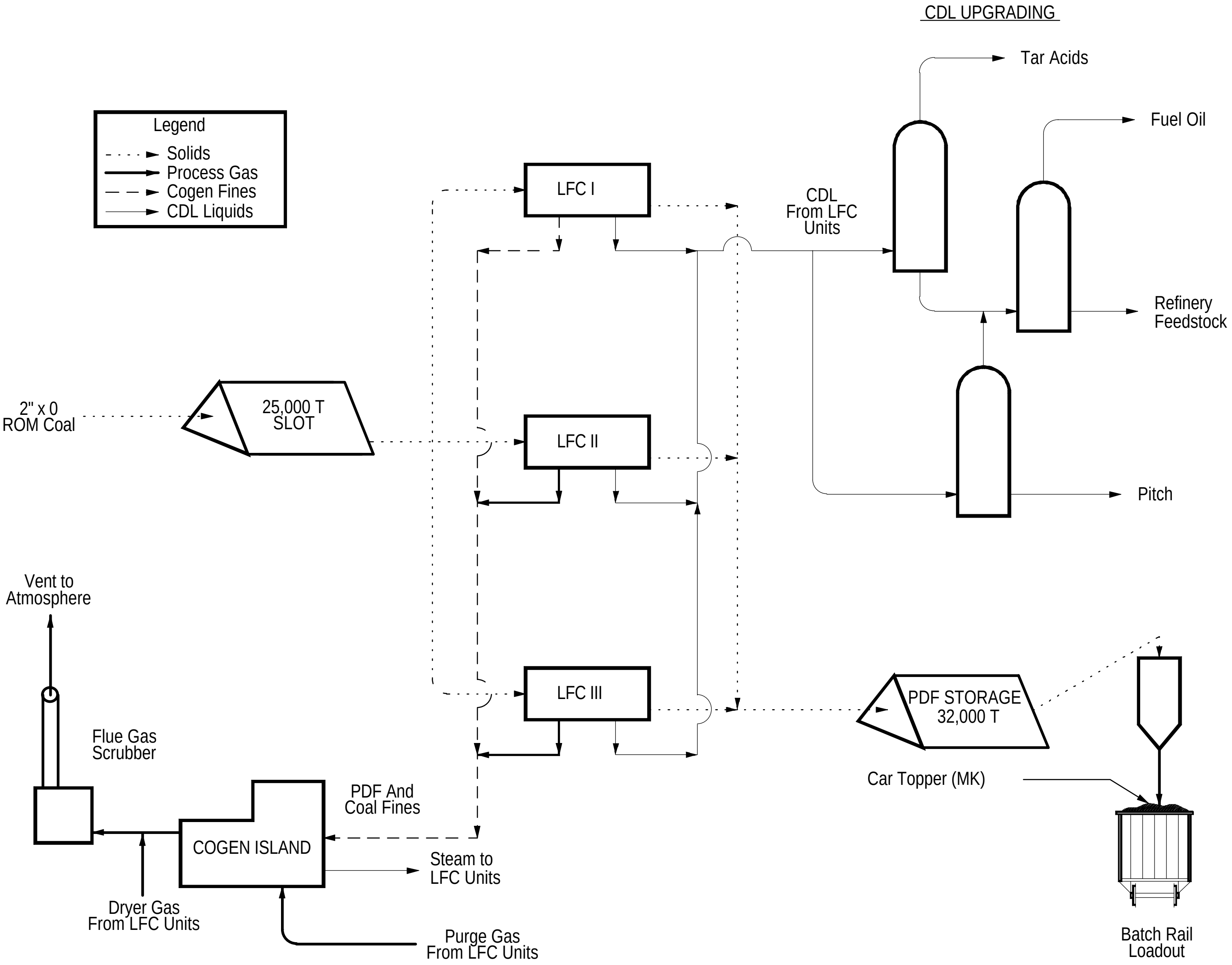
The unrecycled portion of off-gas from the dryer is treated in a wet gas scrubber and a horizontal scrubber, which use water-based sodium carbonate solutions. The wet gas scrubber recovers the fine particulates that escape the dryer cyclone, and the horizontal scrubber removes most of the sulfur oxides from the flue gas. The treated gas is vented to a stack, and the spent solution is discharged into a pond for evaporation. The Plant has several utility systems supporting its operation, including nitrogen, steam, natural gas, compressed air, bulk sodium carbonate and glycol/water heating and cooling systems.

Figure 5.1.4 is an overall concept diagram for the full-scale, three-unit LFC Commercial Plant. CDL upgrading, raw coal storage, PDF storage and flue gas scrubber system are common to all three LFC units. A cogeneration power plant, operated by a third party, is also sited adjacent to the commercial plant. Run-of-mine 2 x 0 inch coal from the mine is transferred to each unit by a transfer tower with a sampler and taken to a large slot storage barn. A single conveyor feeds each LFC unit.

After processing, the PDF from each unit is transferred to a single conveyor that elevates the PDF to a large storage barn. When a customer's unit train arrives, the PDF is loaded into rail cars by an automated batch weigh system, and a chemical car topper is applied to reduce product losses during shipment. CDL from each unit is combined and sent through a CDL solids removal system prior to being piped to the CDL upgrading unit. Here the CDL is converted to four products by distillation and solvent extraction: a crude cresylic acid, pitch, a refinery feedstock and an oxygenated middle distillate.

The fines removed in the drying and pyrolysis steps in each LFC unit serve as a supplementary fuel for a cogeneration boiler. The fines are conveyed in an inerted pneumatic system to the boiler, where they are blended with ROM coal and burned along with dirty gases from the PDF quench system and deactivation loop. A flue gas clean-up system is provided for both a cogeneration boiler and dryer off-gas as shown.

Figure 5.1.4: Commercial Plant Concept Diagram



Intellectual Property

TEK-KOL's assets are inextricably tied to the LFC technology and as such, protection of these assets is paramount. Since the original U.S. patent number 4,395,309 on the overall LFC Process was issued to Dr. Ernest Esztergar in 1984, there have been many improvements and additional discoveries. To solidify TEK-KOL's intellectual property position, nine additional patents have been issued or filed, including an updated version of the overall LFC patent.

In addition to the patentable discoveries, a significant amount of "know-how" and proprietary information is involved in the LFC Control System. Computer code, mathematical algorithms and plant operating data comprise a large body of intellectual property that is protected by maintaining confidential information filing, labeling and distribution controls. Table 5.1.1 illustrates the current status of the TEK-KOL intellectual property.

Conclusion

The following sections describe the engineering work that was performed to scale the ENCOAL Plant up from 1,000 tons/day to a full commercial-size plant with three 5,000-metric ton/day parallel units. The design basis document and information from the material balance were used to develop the design for the commercial plant. MHI engineering developed the design and costs for the LFC modules, and TEK-KOL staff worked up the off-sites, selected major equipment, determined permitting requirements and cogeneration/scrubber design and costs.

Unlike the ENCOAL Plant, the commercial design is based on an MHI combined dryer/pyrolyzer grate design that has been used for quenching coke. Some questions remain on the application of this grate to the LFC Process, but these questions will be answered by modeling and testing in the near future. The cost benefits of using the combined grate design are quite significant. Other differences between the ENCOAL Plant and the commercial design are discussed in later sections.

The transition from the Salem PDU to the ENCOAL Plant was from 200 pounds/hour to 1,000 tons/day. The scale-up to the Commercial Plant is much smaller, and entails much less risk. Risk has also been significantly reduced through hands-on experience with commercial-size equipment and the solution of the process challenges identified during the demonstration phase of the project. In addition, more than 3,000 tons of North Rochelle coal have been processed in the ENCOAL Plant, and no problems have been identified. The plant performance and product recoveries used in this Phase II Study are based on the results of this coal test run, and are tempered by ENCOAL's experience with the Plant over the past few years.

Table 5.1.1: TEK-KOL Intellectual Property Status *(as of 3/12/97)*

No.	Subject of Invention	Inventors	Responsible Person	Filing Date	Estimated Bar Date	Patent Atty. Location	Status
1	U.S. Patent #5,401,364 a process for treating noncaking, noncoking coal to form char with process derived gaseous fuel having a variably controllable calorific heating value.	F. Rinker	F. Rinker	Filed 3/11/93 Name Change CIP 7/94	April 1994	Larry Meenan Toledo, OH	Issue Date: March 28, 1995
2	U.S. Patent #5,372,497 Process and Apparatus for igniting a burner in an Inert atmosphere. Issue Date: December 13, 1994	F. Rinker D. Coolidge	F. Rinker	Filed in Japan 29 November 1995	May 1994	Larry Meenan Toledo, OH	Amended 9 Apr 96 Formal examination by Japanese patent office requested. Patent "Pending."
3	Process for passivation of reactive coal char. Russian Patent #96105953/Feb 97	D. Coolidge F. Rinker E. Esztergar D. Horne	F. Rinker	Filed 9/8/95 U.S. Patent office.	May 1995	Larry Meenan Toledo, OH	U.S. awaiting examiner's response to latest amendment filed 5 Dec 96. Filed 8 Apr 96 in Japan Filed 27 March 96 in Russia. Filed 8 May 96 in Uzbekistan. Filed 15 Apr 96 in Kazakhstan. Filed 25 July 96 in Indonesia. Patent "Pending" in U.S., Japan, Uzbekistan, Kazakhstan & Indonesia.
4	U.S. Patent #5,547,548 Pyrolysis Process Water Disposition.	M. Siddoway F. Rinker E. Esztergar	F. Rinker	Filed 7/18/94	May 1995	Ned Randle St. Louis, MO	Issue Date: 20 Aug 96
5	U.S. Patent #5,582,807 Method and apparatus for removing particulate and gaseous pollutants from a gas stream.	M. Siddoway C.F. Liao	F. Rinker	Filed 11/11/94	November 1994	Ned Randle St. Louis, MO	Issue date: Dec 10, 96.
6	Method for creating a hydrocarbon liquid from coal pyrolysis by condensation of the hydrocarbon liquid from the gas phase.	M. Siddoway A. Cover J. O'Donnell C. Chang R. Londrigan J. Frederick E. Manning S. Anderson	F. Rinker	Filed Nov 4, 1994	November 9, 1994	Ned Randle St. Louis, MO	Final rejection received decision made not to pursue with U.S. Patent Office.
7	U.S. Patent #4,582,511 Spray system for MK dust suppression additive. (Issued Apr 15, 1986)	M. Siddoway C.F. Liao	F. Rinker	Filed 7/18/94	May 1995	Ned Randle St. Louis, MO	Original Patent Expires 2003. Decision made to not pursue with US Patent Office.
8	U.S. Patent #5,601,692 Process for treating non-caking coal to form passivated char. Russian Patent #96105954/Feb 97	F. Rinker E. Esztergar D. Coolidge D. Horne	F. Rinker	Filed 12/1/95 U.S. patent office.	April 1996	Larry Meenan Toledo, OH	Issue Date: 11 Feb 97 Filed 12 April 96 in Japan Filed 27 March 96 in Russia. Filed 8 May 96 in Uzbekistan. Filed 15 Apr 96 in Kazakhstan. Filed 25 July 96 in Indonesia. Patent "Pending" in Japan, Uzbekistan, Kazakhstan & Indonesia.
9	Lean Fuel combustion control method.	D. Coolidge T. Kuhn J. Powers F. Rinker	F. Rinker	Filed 10/30/95 U.S. patent office.	September 1995	Ned Randle St. Louis, MO	Formal Examination Requested. Patent "Pending." Status inquiry to examiner has been sent in Nov 96. Second Letter sent Feb 97.

Note: DOE patent waiver issued for all

5.2 Process Flow Diagrams and Material Flow Balance

Summary

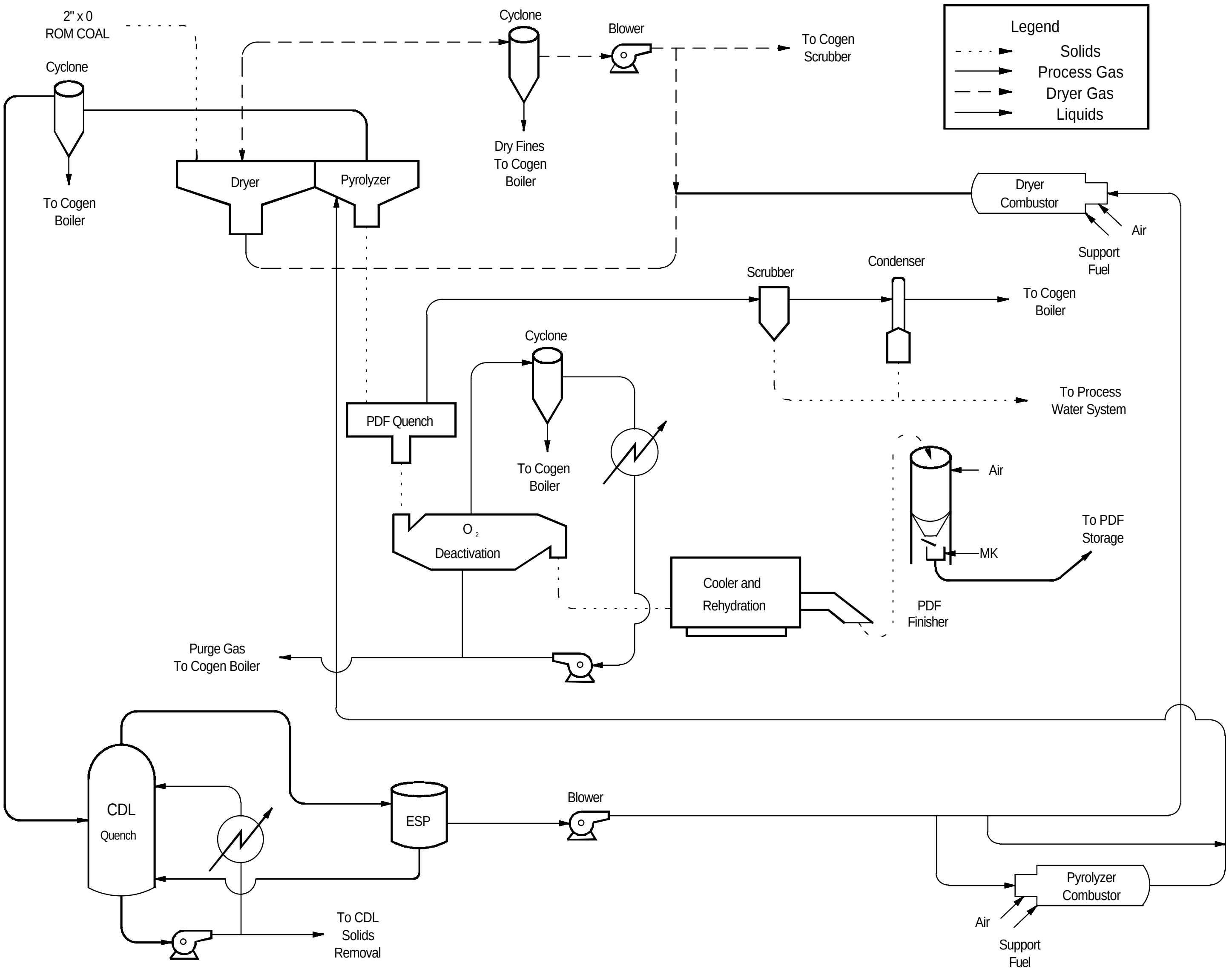
The processing parameters for applying the LFC Technology to Powder River Basin coals have been compiled from over 4½ years of operating the 1,000-ton/day ENCOAL Plant. This information was combined with TEK-KOL Development Center data to predict the material balance for Buckskin coal processed in a 5,000-metric ton/day LFC module. A material balance gives an estimate of product yields and qualities based on a single set of processing conditions. Variations in processing parameters will affect these results, and the ENCOAL Plant has demonstrated the flexibility of operating parameters in the LFC Process.

To make design decisions for the commercial plant, a material balance was calculated using Hyprotech’s process simulator, HYSIM. HYSIM cannot utilize an in-depth characterization of a solid, nor can it accurately simulate the pyrolysis reaction with a stand-alone unit operation. Consequently, the simulation had to be complemented with information from the ENCOAL Plant to accurately predict product yields and qualities. The product recoveries predicted for Buckskin coal in the material balance are 0.45 barrels CDL and 0.5 tons of PDF/ton of coal processed. For the same coal, ENCOAL Plant yields have been demonstrated to be 0.51 barrels of CDL and 0.5 tons of PDF. Laboratory data and a plant test of North Rochelle coal established similarities between Buckskin and North Rochelle products and processing conditions. As a result, the material balance did not have to be adjusted for the differences between Buckskin and North Rochelle coal.

Introduction

The transition between the ENCOAL Plant (as described in Section 5.1) and the proposed LFC Commercial Plant presented a number of challenges that were met with process and design changes. (Refer to Figure 5.2.1 for an overview of the Powder River Basin commercial module.) Variations arose with the first step of the process: coal fed into the ENCOAL Plant is screened to remove oversize and undersize materials that are then returned to the mine. However, a 15,000-metric ton/day commercial plant would return much greater quantities of fine coal to the mine, affecting overall mine product quality and presenting problems in shipping and handling. In addition, the screen used at the ENCOAL Plant is the largest made; scaling-up the current operation would require many parallel trains of equipment, an extremely expensive proposition. To solve this problem, designers replaced the pre-screening with a "vibrating grizzly," which separates and layers the coal on the grate, the larger pieces directly on the grate, the smaller pieces above the larger. This arrangement is intended to keep fine materials from plugging or trickling through the grate. During drying, fines will fluidize, leave the process and be recovered by a bank of cyclones that are much larger than ENCOAL's current four-unit dryer cyclone. From the cyclones, the fines will be pneumatically conveyed to fuel a nearby cogeneration plant, or to an agglomeration system that will recover the fines for later use as fuel.

Figure 5.2.1: Commercial Plant LFC Module



A second variation follows changes in the screening step and in a combined dryer and pyrolyzer piece of equipment: at the ENCOAL Plant, properly sized coal moves onto a Salem Corporation rotary hearth, where drying and pyrolyzing occur in discreet steps in separate pieces of equipment. In the commercial system, the ROM coal is not sized prior to entering the facility, but is segregated just prior to entering the dryer. This means that all of the ROM coal is processed in the facility, not just the +⅛ x 2 inch coal that is currently processed in the demonstration plant. Once segregated, the coarse coal is distributed on a large rotary grate as the bottom layer, and the fine coal is placed on the top of the coarse coal to form the top layer. The coal is then dried and pyrolyzed using a single combined dryer and pyrolyzer grate proposed by Mitsubishi Heavy Industries. The drying and pyrolysis steps remain discreet and separate steps, but are performed on one piece of equipment. Such multi-step processing on a single circular grate has been demonstrated extensively by MHI in commercial-scale coke quenching applications in Nagoya, Japan. TEK-KOL and MHI realize that changes in the screening process and equipment design may produce some technical difficulties, but in anticipation, MHI has already begun a testing program to identify and mitigate any possible problems.

The remainder of the commercial-scale process parallels the demonstration-scale process up to the stabilization segment. Stabilization, returning the char to the same stable state as the parent coal, involves three steps: deactivation at high temperatures, cooling and rehydration, and finishing. As in the ENCOAL Plant process, the deactivation loop in the commercial plant design contacts the solids with a gas stream containing a controlled amount of oxygen to allow oxygen absorption. This step, termed oxidative deactivation, begins to stabilize the reactive solid product. Replicating this process in the larger commercial plant would require numerous VFBs to handle the increased output. To keep down the number of equipment pieces in the commercial plant, TEK-KOL is testing a single quiescent bed concept based on Salem Furnace's “doughnut” design for use as a deactivator. After the deactivation unit, the solids are then cooled and rehydrated to near their ASTM equilibrium moisture content. The fines recovered by the bank of cyclones in the deactivation unit are returned to the product stream prior to rehydration. In the commercial plant design, the cooled PDF is then conveyed to the final finishing unit to ensure stability.

In this final step, pilot tested at the ENCOAL Plant, the solids are contacted with an oxidizing gas stream. Gas temperatures and flowrates are controlled to encourage the maximum oxidation rate without the risk of solid ignition. The gas stream humidity is controlled to keep the solids from adsorbing or desorbing any water. The residence time is sufficient to allow the solids to adsorb enough oxygen to prevent significant additional oxygen uptake, greatly diminishing the risk of spontaneous ignition once the solids are discharged from the plant. Because the solids have minimal free moisture and tend to be dusty, a proven dust suppressant is added as the PDF as it is transferred to a large storage barn.

Other variations occur on the gas side of the LFC process. In the ENCOAL Plant, hot gas produced in the pyrolyzer is sent through a single specially designed cyclone for removal of the particulates. In the commercial plant, multiple cyclones will handle the large flowrates. The new cyclones will be more efficient and have higher pressure drops to prevent solids-carryover into the CDL and prevent duct plugging. As stated above, the fines from the bank of pyrolyzer cylcones are pneumatically conveyed either to a fines agglomeration unit for recovery as PDF, or to a nearby cogeneration unit for use as utility boiler fuel.

In the commercial plant design, CDL captured by the quench tower is passed hot through a centrifuge to remove 90% of the entrained solids in the oil. The CDL is then pumped to storage. This centrifuge process was pilot tested in the ENCOAL Plant, and these test data were used to design the commercial plant systems.

Because of larger gas flows, multiple electrostatic precipitators recover any remaining liquid droplets and mists from the gas leaving the condensation unit in the commercial plant design. The new design multiplies the original three electrostatic precipitators to handle larger gas flows, enhance oil recovery and prevent damaging mists from entering the rest of the equipment.

In the original process design, a single liquid was produced and sold. The commercial plant process differs: after condensation, the CDL undergoes further upgrading, producing four liquids. In this upgrading process, the oil is sent to a crude cresylic acid column where most of the cresylic acids are separated and collected. The oil is then sent to a tar vacuum flasher for recovery of the pitch fraction. The stream remaining after the cresylic acid and pitch recovery is sent through a two-stage naphtha extraction. Here, two additional fractions will be recovered, namely refinery feedstock and an oxygenated middle distillate. A portion of the oxygenated fraction is used as make-up fuel in the combustors.

The use of this oxygenated middle distillate improves on the ENCOAL Plant process. In the current ENCOAL and commercial plant designs, 70% of the process heat is provided by noncondensed hydrocarbons in the pyrolysis gas. In the ENCOAL design, the remaining 30% of support fuel was provided by natural gas, an expensive product that may not be readily available in all locations, especially foreign plant sites. The oxygenated middle distillate, not split off in the orignal process, is an ideal fuel. It is the lowest value CDL product, making it inexpensive, and is readily available from the process.

Incorporating the oxygenated middle distillate as make-up fuel in the combustor operation necessitates changes in combustor controls, and these changes are currently under study.

As stated in the Summary, the material balance was simulated using Hyprotech's HYSIM process simulator. This material balance is a summation of data generated at the TEK-KOL Development Center and process data obtained and analyzed from actual operation of the ENCOAL Plant. The product yields generated in the laboratory generally match Plant data; however, if the data differed, the Plant data were considered more accurate and were used in the development of the material balance. The processing conditions used in the simulation are in agreement with operating parameters in the ENCOAL Plant.

Despite this careful collection and input of laboratory and plant data, some difficulties in the material balance remained. The large array of hydrocarbons in pyrolysis gas makes it extremely complex and almost impossible to characterize. However, pyrolysis gases yield two measurable products:

noncondensable gases and oil. By aiming to match yields of noncondensable gases and oil rather than to actually characterize the gases from the pyrolysis reaction, the simulation could predict a material balance with increased accuracy. Design based on simulated material balances can be further refined by examining the relationship between the two pyrolysis gas product streams. The streams are inversely correlated: increased gas flows reduce oil recovery, and more oil recovery is accompanied by decreased gas flows.

The oil (CDL) recovery predicted by the simulation is 0.45 barrels/ton, but the ENCOAL Plant has actually yielded 0.51 barrels of CDL /ton of coal processed. The reason for this discrepancy is twofold. First, the simulated pyrolysis reaction tends to predict lower oil than is actually recovered, and higher heating value noncondensable gas. Second, the simulation shows a slightly higher production of pyrolysis water than the plant data and laboratory results indicate.

Because increased gas flow means less CDL recovery, assuming a 0.45 barrel/ton recovery of CDL will mean more noncondensable pyrolysis gas, and for this reason, a larger gas processing system was designed. If CDL recovery is 0.51 barrels/ton, as has been demonstrated at the ENCOAL Plant, gas flow will be less.

It is important to note at this point that the predicted quantity and quality of recovered products can be changed in the simulation by manipulating gas constitutents. For example, one of the gases that leaves the coal bed is pyrolysis water. By adjusting the pyrolysis water, the ratio of condensed gases to noncondensed gases is affected, subsequently affecting the simulated production of CDL. Less pyrolysis water means more CDL. Despite the simulated predictions, however, plant data indicate that the commercial plant will show this higher CDL recovery, and plant economics are based on higher CDL recovery figures.

TEK-KOL has a simulation program, LFC SIM (Level 0), which is capable of predicting pyrolysis bed performance. This tool will be used in future design analysis to better predict products of pyrolysis and to utilize the variability of the process.

Data Section

Analysis at the TEK-KOL Development Center showed no physical or chemical differences between Buckskin coal and North Rochelle coal that would require significant design changes. A commercial plant referenced to Buckskin coal will be able to incorporate North Rochelle coal readily.

Laboratory analysis did reveal some slight differences. The higher oxygen content of the North Rochelle coal, as quantified by the oxygen to carbon ratio, appears to generate a greater amount of noncondensable gas dominated by carbon dioxide and carbon monoxide. This make-up would lower the heating value of the recycled pyrolysis gas stream. However, elemental analysis on North Rochelle coal indicates that less pyrolysis water should be produced, increasing CDL recovery.

After laboratory analysis, 2,500 tons of North Rochelle coal were processed at the ENCOAL Plant. Originally, the sample was to have been tested using new processing parameters, but because the coals were so similar, the parameters were not adjusted. Results obtained from processing the North Rochelle coal at these conditions indicate that slightly less CDL is recovered and the PDF has higher volatile matter. This indicates that at under Buckskin processing conditions, the North Rochelle coal was slightly underpyrolyzed. To obtain the same product yields and quality as Buckskin coal, the North Rochelle coal needs to be pyrolyzed to a slightly greater degree than what was accomplished at the Buckskin coal operating parameters.

Conclusion

This section describes the process and provides data for the 5,000-metric ton/day LFC module for Buckskin coal. Information from the 1,000-ton/day ENCOAL Plant was combined with laboratory data to formulate the basis for the LFC Commercial Plant. Data generated at the ENCOAL Plant and the TEK-KOL Development Center agree on important concepts, indicating that the scale-up to the commercial-size plant entails little risk. Laboratory data and process simulation seem to confidently predict the scale-up, and to predict and control differences in product quality and recovery from one coal to another. Furthermore, because the material balance is based on 4½ years of actual operating experience with Buckskin coal, plant performance results carry special weight.

5.3 Equipment Lists and Equipment Data Sheets

Summary

The equipment list and data sheets for this Feasibility Study were jointly produced by TEK-KOL and MHI. These documents define the project scope-of-work and allow for consistent transfer of information between the engineering disciplines.

Introduction

The equipment list includes all numbered equipment items necessary to operate a stand-alone LFC commercial plant. This includes all major LFC process equipment, supporting subsystems, off-sites utilities, CDL upgrading, solids handling and mobile equipment. The equipment list was developed using a combination of process information from the heat and material balance, the design basis document, budget quotes from major equipment suppliers, results of in-depth engineering studies, and scaling-up from the ENCOAL Plant. As much as possible, critical LFC process components were specified based upon ENCOAL Plant experience in successfully operating similar equipment.

Data

Equipment data sheets were produced for the major LFC process components listed in Table 5.3.1. Comprehensive data sheets were developed for these items as they were the most critical process components, and the largest cost impact components of the Powder River Basin Phase II Study. These data sheets were used to obtain reliable, accurate vendor quotes for equipment supply.

Data sheets were not produced for the remaining equipment items found in the equipment list. Although some areas such as solids handling and CDL upgrading included many large components and had a significant cost impact, enough information was available from recent installations or engineering studies to adequately estimate and size the equipment without developing data sheets for vendor quotation.

The remaining equipment data sheets, which consist mostly of support subsystems and off-sites utilities components, will be developed in more detail by the engineering contractor for the commercial plant. Estimates for equipment in these areas were made based upon information from the heat and material balance, the design basis document, and scale-up from the ENCOAL Plant.

Conclusion

The equipment list and data sheets produced for this Feasibility Study summarize the extensive engineering efforts made to quantify, size, specify and price the necessary equipment components needed to operate an LFC commercial plant. The equipment list and data sheets are complete for all critical LFC process components, but may be improved in the areas of deactivation and finishing as more engineering data are obtained from operating and testing in the ENCOAL Plant.

Equipment contained in the areas of solids handling and CDL upgrading were not individually quoted, but were estimated as overall systems based upon recent detailed engineering studies or actual installations. The risk of error in cost is therefore low, but a more complete equipment list and possibly a more accurate estimate could be obtained if these areas were broken down into components rather than systems.

More detailed engineering is required on the plant support subsystems and off-sites utilities before data sheets can be produced to obtain vendor quotes. However, the components included in these areas are technically proven and small in cost when compared to the critical LFC process equipment, reducing the risk of error.

TABLE 5.3.1: Index of Equipment Data Sheets

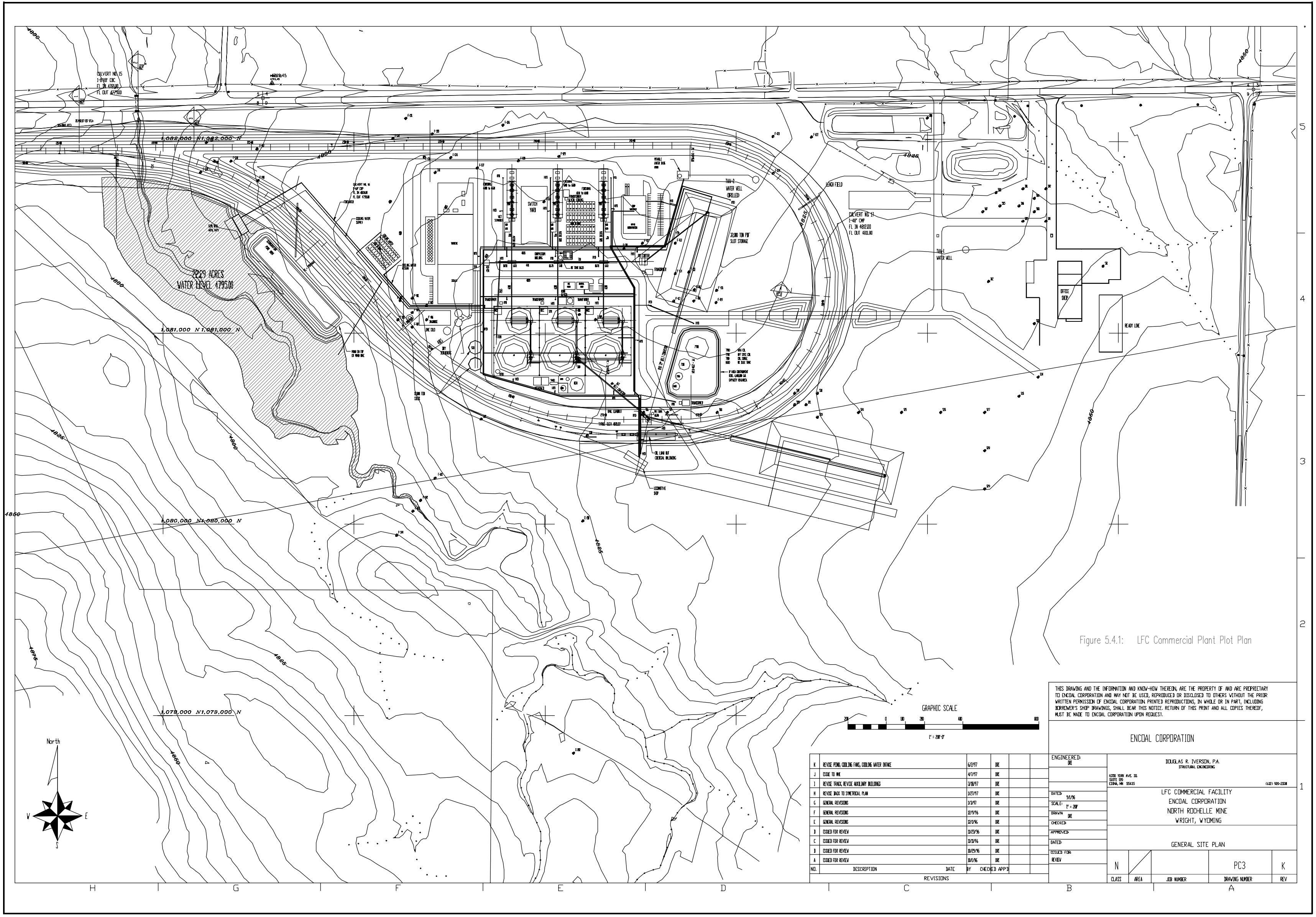
	Equipment Description	Produced By
1.	Circular Grate (Dryer & Pyrolyzer)	TEK-KOL/MHI
2.	Blower & Fan	MHI
3.	Electrostatic Precipitator	TEK-KOL/MHI
4.	Cyclone	MHI
5.	Combustor	MHI
6.	Overhead Travelling Crane	MHI
7.	Grizzly Screen	MHI
8.	Pan Conveyor	MHI
9.	Chain Conveyor	MHI
10.	Pneumatic Conveyor	MHI
11.	Heat Exchanger	MHI
12.	Quench Column	TEK-KOL
13.	Quench Table	TEK-KOL
14.	Oxidative Deactivation Unit(s)	TEK-KOL
15.	Rehydration/Cooling Unit(s)	TEK-KOL
16.	Finishing Unit(s)	TEK-KOL
17.	Flue Gas Desulfurization Equipment	TEK-KOL

5.4 Site Layout and Support Facilities

Summary

The site layout and support facilities sections of this Study were produced by TEK-KOL engineers following the guidelines of the design basis document. The main LFC Commercial Plant facilities were placed inside the North Rochelle Mine rail loop, integrated with the mine's solids handling system. A site plot plan developed according to this concept is illustrated in Figure 5.4.1.

Figure 5.4.1: LFC Commercial Plant Plot Plan.



NO.	DESCRIPTION	DATE	BY	CHECKED	APP'D
K	REVISE POND, COOLING FANS, COOLING WATER INTAKE	6/2/97	DRI		
J	ISSUE TO MHI	4/7/97	DRI		
I	REVISE TRACK, REVISE AUXILIARY BUILDINGS	3/18/97	DRI		
H	REVISE BACK TO SYMETRICAL PLAN	1/27/97	DRI		
G	GENERAL REVISIONS	1/3/97	DRI		
F	GENERAL REVISIONS	12/9/96	DRI		
E	GENERAL REVISIONS	12/1/96	DRI		
D	ISSUED FOR REVIEW	11/23/96	DRI		
C	ISSUED FOR REVIEW	11/11/96	DRI		
B	ISSUED FOR REVIEW	10/29/96	DRI		
A	ISSUED FOR REVIEW	10/1/96	DRI		

REVISIONS

Introduction

The site layout includes all plant and support facilities required for the operation of a stand-alone LFC Commercial plant. This consists of the main LFC Plant, off-sites utilities, CDL upgrading, tankage, solids handling, mobile equipment, miscellaneous personnel and facility support structures, a rail siding and liquids loadout facility.

The solids handling layout and equipment were chosen using the basic design assumptions listed in the design basis document. The solids handling system includes all the equipment and structures necessary to obtain raw coal from an expanded mine storage barn, transport feed coal into the plant, transfer PDF out of the plant, store PDF product, and load out PDF using the mine batch load out system. The solids handling facilities also include a system to handle below specification PDF. Existing mine sampling systems were utilized rather than including separate raw coal and PDF sampling systems.

Data

Major impacts on the design and cost of the solids handling system consisted of:

1. The required storage capacity in and out of the LFC Plant,
2. Distance between the mine feed coal transfer point to the LFC Plant raw coal storage,
3. Distance between the LFC Plant, PDF discharge, and the PDF batch loadout located on the mine rail loop,
4. Overall height of the LFC Plant and finishing structures,
5. Use of slot-type storage versus silo storage for PDF , and
6. Minimum sizing of belt conveyors to be 36 inches wide with a maximum angle of incline of 16 degrees.

Unit costs for most of the solids handling components were estimated using data from a Roberts and Schaefer Company design proposal prepared for the North Rochelle Mine in 1995. These costs were compared to other Zeigler Coal Holding Company installations, adjusted to present day dollars, and input as unit costs for the purposes of this Study.

The LFC Commercial Plant rail siding layout consists of two parallel tracks totalling over 3 miles of storage for rail cars. These tracks were spaced 15 feet apart, (center to center, minimum required space being 13 feet), and were oriented to run adjacent with the proposed mine rail loop. The design also included a locomotive warming shed and a covered loading and unloading area, with the ability to load up to four rail cars at the same time. Estimated costs for the rail siding were assembled using vendor quotes to install track and ballast on a dollar/foot basis, and switches on a dollar/switch basis. Grade work and construction of the subballast for the siding was not included in this section.

A complete list of all structures was jointly developed by TEK-KOL and MHI, and includes all structures needed for the main process equipment, supporting subsystems, electrical power distribution, solids handling, CDL upgrading and personnel buildings. The function, dimension and loading of each structure were analyzed individually to determine the type of construction needed in each case. Costs were estimated for smaller structures based upon a dollar/square foot or vendor quote. MHI engineering factors were used for estimating the main LFC buildings. Foundations and heating, ventilation and air conditioning were considered as part of the building estimate in all cases.

Tankage requirements to support the LFC Commercial Plant were estimated using the design basis product and chemical storage requirements, CDL product flows from the heat and material balance, scale-up from the ENCOAL Plant, and duplication of facility support tankage found on the Buckskin Mine site where the ENCOAL Plant is located. All storage tanks estimated were divided into two categories. Bulk storage tanks were typically 300,000 gallons or greater in capacity and were located in the tankfarm containment areas adjacent to the CDL upgrading facilities and rail loop. Day storage tanks were considered to be less than 300,000 gallons capacity and were located throughout the plant site. Cost estimates were based upon vendor quotation in 1996.

Mobile equipment needed for the LFC Commercial Plant was estimated based on the number of personnel, operating experience at the ENCOAL Plant, and maintenance of the road and rail system for the stand-alone facilities. Cost estimates for all mobile equipment were obtained either from vendors or recent Zeigler Coal Holding Company purchase records. This system does not include the installation of a fuel island and ready-line in support of the mobile equipment fleet, but uses the proposed mine fuel island to support the fleet.

Conclusions

Site layout and support facilities are fairly specific to a given location. Every potential host site for an LFC Commercial plant will require substantial site assessment work prior to finalizing a plant site. However, many of the same assumptions used to develop the Powder River Basin LFC Commercial Plant layout may transfer to other locations, and will require only minor modifications based upon the site location. Main areas impacted by location are the solids handling system, railroad track and miscellaneous structures.

Cost estimates made for the support facilities discussed in this section are heavily supported by recent cost data or extensive engineering studies. Some consideration could be given to modifying some assumptions affecting the layout of the solids handling equipment, however, as it is the largest cost item of the support facilities.

Other savings in capital costs could be realized if the LFC Commercial Plant were built and operated integrally with mine facilities. Facility personnel structures, mobile equipment and joint plant water systems are some examples of possible areas of duplication with a mine.

TABLE 5.4.1: Index of Structures and Buildings

	Description	Lead Role
BL 1a BL 1b BL 1c	LFC I Structure LFC II Structure LFC III Structure	MHI MHI MHI
BL 2a BL 2b BL 2c	LFC I Finishing Structure LFC II Finishing Structure LFC III Finishing Structure	TEK-KOL TEK-KOL TEK-KOL
BL 3	Control Room Building	TEK-KOL
BL 4	Admin, Shop, Warehouse	TEK-KOL
BL 5	Potable Water Building	TEK-KOL
BL 6a BL 6b	Locomotive Building Covered Loadout	TEK-KOL TEK-KOL
BL 7	Lime Transfer Building	TEK-KOL
BL 8a BL 8b BL 8c BL 8d	Main MCC/Switchgear Building MCC - CDL Upgrading MCC - Batch Loadout/PDF Storage MCC - Raw Coal Storage	TEK-KOL TEK-KOL TEK-KOL TEK-KOL
BL 9	Substation Building	TEK-KOL
BL 10	Cooling Water Building	TEK-KOL
BL 11	Waste Water Pond Building	TEK-KOL
BL 12	Process Water Building	TEK-KOL
BL 13	CDL Upgrading Building/Pad	TEK-KOL
BL 14	Air Compressor Building	TEK-KOL
BL 15	LFC Nitrogen Building	TEK-KOL
BL 16a BL 16b BL 16c	LFCI Finishing Scrubber Building LFCII Finishing Scrubber Building LFCIII Finishing Scrubber Building	TEK-KOL TEK-KOL TEK-KOL
BL 17	Guard House	TEK-KOL

5.5 Site Preparation and Drainage

Summary

This section addresses topsoil removal, excavation and grading work required for the construction of the LFC Commercial Plant and related facilities. TEK-KOL engineers estimated site preparation costs based on a Site Layout (see Figure 5.4.1) as described in Section 5.4, experience at the ENCOAL Plant, and unit costs obtained from recently completed jobs. Estimates for the LFC structure foundations and subfoundations were the responsibility of MHI and fall outside the scope of this section. Also, foundations for smaller buildings, slot storage facilities, railroad facilities, conveyors, pipelines and bulk storage facilities are addressed in other portions of the Feasibility Study.

While the unit costs employed in this estimate are well documented, the estimated acreages and excavation quantities are somewhat sensitive to exact plant location. The topography and soil horizons at the actual site selected could affect the total cost estimate.

Introduction

Site preparation includes topsoil removal, rough grading, mass excavation, road and drainage construction, pond excavation and lining, rail siding grade and subgrade, bridge access and fencing. The site plan calls for topsoil removal in the area of the LFC plant, the offsite storage and tank farm areas, along road alignments, and in the area of the reservoir. Topsoil removal costs include clearing and grubbing as required. Rough grading and mass excavation were estimated for building areas and foundations. Grading and excavation for ponds and tank farms were included in those particular estimates.

Key assumptions in developing a site preparation cost estimate involve unit costs, area topography and disturbed areas associated with the LFC plant, roads, lesser buildings, ponds, storage areas and tank farms. Unit costs for cut and fill, road construction, scoria for road surfacing, pond and containment area liner, and fencing were obtained from Triton Coal Company. Topsoil and excavation costs assumed a relatively short haul distance and/or a relatively large cut.

The topography of the commercial plant site was assumed to be similar to the rolling hills of the ENCOAL Plant site. The depth of topsoil was estimated at 26 inches. Disturbed acreages and excavation quantities were estimated based on design requirements for roads, ponds, storage areas and tank farms. Road and fence lengths were based on the Site Layout Plan (Figure 5.4.1).

Pond and tank farm sizes were calculated from the design basis. Specifically, pond size calculations resulted from LFC plant water needs and heat removal requirements. Tank farm size calculations were based on production rates, reserve requirements and shipment or receipt frequencies for raw CDL, upgraded CDL products and chemical bulk storage.

Data

Unit costs were applied to soil quantities, road and fence lengths, and pond and tank farm areas to generate a cost estimate for site preparation and drainage.

Conclusion

The cost estimate for site preparation and drainage was based on the commercial plant design basis document, as well as experience at ENCOAL and Triton. In cases where the two did not agree, the higher cost figure was used. Site topography was well defined, and a geotechnical report compiled for the North Rochelle Mine in 1982 provided fairly detailed soils information in the immediate area of the LFC facility. Based on the quality of this information, capital estimates for this section should be very sound.

5.6 Piping and Instrumentation Diagrams

Summary

This section covers piping and instrumentation diagrams (P&ID)s that serve to document the LFC Process as currently envisioned in the commercial plant. The P&IDs were generated by TEK-KOL engineers using the MHI circular grate approach to drying and pyrolysis. With the subsystem flow diagrams as a foundation, the commercial plant P&IDs were patterned after ENCOAL Plant P&IDs. They were developed in sufficient detail to document the process, its support systems, major equipment and control schemes, but not in sufficient detail to specify actual construction.

The P&IDs are divided into three categories: solids handling, main process and supporting utilities and subsystems. Potential design changes to certain components of the process could affect the P&IDs. Foremost among these are the deactivation, finishing and CDL upgrading systems.

Introduction

Subsystem flow diagrams were generated by TEK-KOL engineers to show major equipment and overall control logic for each process and support subsystem. The P&IDs were developed from these flow diagrams, adding major instruments, smaller equipment items, and flow paths for all solids and fluids affecting each subsystem. The P&ID symbols and overall design approach utilized the ENCOAL Plant P&IDs for guidance. In their present form, the commercial plant P&IDs do not contain secondary instruments and associated circuits (e.g, instruments that control secondary fluids such as instrument air and instrument purge). Additional detail will be added as engineering progresses.

The commercial plant P&IDs were not used for cost estimating; instead the instrumentation and control cost estimate was developed from a scale-up of the ENCOAL Plant. Because the ENCOAL Plant was the first LFC plant and one of its primary purposes was to gather data, it was heavily instrumented. Using this as a basis for estimating instrumentation and control provides a conservative cost estimate for the full-scale production facility. Some optimization of scale was obtained however, through the combination of utility systems into one to support a three module LFC Commercial Plant. This allowed for single system instrumentation and control versus three independant systems.

Conclusion

The P&IDs provide documentation for key process and support subsystems, showing significant equipment, primary instruments, piping/ductwork and control schemes. The P&IDs were not used to estimate control and instrumentation cost; rather, those costs were developed by scaling up the ENCOAL Plant instrumentation and controls. Section 5.9 of this report discusses this cost estimate.

It is expected that the current P&IDs will provide the basis for future refinements to the process and equipment list. These changes, along with greater detail, will be reflected in future revisions to the P&IDs.

5.7 Generic Subsystem Drawings

Summary

TEK-KOL engineers produced generic subsystem drawings using ENCOAL Plant subsystems as guides. These drawings were produced to aid in the design, layout and description of all plant support utilities and minor plant systems. Once produced, these drawings served as the foundation for the plant piping and instrumentation diagrams discussed in Section 5.6, and aided in the production of equipment and motor lists discussed in Sections 5.3 and 5.9 respectively. These drawings also aided in estimating the cost of individual support systems for the LFC Commercial Plant.

Introduction

The subsystem drawings include all plant utilities and minor plant systems that will support the operation the LFC Commercial Plant. These drawings also include CDL upgrading, a major facility not discussed in other sections of this study.

LFC Commercial Plant subsystem drawings were developed using ENCOAL Plant subsystems as models. The ENCOAL Plant systems were modified using accumulated operation knowledge and adjusted to fit commercial plant design basis. Nine major plant support subsystems perform a variety of functions.

1. Fire water - a network of underground and aboveground piping that supplies emergency water for fire control throughout the plant site.

2. Nitrogen - a centralized header and piping system supplying an inert gas for vacuum protection, equipment purges and instrument purges.

3. Glycol Water - a network of aboveground piping that continually circulates a 50/50 glycol/water mixture throughout the plant site. This system removes heat from the raw CDL subsystem, vaporizes liquid nitrogen and supplies heat tracing for all equipment and piping.

4. Cooling Water - continuously circulates pond water through a network of underground and aboveground piping throughout the plant site. Low pressure cooling water is used as a heat exchange medium and washdown water at low plant elevations, while high pressure water is used in higher plant elevations.

5. Utility Air - a network of piping to supply 125-psig air for maintenance or process requirements.

6. Instrument Air - a network of piping to supply "dry" 125-psig air for control valve and instrument applications.

7. Utility Steam - a network of piping suppyling low-pressure steam throughout the plant for cleanup and light process needs. Cogeneration steam will probably be the source for this purpose, but a small plant boiler was estimated for backup.

8. Process Water - continuously circulates a closed loop of water throughout the plant. This water is designated "process" water as it may come in contact with process gas streams and gather fines particulates and some light hydrocarbons.

9. Vapor Recovery - a blower, carbon filter pack and suction ductwork that collects plant odors from the process water system and vents to atmosphere.

Data

The commercial plant CDL recovery system varies from the ENCOAL Plant system in two respects. First, the commercial plant design calls for removing solids from CDL before it is sent to storage. This system design, pilot tested at the ENCOAL Plant, utilizes a centrifuge to remove 90% of the entrained solids from the hot oil.

Secondly, the commercial plant CDL recovery system includes an extensive CDL upgrading facility to produce four CDL products from the raw CDL. These products are crude cresylics, refinery feedstock, fuel oil and pitch as discussed in section 4.2. The CDL upgrading process was jointly developed by TEK-KOL, Dakota Gasification, Beulah, North Dakota, and M.W. Kellogg, Houston, Texas, in 1995. Development of this process used ENCOAL Plant CDL as the laboratory test material. Study results indicated that fractionating CDL into the four above components offers an attractive investment opportunity. Costs for installing a CDL upgrading facility at the ENCOAL Plant were estimated by M.W. Kellogg, and these costs are scaled-up to a common system for the three module LFC Commercial Plant for the purposes of this Phase II Report.

The commercial plant fines handling conveyance system differs from that used at the ENCOAL Plant. The ENCOAL Plant modified its fines handling system several times because of operational and safety problems, and presently uses a slurry system to pump the fines to a settling pond for disposal. This system has proven adequate and reliable for the ENCOAL Plant since the relatively few fines are generated, and there are no uses for the fines as fuel. However, since the higher-throughput LFC Commercial Plant will generate more fines, the commercial plant design uses inert pneumatic conveyance and storage systems to move fines between plant collection points and end users of the fines. These fines are collected in inert storage bins to be agglomerated and used as PDF, or sold to an adjacent cogeneration facility as fuel. Pneumatic conveyance systems are widely used in industry to transport powdered materials, so this design offers an acceptable solution for recovering the fines for fuel rather than disposing of them. Agglomeration of the fines has also been tested at the ENCOAL Plant, and has indicated that method of fines recovery is feasible.

Conclusions

The LFC Commercial Plant subsystems drawings were modeled after the ENCOAL Plant subsystems. Improvements growing out of operating experience were incorporated into the commercial versions whenever possible. The deviations from the established ENCOAL Plant systems discussed above are either minor, use proven industrial technology or are heavily supported by in-depth engineering studies.

Future improvements could be made to the subsystems package to include all of the major process loops in the plant. This combination of main process and support subsystems could then be used to train plant operating personnel. This was not completed at this time, as the main process has been adequately covered by the process flow diagram and heat and material balance documents.

5.8 Plant Profile Drawings

Summary and Introduction

Plant profile drawings were jointly developed by TEK-KOL and MHI. These drawings aid in the layout and orientation of main process equipment within the LFC Commercial Plant. When used in conjunction with the process flow diagram, heat and material balance, equipment list and site plot plan, the plant profile drawings serve as valuable tools for transfer of information to the various engineering disciplines. The final Powder River Basin LFC Commercial Plant profile is shown in Figure 5.8.1.

Figure 5.8.1: LFC Commercial Plant Profile and Plan View

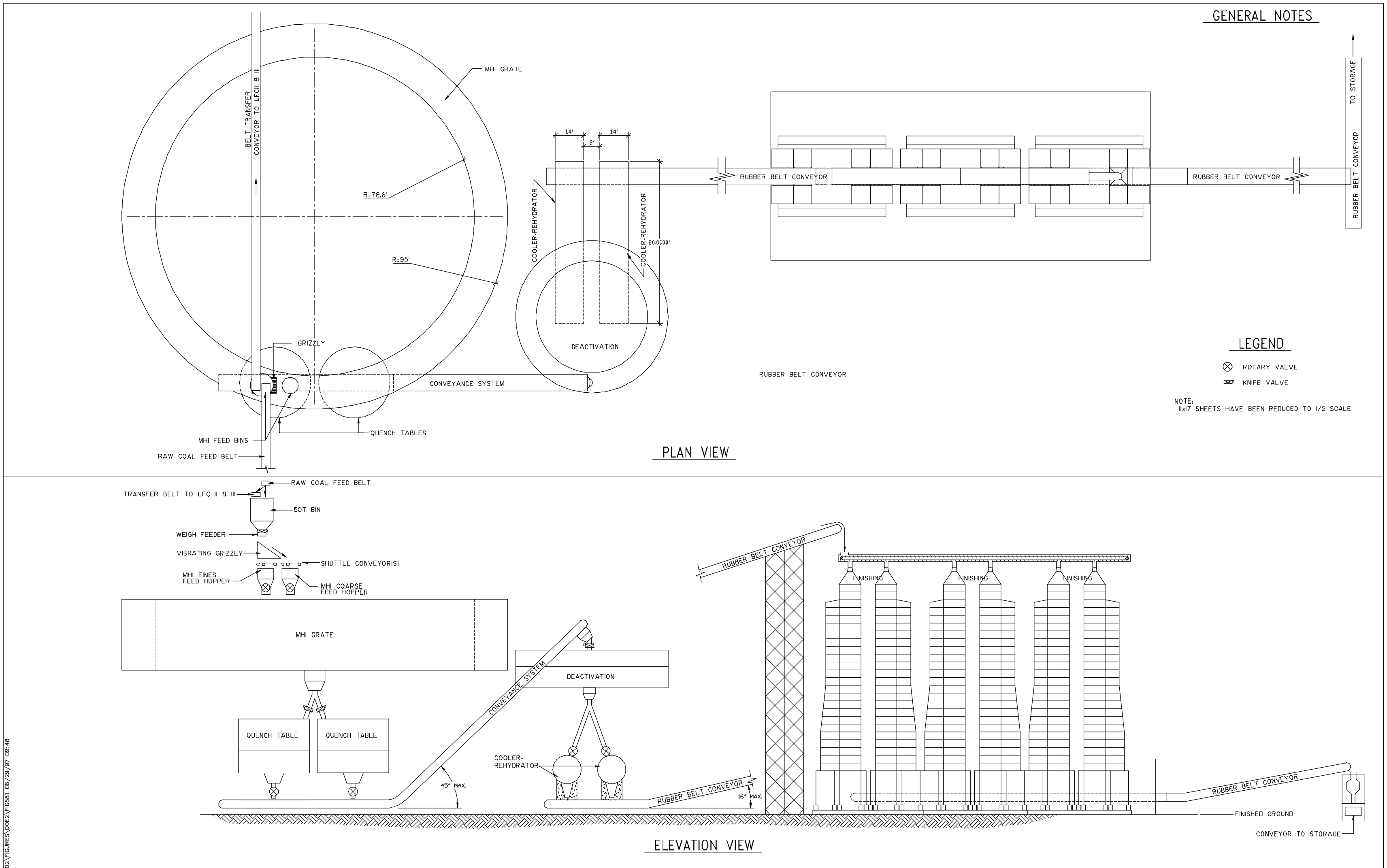


FIG. 5.8.1: LFC COMMERCIAL PLANT PLAN/PROFILE DRAWING

Data

Several arrangements of main process equipment were studied before settling on the final plant profile. In particular, different arrangements affecting the overall height and dimensions of the plant were investigated. These arrangements varied from a "stacked" plant to a horizontally staged plant and affected the placement of the dryer/pyrolyzer, PDF quench, deactivation, and rehydration/cooling pieces of equipment. The finishing step was placed horizontally on grade to the rehydration/coolers in all cases, and solids were fed to this step on a rubber belt conveyor.

The stacked plant concept had the dryer/pyrolyzer, quench tables, deactivation, and rehydration/cooling equipment arranged vertically and relied on gravity flow between process steps. This version resulted in a tall structure, with the large MHI dryer/pyrolyzer grate located at the top.

The horizontally arranged plant had each processing step located on grade, with conveyance systems to transfer solids between steps. This resulted in a fairly short but large-footprint LFC structure. This arrangement also had a questionable conveyance system of hot, reactive solids between steps, and required a sealing system between all units.

A third arrangement combined the two concepts discussed above. This "split-plant" concept divided the stacked plant layout between the quench tables and deactivation, and connected the solids flow via a pan conveyor. The result was a reasonably tall structure with a moderate footprint.

The three concepts were compared from several different perspectives, and the split-plant version was selected as the final plant profile. MHI conducted a construction cost comparison of the three arrangements and found the split-plant version to be the least expensive. TEK-KOL engineers studied the three concepts from the perspective of adaptability to potential customers, and found the split-plant version to be the most accommodating. Breaking the plant below the quench tables allows for potential construction of an LFC plant without the deactivation, rehydration/cooling, and finishing steps, while leaving the remaining portions of the plant layout essentially untouched. This would fit particularly well with metallurgical applications and sites adjacent to power plants where an LFC plant would be located adjacent to the customer facilities, eliminating the need for these process steps.

Conclusions

The split-plant profile was chosen for the purposes of this Feasibility Study because this concept was the least expensive arrangement to construct. In addition, it allowed for relatively easy adaption of an LFC plant to metallurgical applications by removing the deactivation, rehydration/cooling, and finishing steps without changing the rest of the plant layout. Applying this technology to future installations makes much of the baseline engineering cost for LFC plant layout unnecessary. This met an overall objective of the Feasibility Study: design standardized facilities to minimize engineering costs of future LFC plants -- not an insignificant cost.

For future plant layouts, the option of feeding the finishing step with a vertical conveyor instead of a 16-degree-incline belt could reduce the overall plant footprint, accommodating LFC plant sites where a smaller footprint was required. The Powder River Basin LFC Commercial Plant should stay with the incline belt concept however, since operating experience with vertical belts in this climate has been poor, and overall plant footprint space is not an issue.

5.9 Electrical, Controls and Instrumentation

Electrical Summary

The power system design for the LFC Commercial Plant distributes and transmits electric power to the plant and all its supporting structures. The main components of this system are substations, transformers, starter line-ups, switchgear and Motor Control Centers (MCC)s. A computer model of the power system verified that the proposed design is theoretically sound.

Motor sizing estimates are the biggest risk factors to this design and were estimated conservatively by upsizing existing ENCOAL motor sizes, or were specified by process engineers. The system was proven economically feasible with a comprehensive budget estimate.

Introduction

To formulate a design basis for a safe, reliable electric power system, many assumptions and design considerations had to be made. One primary design basis was the system layout for the existing ENCOAL facility, which has ensured greater than 99% power availability for each of the last 4½ years. A one-line diagram was generated from the original ENCOAL electrical diagrams. This diagram was utilized to generate a computer model of the commercial-size power system using the Distribution Analysis of Power Planning, Evaluation, and Reporting (DAPPER) program. This model generated a Load Center Study, a Load Flow Analysis, a Fault Study and a Demand Load Analysis. These studies ensured that adequate power would be available for operation of the plant and all its equipment.

A motor list derived from the equipment list was utilized in conjunction with a demand load library as system loads in the computer studies. Approximately 35% of the motor horsepowers were estimated conservatively by upsizing motors from the existing ENCOAL facility, and the remaining motors were specified by process engineers. Motor voltage thresholds were defined and strictly adhered to for this system's specifications: all motors less than 225 kW (300 hp) will be 480 V and defined as low voltage. Motors greater than 300 hp will be 4,160 V and defined as medium voltage.

General voltage guidelines were specified as follows: 120/240 V for utilities and the Uninterruptible Power Supply (UPS), 277/480 V for plant and offsite lighting. The X_o connection on all transformers will be resistance grounded with a 50-A limit. Illuminating Engineering Society lighting standards will be utilized for this facility.

It was assumed that the proposed LFC Commercial Plant would be located at the North Rochelle Mine site, and equipment was sized and specified accordingly. This assumption dictated that the existing 69-kV power lines would feed the plant substation, using an estimated ¼ mile of additional transmission line. The cost of the system was estimated in two separate segments: TEK-KOL estimated the cost of the system outside plant boundaries, while MHI estimated all the electrical components within plant boundaries. The whole system will provide electric power to all components within the engineering battery limits.

Data

The Load Center Study indicated that the proposed power system would supply required power reliably and safely. Demand full-load amperages were balanced among the MCCs, which were designed with an 800-A horizontal bus rating and ample expansion space. The Emergency Motor Control Center (EMCC) was minimally loaded for the study. A review of essential equipment must be performed to properly assign loads to the EMCC.

The one-line diagram specifies a host of circuit protection devices to ensure safe operation: fused disconnects, lightning arrestors, air-break over-current trip shunts and manual disconnecting switches. A 500-kVA diesel generator and a 100-KVA UPS were added for emergency backup power, thus ensuring a source of power and lights for controlled plant shutdowns.

A Load Flow Analysis was performed to determine available load capacity on the 4,160-V feed busses and MCCs. The source bus is loaded to 28.3 MVA with a unity Power Factor (PF) and no feeder losses. The heaviest loaded 4,160-V feeder has loads of 4,360 kVA with a .99 leading PF and minimal feeder losses. The CDL-upgrading MCC was the most heavily loaded, at 490 kVA with a 0.95 lagging PF and virtually no feeder losses.

The Fault Studies proved that the system fault values were reasonable for standard industrial distribution equipment. The 69-kV source bus has a three-phase fault of 837 kA and requires an asymmetrical interrupting current rating of 856 kA at 3 cycles. The typical 4,160-V bus had a three-phase fault of 29 kA and required a momentary asymmetrical interrupting current rating of 37 kA. In addition, a single line to ground duty of 27 kA was determined for the 4,160-V busses. The largest MCC had a three-phase fault of 25 kA and required a momentary asymmetrical interrupting current rating of 37 kA. The single line to ground rating for all MCCs is 50 A.

The Demand Load Analysis showed that the peak demanded loads for the LFC Commercial Plant will be 17.6 MVA or about 2,446 A. These figures are for the commercial plant alone and do not include loads contributed by a cogeneration facility.

The budget estimate proved this system to be economically feasible and within the targeted cost range. The total cost of the system is $8.6 million. This study also included a plant communications estimate. The intercom communication system includes 30 multi-channel, loud-speaking telephones that will be installed in the plant and support buildings. This system will also be used to sound alarms alerting plant personnel when equipment is started, when major or minor faults occur, or when plant evacuations or emergency shutdowns take place. Two-way radios were also specified for all plant personnel.

Although the program uses a load library based on the ENCOAL Plant, which is a good representation of real world devices, it must be noted that the computer model of the specified power system is not completely representative of an actual system. The data from a comprehensive load flow analysis currently being conducted at the ENCOAL facility will be correlated with the existing load library for improved accuracy. Also note that the motor list was originally specified conservatively; therefore, the results from the computer studies may be skewed.

Conclusions

The Load Center Study proved on a theoretical basis that the specified power system for the LFC Commercial Plant is adequately designed. In order to verify that the system was sized properly, a Load Flow Analysis was performed to compute the load capacity of various components. Balanced and unbalanced Fault Studies were conducted to determine the interrupting ampacity ratings of system components. The Demand Load Analysis indicates that the peak demand loads for the commercial plant, without a cogeneration facility, will be 17,625 kVA or about 2,446 A. The budget quotes established that a system cost of $8,600,000 is economically feasible. As engineering work on the LFC Commercial Plant continues, the motor list will need to be refined. This will improve the overall accuracy and credibility of the computer model and verify that the power system is adequately designed.

Controls Summary

The control system design for the Powder River Basin LFC Commercial Plant is specified to control digital and analog I/O points in the field. The main components of this system are Programmable Logic Controllers (PLC)s, digital and analog I/O cards (and associated hardware), operator interface stations, and several personal computers. The system, based on the ENCOAL Plant, has been proved experimentally and theoretically sound.

Introduction

The control system for the Powder River Basin LFC Commercial Plant was based upon the control scheme for the existing ENCOAL Plant. Several design constraints and assumptions were used in the design of this system. Allen-Bradley PLCs, software, and operator interfaces (ControlView and PanelView stations) will be used for this system. All digital inputs are 24 Volts Direct Current (VDC) except the "Starter Healthy," which is a 120-V isolated input. All outputs for this system will be 24 VDC. Rotating equipment sends a 24 VDC output to an interposing relay for motor starting and stopping. PLC’s are used to control all components in the plant, and Figure 5.9.1 depicts the control scheme.

The highest level in the control scheme is Level 0, which performs data storage and archiving, reporting and expert system control functions. The Level 0 code is written in FORTRAN 77, which has the capability to handle computationally intensive mathematics. Unfortunately, it is cumbersome to modify and understand; therefore Level 0 is currently being rewritten in C++. Level 0 code stores and monitors 130 major plant parameters, operating as an expert control system. In short, it gives a scorecard on plant performance. Process simulation algorithms are currently being upgraded to take advantage of recent advances in microcomputer technology. A file server personal computer polls data from the main PLC (Allen-Bradley PLC 5/250) every 5 minutes. These data are stored and sent to a system simulation program. The program makes running parameter recommendations based upon the data it receives from the 5/250 and process simulation algorithms. There are nine major control parameters in the LFC Process that Level 0 predicts; these parameters correspond to changes in temperature or flow in the process loops. Level 0 bases its recommendations on past operating history for given situations. The advantage of Level 0 is that it does not have to be on line to run the simulation program; instead, it runs the system simulation as a background task.

Level I control, the next level of hierarchical control, utilizes a 5/250 PLC as its core processor. This processor acts as a central processing unit for the entire control system. The main functions of the 5/250 are plant interlocking and digital control. The 5/250 contains all digital logic and digital I/O, as well as the algorithms to run plant equipment. All rotating equipment (motors, blowers, pumps, conveyors, fans, etc.) and discrete (on/off) valves are controlled by the 5/250 processor. In addition, temperature, pressure, flow measurements, and other parameters not used for control are taken and reported to the 5/250 via analog I/O.

Level II control includes five PLC 5/40s, which are slaved to the 5/250 as remote I/O. Three of these controllers are used for temperature, level, pressure, and flow control PID (Proportional-Integral-Derivative) loops. These processors also send monitoring information via analog I/O to the ControlView operator interface stations. When an interlock is required for a given piece of equipment, information is sent back and forth between the PLC 5/40s and PLC 5/250 as needed. The other two 5/40 PLCs control the dryer and pyrolyzer combustors. Each combustor has two PanelView operator interfaces, one local and one in the control building.

The ENCOAL Plant is monitored with two ControlView stations that are fed information from the PLC 5/250. Raw data values from the PLCs are scaled for display on the operator interfaces. Overall, the PanelView and ControlView operator interfaces are not used for plant control, but enable plant personnel to operate and monitor plant equipment from a remote location. True control resides in the PLC ladder logic. One ControlView station is designated for event detection and plant reporting, which includes trending and data logging. The other ControlView is utilized for monitoring and logging plant alarms. Each complete LFC plant will have a common engineering ControlView station. This ControlView will be used for ladder logic modifications and backup plant operation. The control system for the proposed third-party cogeneration facilities is not part of this estimate.

Data

The LFC Commercial Plant controls are based on the ENCOAL control system, which has performed extremely well. PLC-based control systems are user-friendly -- easy to learn and understand. Electricians can readily adapt to PLCs because ladder logic resembles components in a motor circuit. Because every I/O point is hardwired, PLCs are easy to troubleshoot. Program troubleshooting and editing are convenient because program changes can be tested on line before implementing them into the system. PLCs offer a great deal of power and limitless room for expansion at a low cost when compared to other types of automation systems. Remote racks can be constructed locally to minimize needed wiring.

PLCs also are easily adaptable to changing control needs. Larger processors can be implemented for more memory, or I/O cards can be added or removed as needed. This adaptability minimizes the amount of hardware needed for system control.

Allen-Bradley PLCs are highly reliable even in less-than-ideal environments, and have caused no plant downtime since they were installed at ENCOAL. On the rare occasion that processors fail, they can be changed out in a matter of minutes. In addition, Allen-Bradley has an excellent training program that is readily available, detail oriented and inexpensive.

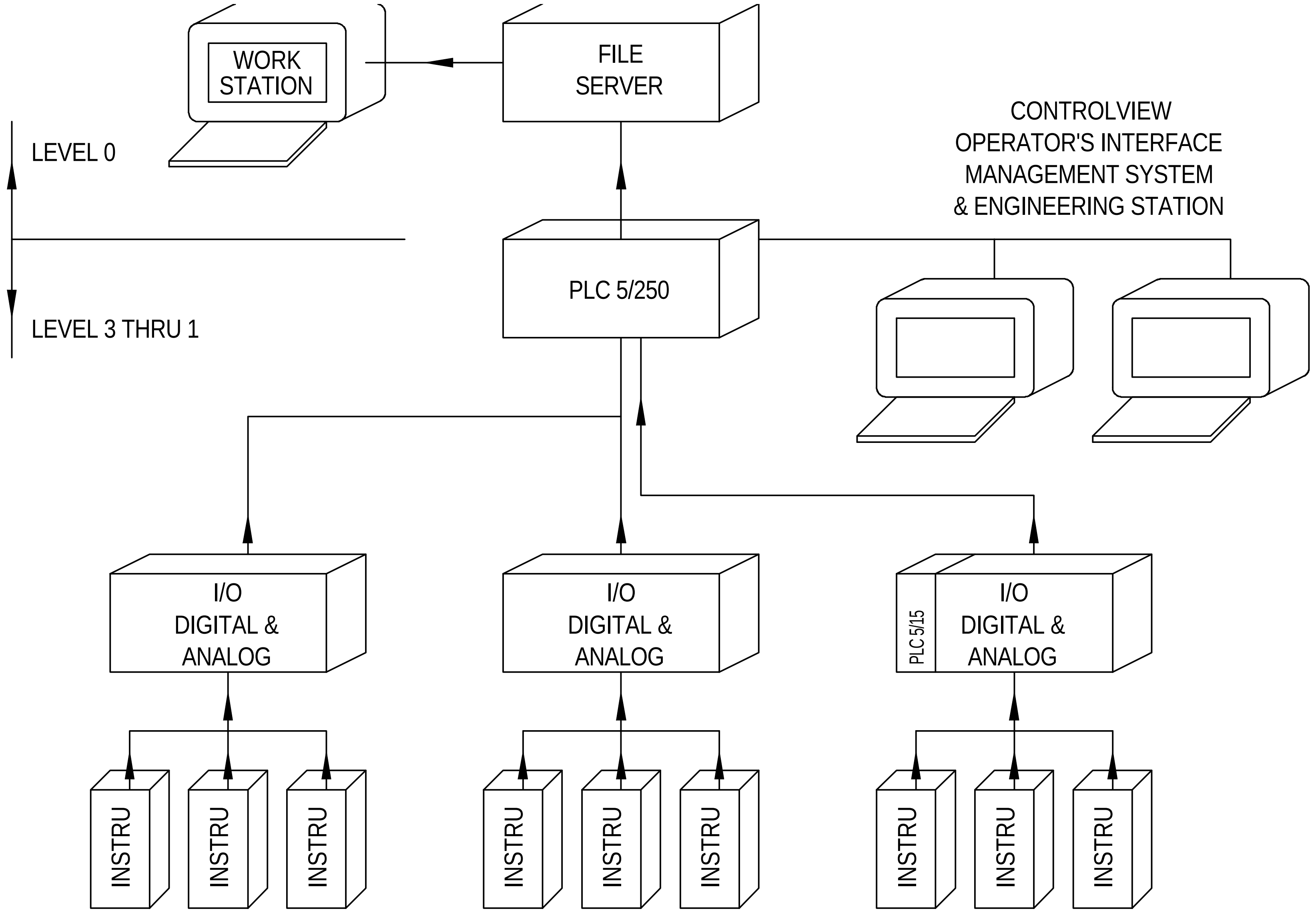
The existing ENCOAL system has been demonstrated with about 730 digital I/O points, 125 analog I/O points, 90 analog PID I/O points, and 50 combination digital/analog I/O points. This constitutes approximately 210 kBytes of program in the 5/250 and 55 kBytes of program space in the other PLC 5s. Four man-years of program development have been vested in the ENCOAL control system.

Conclusions

The LFC Commercial Plant control system will perform as well or better than the existing ENCOAL control system. Level 0 control will be even better after the software rewrite. Process simulation algorithms are also being upgraded, thus adding even more accuracy. Overall, past performance indicates that the proposed control system is user-friendly, easy to troubleshoot, inexpensive, reliable and readily adaptable to changing control needs. Each LFC module will be controlled seperately, with a fourth control for common utility support equipment.

Because commercial plant P&IDs did not contain all detail instrumentation at the time of this Phase II Study, MHI estimated the instrumentation for the LFC Commercial Plant by roughly scaling-up existing ENCOAL Plant P&IDs. This estimation should be conservative, as the ENCOAL Plant systems contained more than the usual number of instruments for scientific data collection. Capital estimates for the electrical and equipment instrumentation, located in Section 9.2, can be refined when the commercial plant P&IDs become more detailed.

Figure 5.9.1: Control Scheme



Section 6.0 Environmental and Permit Requirements

Summary

This section covers all significant environmental requirements imposed by public regulatory agencies for the construction of a commercial-scale coal upgrading facility located at Triton Coal Company's North Rochelle Mine in the Powder River Basin of Wyoming. The Phase II permit requirements analysis was performed by TEK-KOL with input from appropriate agencies and environmental consultants. The approach for each permit was to determine the governing authority, define associated data and design requirements, and identify key decision points and issues impacting those decisions.

Environmental permit requirements are enforced by both state and federal authorities. Most key State agencies are divisions of the Wyoming Department of Environmental Quality (WDEQ), including the Air Quality Division (AQD), Industrial Siting Division (ISD), Land Quality Division (LQD) and the Water Quality Division (WQD). The State Engineer's Office provides regulatory authority for water appropriation permits. Federal agencies involved in the early stages of permitting are the Mine Health and Safety Administration (MSHA) which will become involved only if certain size requirements are met for a major water impoundment and the U.S. Forest Service (USFS). The USFS owns the surface where the proposed LFC plant site is located. This section addresses permits and activities associated with each of these agencies.

Groundwater availability, application turnaround times and negotiated requirements constitute the principal uncertainties associated with permitting a commercial plant. The experience of ENCOAL, as well as discussions with regulatory agencies and review of existing precedent, indicate minimal permitting risks. Environmental costs and permitting schedules have been estimated based on conservative assumptions.

Introduction

Prior to authorizing construction of a commercial LFC plant, the WDEQ must issue a construction permit through its AQD, an industrial siting permit through its ISD, a License to Mine from the LQD and a National Pollutant Discharge Elimination System (NPDES) permit from the WQD. Before the plant can operate, groundwater and surface water permits must be obtained through the Wyoming State Engineer. In addition, MSHA may be asked to grant a permit for a large water impoundment if certain size restrictions apply, and a land exchange with the USFS may be necessary in order to site the plant at the planned location.

In order to determine requirements for each permit, TEK-KOL consulted appropriate statutes, regulations, procedure manuals and key officials from WDEQ. In addition to identifying procedural requirements, this effort produced cost and time estimates. Several permit requirements offer some flexibility or provide for negotiation between the applicant and the agency. In these cases, TEK-KOL conducted in-depth discussions with agency personnel and industry consultants to determine the most probable compliance level. For the air quality and industrial siting permits, a recent proposal by Kennecott Energy provided supporting precedent. The Kennecott proposal would have utilized the "PURON" process to produce a high-Btu, pelletized coal byproduct, and projected environmental impacts were similar to those for a large LFC plant. The Kennecott project was permitted, then suspended prior to construction, and those permits were later withdrawn.

The air quality permitting process is determined by three factors. First, a waiver application was approved, relieving TEK-KOL of the 12-month ambient air monitoring requirement. AQD waived the monitoring requirement based on background data already available from mines and power plants in the Powder River Basin.

Second, this Feasibility Study assumed successful application to the Wyoming Environmental Quality Council (EQC) for a PSD (Prevention of Significant Deterioration) baseline area redesignation similar to one granted to Kennecott in December 1994. This redesignation would isolate the LFC Plant (a "major emitter" of particulates) from mines in the basin and avoid triggering for them a PSD baseline date. Mine operators believe exposure to lower particulate thresholds under PSD regulations could limit future expansion. It is important to note that the redesignation is not required for the LFC Plant and does not affect compliance levels for the plant. Also, granting of the redesignation is not guaranteed, and may depend on public pressure, composition of the EQC and support from the Governor's office. Failure to redesignate, though extremely unlikely and in any case not essential for the LFC Plant, could expose the Powder River Basin mines to some risks.

A third air quality permitting issue concerns the state-required Best Available Control Technology (BACT) to limit plant stack emissions of particulates, SO_2 and NO_x. The AQD provided TEK-KOL with objective emissions limits for these and other regulated pollutants, based on current BACT. In turn, TEK-KOL generated design specifications and sought prices for plant equipment, such as a flue gas scrubber, that will meet these levels. Although future BACT improvements may result in tighter restrictions, this study assumed the permitting process would not incur undue delays researching available technologies and negotiating with WDEQ. Recent approval of the Kennecott proposal and an 80-MW power plant near Gillette support this assumption.

Taking these three factors into account, an 8-month air quality permitting process seems likely.

The Industrial Siting Act requires a socioeconomic impact analysis and provides for the Industrial Siting Council to assign impact assistance payments to affected counties and municipalities. The money for assistance payments is derived from sales and use taxes generated by the project. Also, companies are expected to negotiate up-front monetary settlements with impacted public entities that do not qualify for impact assistance under the Act, such as school or hospital districts. This Feasibility Study assumed impacts and infrastructure needs similar to those developed for the Kennecott Industrial Siting Permit. Depending on final plant location and prevailing political forces, the Industrial Siting Division has indicated that the impact settlement would likely be far less for the LFC Plant.

This study assumed a routine procedure for obtaining a groundwater permits to supply water for the LFC Plant. This includes groundwater modeling to quantify the availability of water from various geologic formations, and to predict impacts of pumping from these formations. The Fort Union formation in the vicinity of Gillette is a preferred water source for area mines and municipalities, but has recently been subjected to closer scrutiny and regulation by the State Engineer. Because the permitting process includes public involvement, there is potential for strong opposition from area groundwater users such as the City of Gillette. Modeling studies have shown that locating a plant in the southern Powder River Basin would not impact the Gillette area, allowing the permitting of a Fort Union well. But if necessary, other producing formations such as the shallow scoria aquifer or the deeper Lance/Fox Hills formations could supply the LFC Plant with sufficient water, subject to water quality constraints.

The LQD permit covers site preparation, facilities, water diversion and storage structures, spill prevention/containment, surface water runoff and reclamation requirements. The abundance of mining permits issued in the area provides a reliable basis for estimating permit requirements. Two options are available in obtaining an LQD permit: modify the existing North Rochelle Mine permit to include the LFC facilities, or submit a new and separate application pertaining only to the LFC plant. The most time-consuming components of the second option will include baseline studies for soils, vegetation, archaeology, wildlife, and land use. The first option will allow TEK-KOL to achieve an early construction start and file for a separate permit document later.

One aspect of the proposed site at the North Rochelle Mine is that a land exchange with the USFS will be required prior to authorization to construct. The USFS made a finding that an industrial facility of this kind and magnitude is in conflict with provisions of the Bankhead-Jones Farm Tenant Act and cannot be constructed on federal surface. Therefore, a land exchange with the USFS will be considered as part of the permitting effort.

Data

Based on information currently available, the permitting process should be completed within 12 to 20 months. The waiver of the air quality monitoring requirement will shorten the pre-construction permitting schedule, but MSHA permitting of the large impoundment, if required, could require an additional 6 months. The cost of obtaining all environmental permits for a commercial LFC plant is estimated at $900,000. Up to $250,000 of this will serve as up-front impact assistance.

The air quality permit represents the critical path; this permit and the industrial siting permit must be obtained prior to starting construction of the LFC Plant. Approval must also be obtained from LQD prior to performing site grading. Normally, a stormwater runoff permit would be required from WQD prior to construction, but the proposed area is already covered under the North Rochelle permit. Once sediment control structures are in place and a NPDES permit obtained, a stormwater permit will be required only for those areas not contained under the sediment control plan, namely, the railroad corridor to the main line.

Cost estimates include in-house and consultant time because TEK-KOL sought budgetary estimates from outside consultants for major components of the permitting process. For the air quality permit, these components include BACT analysis, air quality dispersion modeling and stack testing. For the industrial siting permit, an outside consultant provided an estimate for processing the entire permit, including negotiation of impact assistance money to those entities not qualifying for aid under the Act. The actual amount of the impact settlement was estimated based on discussions with the Industrial Siting Division and on the Kennecott settlement negotiated in 1995. For groundwater permits, consultant fees were obtained for well design and for a groundwater supply and yield analysis that utilize a computer model. For the mining permit, TEK-KOL assumed outside consultants would design the storage and containment reservoirs, as well as diversion and drainage structures.

Conclusions

Based on an in-depth analysis of environmental permitting requirements for an LFC commercial plant constructed in the Powder River Basin, it appears that all permits can be obtained at a reasonable cost and within a 2-year time frame. No fatal flaws have been identified that would preclude the necessary approvals to construct and operate the plant. Several uncertainties such as groundwater availability, background air quality monitoring requirements, PSD baseline area redesignation, impact mitigation settlement and a successful land exchange with the USFS pose cost and schedule risks, but do not threaten the permits themselves. In some cases where appropriate, conservative assumptions were made such that cost and time estimates represent a “worst case.”

Permitting schedules can be impacted by the level of public involvement and by the degree of departure in the basic plant design from previously permitted facilities. As of this date, no commercial coal enhancement facility has been constructed in the Powder River Basin; however, air quality and industrial siting permits were issued for a plant proposed by Kennecott Energy, in 1995. These permits provide an appropriate precedent for the proposed LFC Plant, given the similarity of projected environmental and socioeconomic impacts. Along with other factors, the time estimates and negotiated requirements reflect agency experience with the Kennecott permits.

Section 7.0 Commercial Plant Implementation Schedule

Summary

The LFC Commercial Plant implementation schedule outlines a 36-month path. The road begins with the environmental permitting process, travels through detailed engineering, procurement and construction, and ends with the commissioning and start-up of the LFC Commercial Plant.

Keys to the implementation schedule's success lie in several factors. It will be important to begin the environmental permitting process as soon as LFC project funding efforts are launched -- 1 year in advance of the start of detailed engineering. Although preconstruction permitting could take as long as 20 months, this Study assumes that permitting will take a "fast track" and be completed in 12 months. The schedule assumes detailed engineering will be completed in 15 months, with construction starting in the 6th month of detailed engineering. This will be followed by start-up and commissioning. The Plant will achieve 50% plant availability in the first year of operation, 75% in the second year followed by continuous operation at 90% availability.

To avoid delays, the environmental permitting process begins as soon as the LFC Project funding efforts are launched. Although it can avoid impact on the implementation schedule, the permitting effort could cost as much as $900,000 that would be lost if project financing were not obtained.

Introduction

Figure 7.1 shows the "LFC Commercial Plant Implementation Schedule." The 36-month schedule moves from the detailed design stage to plant commissioning/start-up and is based on the following assumptions:

1. Procuring project financing coupled with financial due diligence for the project is estimated to take 12 months.

2. It is assumed that the environmental permitting process will take 12 months from the start of the process. Monitoring and data collection are waived in this case, and the mining permits become the critical path for the permitting process. The permitting process will run concurrently with the project financing process, and preconstruction permitting will be complete by the end of the fourth month of the detailed design phase.

3. Detailed design will be conducted by MHI at the MHI Engineering Offices in Hiroshima, Japan, with guidance provided by a 20-person TEK-KOL engineering team.

4. Process design configurations will be selected before beginning detailed engineering.

5. A process design freeze will be established at month 6 of detailed engineering.

6. The bid/award process for the primary Procurement/Construction Contract will require 6 weeks.

7. The primary procurement/construction contractor will assemble complete engineering bid packages for third party Procurement/Construction. These will consist of five major and 10 to 15 minor contracts. Bidding of the major contracts will require 3 to 4 months, and the minor contracts will require approximately 1 month.

9. Construction will start at month 6.

10. Long lead equipment items may require up to 50-week delivery times.

Data

The environmental permitting process, outlined in Section 6.0 of this report, consists of obtaining various state and federal permits. Air quality, water impoundment and surface water discharge permits are obtained through various divisions of the Wyoming Department of Environmental Quality. Depending on reservoir sizes and jurisdictional issues, impoundments may also require MSHA permitting. In addition, an industrial siting permit will be required from the State of Wyoming to deal with socioeconomic impact. The air quality construction permit will likely require the most time, but because there is a wealth of site information available, it is assumed that a waiver of air quality monitoring and baseline data collection will be granted by the State.

It is anticipated that the air quality permit would be granted within 8 months. In this case, mining permits may become the critical path in the overall environmental permitting process. These permits will need to be prepared early in the detailed engineering phase, as site layout and capacity requirements must precede pond and well permit applications.

The industrial siting permit should require no more than 6 months, subject to final negotiation of impact assistance money.

Engineering

The Engineering section of the implementation schedule consists of detailed engineering. The TEK-KOL Engineering Team, 20 engineers with specialities in mechanical, civil, chemical, process, electrical, instrumentation and computer control, will oversee approximately $32 million or 300 man-years worth of detailed plant engineering. The detailed engineering will be performed by MHI at the MHI Engineering offices in Hiroshima, Japan. During this phase, the two teams will accomplish a great deal. They will complete P&IDs and flow diagrams, specifications and data sheets, one-line diagrams of electrical substations, and conduit and wiring layouts. The teams will also perform early identification of long lead items; soils mechanics; civil and structural design; mechanical design; piping, instrument and controls design; and equipment selection. Finally, they will assemble bid packages for equipment and construction.

Procurement

The Procurement section of the implementation schedule includes ordering, expediting and receiving equipment and building materials. During this phase, teams will bid equipment and construction contracts, expedite, accept delivery and inspect equipment. Several major contracts for site civils and foundations, plant erection, electrical/instrumentation, support buildings and structures, railroad and track work and power line construction will minimize the number of construction contracts. Minor contracts for HVAC, testing and fencing will also be issued. Purchasing will consist of acquiring equipment and executing contracts on lump sump prices as much as possible.

Construction and Start-Up

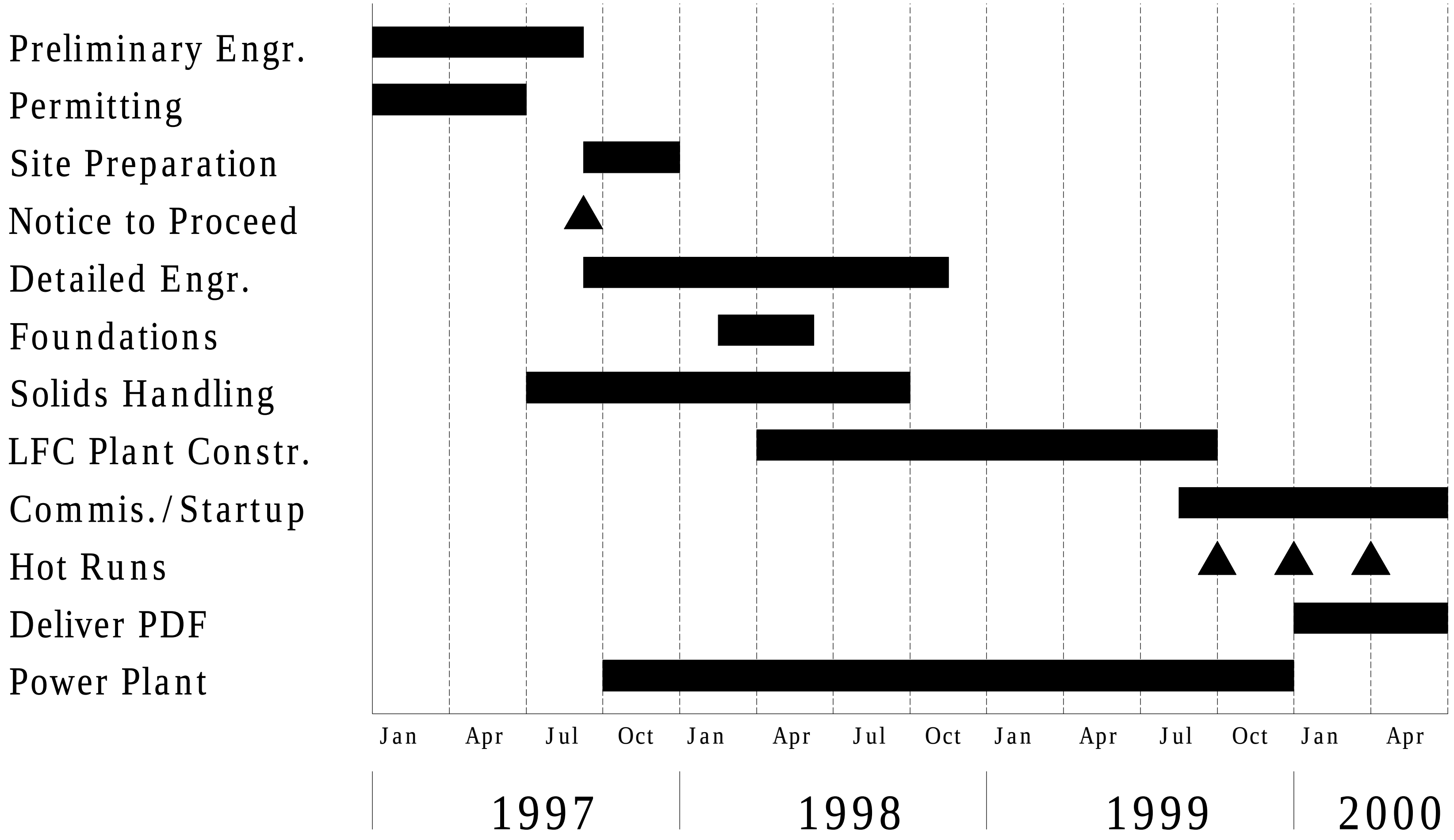
The Construction section of the implementation schedule consists of the foundation, miscellaneous civil and structural, installation of equipment, piping and electrical work. During this phase, construction will be broken into logical packages, i.e., earthwork and civil, storage units, railroad work, plant erection, electrical and instrumentation, foundations and buildings. The Project Manager will be responsible for coordinating the various subcontractors. It is anticipated that approximately $21 million will be required for construction management with 20 TEK-KOL engineers and construction inspectors taking part in field purchasing, field engineering, assembly of equipment data books, spare parts procurement and inventory, as-built drawings, and initial equipment testing.

The Plant Start-up section consists of precommissioning and commissioning of plant equipment. During this phase equipment is inspected for completeness on installation, leak tests are performed where air/water tightness is required, valve and piping alignment is carried out, together with start-up and check out of machinery. Other topics include responsiveness to local and remote control, development and completion of punch lists, rotation of machinery, initial lube, receiving initial supply of chemicals, setting up spare parts inventory, training of operators and vendor start-up assistance.

Conclusions

The primary constraints on the schedule are the contracting strategy of Procurement and Construction by a third party and the impact of the environmental permitting process. The overall schedule has been shortened by starting several efforts concurrently: the environmental permitting and project financing efforts commence simultaneously, procurement activities for long-lead items commence during the detailed engineering stage and construction is "fast-tracked" while the detailed design is still going on. The schedule relies on the experiences and lessons learned from construction of the first near-commercial size LFC Plant at the Buckskin Mine by ENCOAL personnel.

Figure 7.1: Commercial Plant Implementation Schedule



Section 8.0 Project Economics

Overview

A solid economic basis for the investment is crucial to the development of an LFC Commercial Plant. Capital costs, operating costs, product marketability and prices, and the impact of project financing are major factors affecting plant economics. These topics are discussed and evaluated in this section through the various case studies discussed below..

The base case for this Feasibility Study is the 15,000-metric-ton/day, three-unit North Rochelle LFC Plant with an independent 80-MW cogeneration unit. Cogeneration is considered a corollary to the design basis document because significant quantities of fines will be produced in the large-scale LFC Process, and power generation and/or agglomeration for later use are the most economical possibilities. However, commercial plant economics do not include the cogeneration facility. It is assumed that the cogeneration unit is owned and operated by an independant third-party.

Project economics were calculated in two ways. First, the project was evaluated on a 100% equity basis. Sensitivities to operating cost, capital cost, revenue, tax credits and project timing were calculated for the base case. Independently, the project was then evaluated for the impact of project financing arrangements. The objective was to maximize the financeable debt ratio and determine the resulting return on investment.

Capital Cost Estimate

Summary

Capital costs greatly influence project economics, especially for a project as large as the three-unit LFC Commercial Plant contemplated by this Study. One of the primary objectives of this study, then, is to develop a reasonably accurate capital cost estimate in order to determine the economic viability of commercial LFC ventures.

Using the ENCOAL Plant design and newest available information as a base, the current estimates are built from scratch and do not rely on previous estimates. The accuracy of some component estimates is very close, while others such as CDL upgrading, PDF deactivation and finishing, are not as accurate. While some inaccuracies still exist, engineering work continues to refine capital estimates. As shown in Section 9.0, overall project economics are not overly sensitive to variations in capital estimates, which are well within sensitivities of ±20%.

Table 8.1 is a summary of the capital costs for the base case three-unit LFC plant. The bottom line capital cost for a full scale three module LFC plant is $475 million.

Introduction

While several previous estimates were developed by ENCOAL and TEK-KOL, they were not used for this Study. Instead, a design basis document for the engineering work was developed, and battery limits for the project were defined in light of the North Rochelle Mine location.

Within the overall project limits, a subset battery limits outline was developed for the division of work between TEK-KOL and MHI. Essentially, MHI's scope of work involved the LFC Plant and structures, and TEK-KOL's scope covered the balance of the off-sites, electrical systems, control systems and P&IDs. Appropriate equipment estimates were developed; then contingencies, engineering and construction management were added to the estimate by taking a percentage of the base capital.

Data

Sections 5.0, 6.0 and 7.0 describe in detail the basis for the capital estimate summarized in Table 8.1. The information for individual pieces of equipment is based either on vendor engineering quotes or actual purchases by the Zeigler-affilliated companies. Some of the off-site facilities are based on engineering studies done for the North Rochelle Mine. For the LFC Plant and structure estimate developed by MHI, preliminary engineering has been done and an estimate developed independently in U.S. dollars. PDF quenching, deactivation, cooling and finishing were added to the MHI estimate according to the battery limits outline.

Some assumptions had to be made to proceed with the design and estimating work; most of the engineering assumptions are contained in the design basis documents. The following list also pertains specifically to the capital cost estimates:

1. Construction management for the project will include MHI and TEK-KOL support and a subcontractor. These costs are assumed to be 4% of total capital.

2. Engineering will be done by a team of TEK-KOL engineers and a contract engineering, procurement and construction group, like MHI, and is assumed to be 9% of total capital.

3. The accuracy of the estimate does not require the addition of contingencies to the single LFC plant total capital. However, the estimate for the combination of three units was made with less information than would have been prefered, so $10 million is allowed for contingencies for this case.

4. The North Rochelle Mine is assumed to be in place and in production when the LFC Commercial Plant construction commences.

5. Design and construction will take 36 months. A non-overlap six-month lead is assumed for the design work.

6. All three LFC units are constructed at the same time.

7. The LFC plants are essentially stand-alone facilities but do rely on the mine for raw coal storage, PDF loadout and water supply facilities.

Conclusions

A detailed capital cost estimate has been completed for a three module 15,000 metric ton-per-day commercial LFC plant at the North Rochelle Mine in Wyoming's Powder River Basin. These estimates are sufficiently accurate to support economic evaluations for a commercial plant venture, including financial participation options. A list of assumptions specific to the capital cost estimates has been presented.

Table 8.1: Capital Cost Summary

Item	Capital Cost ($MM)
Main LFC Facilites	319
Support Facilities	37
Flue Gas Scrubbing	16
CDL Upgrading	19
Environmental	9
Engineering & Other	75
Total ($MM)	**475**

Operating Cost Model

Summary

Economic benefits from an LFC Commercial plant are derived from the margin in value between a raw, unprocessed coal and the upgraded products, making an LFC plant dependent on the cost of feed coal. In fact, this is the largest single operating cost item. For this study, market prices for North Rochelle coal are used. The balance of the operating costs for the full-scale, three-unit LFC

Commercial Plant are developed from scratch using the ENCOAL Plant as the basis. Labor rates and productivity expectations are based on ENCOAL experience in Wyoming. Assumed to be a stand-alone facility, the Commercial Plant does not rely on the adjacent North Rochelle Mine for operating or administrative assistance. The total estimated operating cost is $9.00/ton of feed coal including the cost of feed coal, chemical supplies, maintenance and labor.

Introduction

A spreadsheet has been created to model the operating costs for the Commercial Plant. The model is combined with the economics spreadsheet to eliminate hand entry of data from one model to the other. An input data sheet is provided for all cost variables. These variables are used to calculate annual operating costs for the 30-year life of the project in an output data sheet. Project economics and financial evaluations use this data directly. In general, actual costs for chemicals, parts and supplies, labor and utilities are used from ENCOAL's operating experience. These are apportioned on the basis of throughput, number of people, capital cost and other factors as appropriate to arrive at the Commercial Plant costs.

Data

A summary of the cost categories is presented in Table 8.2. Permanent employment of 80 operating technicians and 22 staff is anticipated, and periodic contract assistance is allowed for major turnarounds. Maintenance has been assumed to be 2.5% of the major installed equipment cost.

Table 8.2: Operating Costs at Full Production

Item	**Operating Cost ($MM/Year)** *(Year 2001 Dollars)*
Feed Coal	26.0
Labor and Staff	7.2
Supplies and Services	9.2
Chemicals	5.4
Utilities and Fuel	4.8
Total Per Year ($MM)	**52.6**

Conclusions

A detailed evaluation of the expected operating costs for the full-scale, three-unit plant has been completed. A computer model has been developed and integrated with the economics model. Comparison with previous estimates shows very good agreement, and the current estimate has been independently developed based on the latest ENCOAL Plant operating experience.

Economic Assessment

Summary and Introduction

A financial model was constructed using a spreadsheet to evaluate the project's financial viability. The key measurements utilized for internal evaluation are Internal Rate of Return (IRR) and Net Present Value (NPV). The significant assumptions relating to the financial analyses are listed in Table 8.3. The term "base case" refers to the three-module plant with 15,000-metric ton/day capacity, excluding the synthetic fuel tax credit (29c tax credit). The IRR and NPV are most sensitive to revenue and to a lesser degree, capital investment. Operating costs variations had only a slight effect on IRR or NPV. The unleveraged IRR on the base case of around 15% is encouraging given the project's upfront capital requirements, long construction period, and 30-year project life. The project does generate impressive after-tax cash flows (ATCF's) with payback on the base case of less than 9 years from plant startup and cumulative ATCF's over 30 years, exceeding $2 billion.

The base case unleveraged IRR will change as capital costs and revenue estimates are refined. The probability of reaching the 18% to 20% range for IRR is good, given a combination of lower capital costs and increased revenues. An increase in revenue of 10% coupled with a decrease in capital cost of 10% would provide an unleveraged IRR in excess of 18%.

A possible upside to the base case is utilization of the non-conventional fuel tax credit commonly referred to as 29c. This tax credit is calculated by converting PDF and CDL to a Barrel of Oil equivalent (BOE) base and then applying a rate per BOE. The addition of 29c to the base case evaluation adds over 15% to the unleveraged IRR, and more than doubles the project NPV. This positive financial impact would ease the financing of the project, and add greatly to the potential of building the first U.S. LFC Plant.

Conclusions

Overall, the base case looks strong on the basis of IRR and NPV with a good probability of improvement as the capital and revenue estimates are refined. The ATCF's are impressive with a payback period of less than 9 years. (See Table 8.4) The inputs to the model that are the least sensitive are the direct operating costs. The revenue is most sensitive variable, and the capital is somewhere in the middle. The ability of the project to qualify for the 29c tax credit is an unknown and should be resolved in the near future. The evaluation is subject to normal market risks on the revenue side with the chief area of opportunity being market values for the CDL product stream.

Table 8.3
SIGNIFICANT ASSUMPTIONS

- Project has a 30-year life from commissioning.
- Project assumes power plant is constructed, owned, and operated by a third party.
- Discount rate 12% on after cash cash flows for NPV calculations.
- Utility market volume is 80%, steel industry 20% of total PDF volume.
- Escalation equals inflation (3%) for revenue.
- Initial capital costs for construction - $475 million.
- Construction timeframe - 20-24 months from notice to proceed.
- Regular tax rate for FIT (35%).

Table 8.4: **Commercial Plant Economics Summary**

	Base Case
IRR - Unleveraged	≈15%
NPV_{12}	≈$169 Million
Total Capital Investment - *(Excludes Capitalized Interest)*	$475 Million
Operating Cost $/Ton Feedstock	$9.00
Payback Period (Measured from Start-up)	9 years
Cumulative After Tax Cash Flow	>$2 Billion

Section 9.0 Project Risk Assessment

Technical Risk

Summary and Introduction

Throughout this report, the discussions have made comparisons to the existing 1,000-ton/day ENCOAL Plant. This near-commercial-size plant was built and operated for the stated objective of "furthering the development of commercial LFC plants." More than any other single factor, 4½ years of successful operation of the ENCOAL Plant reduce the risks in scaling up the LFC processing unit to 5,000-metric tons/day. TEK-KOL believes the overall risk associated with the first commercial plant is reasonably low and is willing to make process guarantees on that basis.

Factors Reducing Risk

A number of other factors reduce the technical risk associated with the commercial venture. The ENCOAL Plant has been in operation periodically since June 1992, and runs approaching 90 days have been achieved with availability of 90% for the planned run period. Most of the equipment used in the ENCOAL Plant is commercially available with only minor modifications required to some units, and there are no prototype or first-of-a-kind devices. The combination of processing steps and equipment is unique, as is the control system used for the LFC Process, and these elements have been a resounding success at the ENCOAL Plant. More than 12,000 hours of operation have been logged processing 219,000 tons of Buckskin coal. Saleable PDF produced exceeds 75,500 tons and saleable CDL exceeds 189 tank cars.

The capital and operating costs developed in this Feasibiltiy Study should be fairly conservative. They are based heavily on the ENCOAL Plant, which went through a great deal of testing and modification in the early years. This resulted in more labor and maintenance effort than a continuously operating commercial plant should require. Larger, more cost-effective equipment may be available for some process steps when it is time to actually build the commercial plant. This has not been considered in these estimates; instead, the current basis is the largest unit currently offered by the ENCOAL Plant manufacturers. In short, the capital and operating costs have not been optimized.

As pointed out in Section 5.3, capital cost savings could result from more extensive integration of the LFC plant facilities with the mine or customer facilities depending on the LFC plant location and timing of construction. In some cases, the final rehydration and finishing steps may not be required, improving product quality and lowering capital costs significantly. The solid product would have to be inerted or used very quickly in this instance, since it would not be stable. These economics have not been considered in this evaluation.

The protection of intellectual property is crucial to risk mitigation. It is TEK-KOL's intent to maintain a licenseable package that has value to others. This is being done through patent protection and development of a working proprietary control system.

Factors Increasing Risk

At the time of this Study, four areas require further work to minimize risk: the PDF deactivation step, the PDF finishing step, CDL upgrading and use of the MHI combined dryer/pyrolyzer grate. All this work is currently underway, and equipment estimates for these process steps have been made on the basis of engineering studies, pilot testing and vendor claims.

PDF deactivation has been shown to be an essential process step in the ENCOAL Plant. A 6- by 30-foot vibrating fluidized bed reactor built by Carrier Corporation is used in the ENCOAL Plant, and it will only handle 50% of rated plant throughput. It is the largest such unit made, and at 11 units for the commercial plant, not a practical choice. The current estimate is based on a 142-foot diameter Salem Furnace quiescent bed, but this is untested. Engineering studies are underway, and plans are to test alternate equipment to accomplish oxidative deactivation in the laboratory and at the ENCOAL Plant. Costs for the alternate equipment could go above or below the current estimate.

PDF finishing will occur in a humid-air contacting vessel and has been pilot tested at the ENCOAL Plant. It has also been accomplished in a batch operation by outdoor pile layering, which has been used to stabilize all the PDF shipped to ENCOAL's customers to date. The conditions required for final PDF finishing are fairly well known. Currently, ENCOAL has located suitable equipment and plans to modify the ENCOAL Plant in the next few months using a commercially available unit that can be applied to the larger commercial plant.

CDL upgrading has been the subject of engineering studies, and a laboratory pilot plant was used to demonstrate process feasibility. The unit operations in the process flow sheet, such as vacuum flash, distillation and solvent extraction, are well demonstrated in the industry. The estimate used for this Feasibility Study is factored from the estimate made for a proposed ENCOAL Plant modification project.

Use of the MHI circular grate instead of the proven Salem Furnace Company grate design entails some risk. MHI has quenched coke with one of their grates for many years at the Toho Gas Works in Nagoya, Japan, so mechanical reliability is not an issue. Other questions on the grate application have been addressed by engineering studies, but several issues involving the processing of nonagglomerating fine coal remain to be answered. To answer these and other questions, MHI has built a pilot-size grate, and construction and testing will be complete by the end of 1997. There is a significant cost advantage in using the single grate, and if necessary, Salem equipment can serve as a fall back.

Many coals from around the world have been tested in the LFC Sample Production Unit at the TEK-KOL Development Center in Perrysburg, Ohio. This pilot-scale unit has been calibrated to the

ENCOAL Plant to give dependable answers on the performance of various coals' processing charactistics, except the effect of particle degradation. Some coals disintegrate when dried and pyrolyzed in the LFC Process. The impact of such an event would be a marked increase in the fines generated and possibly the requirement of an agglomeration step. While this would negatively affect costs, it is a well-known technology.

Conclusions

TEK-KOL believes that on balance the technical risks are reasonable for the LFC Commercial Plant. The factors affecting risk are fairly well known, and the ENCOAL Plant operating experience provides overwhelming evidence that the basic LFC Technology works. TEK-KOL and its partners plan to guarantee the LFC Process and equipment to alleviate potential investors' concerns.

Product Revenue Risk

The products' revenue risk centers around conformance with customer/market product specifications, the stability of product revenue over time, and the credit worthiness of expected customer base.

Conformance with Customer Product Specifications

It has been proven that PDF will burn very well, and that PDF is anywhere from less dusty than, to as dusty as ROM Powder River Basin coal. ENCOAL has also shown that it can produce stable PDF through a ground-spreading technique, and commercial shipments of PDF stabilized using that method showed no tendency toward self-heating. A faster mechanical stabilization process has recently been proven in trials run at the ENCOAL Plant, and a commercial-sized version is incorporated into the design of the LFC Commercial Plant.

CDL Specification Conformance

While development of the CDL products is still in the early stages, it is possible, even conservatively, to predict considerable potential in marketing these products.

1. Crude cresylic acid - It is possible that the percentage of useful cresylics in the crude cresylic acid fraction could vary as a result of feedstock variability or fluctuations in process conditions. The value of the crude cresylic acid will be directly related to the concentrations of useful cresylics contained.

2. Pitch - This product is not expected to meet the specifications for finished anode pitch on its own. Since it will be a blend material, any deviation from the targeted specifications will reduce the portion of the blend made up of CDL pitch.

3. Refinery Feedstock - The biggest risk associated with this product is keeping the oxygen level low. High oxygen is not desirable in most refinery processes and the

value could be substantially affected if it is not possible to sufficiently lower the oxygen through the solvent extraction process.

4. Oxygenated Middle Fraction - For purposes of this Study, this product has been valued based on a fuel application. The major risk of specifications nonconformance would be in the area of compatibility with other residual fuels. This risk area could be overcome by working with customers to develop systems to segregate this material. There will probably be greater potential associated with this product as catechol producers are identified and contacted. It should be noted that because of this risk, an extremely low price of $5.50/bbl has been assumed.

Stability of Product Revenue Over Time

The key to creating stable product revenue over time is to develop long-term contractual relationships with specific customers. It is believed that the majority of the revenue stream can be made predictable through long-term contracts. The product streams in particular that could be long-term contracted are PDF (utility market and metallurgical market), crude cresylic acid and pitch.

PDF

Historically, high percentages (70-80%) of the total coal sold to the utility sector has been under long-term contract. With utility deregulation on the horizon, utilities have increased the portion of purchases made under short-term agreements and have generally shortened the contracting period for their longer term commitments. The average utility's objective is to keep the cost of coal purchased in line with market cost. Most of the PDF can be sold under long-term contract, but any contract will likely have periodic market reopeners. Therefore, PDF revenue over time will roughly track the value of competitive coals in the market place, which does fluctuate over time. The risk for the PDF portion of the revenue stream would be comparable to the price risk associated with a new coal mine.

CDL Products

Much remains to be learned about the product markets of the industries that the CDL distilled product will be sold into. Declining coke oven production over time should lead to lower crude cresylic acid and pitch availability; this should translate into a stable market and upward price pressures for those CDL distillation products. Sales of both of these products under long-term sales agreements should be possible.

The market for the refinery feedstock should be a commodity priced market subject to short-term price fluctuations. Future pricing for this product should track price fluctuations in crude oil and gas oil.

If the oxygenated middle distillate is sold as a fuel (potentially its lowest value) it should be possible to sell under long-term contracts, but product pricing would probably be subject to a market pricing mechanism for comparable fuels.

Financial Risk

A preliminary review of financial risk indicates that the three-module, 15,000-metric ton/day facility referred to as the base case will be an investment-grade project. The project has an unleveraged IRR in the 15% range. On a leveraged basis the project IRR will most likely be between 25 and 30% depending on the project's debt capacity. Utilizing a debt coverage ratio hurdle of 1.5 and a borrowing rate of 8.25%, the debt equity ratio will probably settle between 65 and 80%.

The project will definitely be viewed as "new technology" by the financial community given the 5-to-1 scale up; however, the large-scale demonstration to date at the ENCOAL Plant is certainly an advantage. When financing is arranged, it is expected that the tenure of the debt will range between 8 and 10 years with the total door-to-door debt financing in the 14 to 15 year range. Given the long tenure required for this project, the most likely lenders will be the export credit agencies and the export/import banks. These lenders offer below-market rates and significant percentage of project financing.

Overall, the ability to finance the project is high, and considerable effort will be expended to allocate project risk in such a way as to attract quality debt financing.

References

1. "The ENCOAL Project: Initial Commercial Shipment and Utilization of Both Solid and Liquid Products;" Topical Report, Report No. DOE/MC/27339-4088. ENCOAL Corporation, March 1995.

2. "Preliminary Report of EPDC PDF Laboratory Combustion Test Results," March 1995.

3. S.A. Johnson, B.A. Knottnerus, "Results of the PDF Test Burn at Clifty Creek Station," U.S. Department of Energy Topical Report, October 1996.

4. "ENCOAL Project Final Report," U.S. Department of Energy Report, July 1997.

GLOSSARY

ASME	American Society of Mechanical Engineers
BS&W	Basic Sediment & Water
Btu	British Thermal Units
CDL	Coal Derived Liquid
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
ENCOAL	ENCOAL Corporation, wholly-owned subsidiary of Bluegrass Coal Development Company
ESP	Electrostatic Precipitators
^0F	Degrees Fahrenheit
ft.	Feet
$ft.^2$	Square Feet
HP	Horsepower
H_2O	Water
H_2S	Hydrogen Sulfide
in.	Inches
Kellogg	The M. W. Kellogg Company
lb/hr	Pounds per Hour
LFC Technology	Liquid From Coal Technology
MM Btu/hr	Million British Thermal Units per Hour
Max	Maximum
MSHA	Mine Safety and Health Administration
NO_X	Nitrogen Oxides
O_2	Oxygen
PDF	Process Derived Fuel
PLC	Programmable Logic Controller
%	Percent
pH	Measure of alkalinity and acidity on a scale of 0 to 14
psia	Pounds per Square Inch Absolute
psig	Pounds per Square Inch Gauge
RPM	Rotations per Minute
SMC	SMC Mining Company, renamed Bluegrass Coal Development Company, wholly owned subsidiary of Zeigler Coal Holding Company
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
turnkey	Subcontracting method that includes design, furnishing and installation responsibility
vol	Volume

Final Design Modifications Report

This report general contents page has been set up with each section linked to the page where the corresponding section begins. To use this feature, move your cursor to the section you wish to view. (Your cursor arrow will change to a pointing finger.) Click your left mouse button to jump to the correct page in the report.

Cover

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Appendix

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ENCOAL MILD GASIFICATION PROJECT:

FINAL DESIGN MODIFICATIONS REPORT

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THE UNITED STATES DEPARTMENT OF ENERGY
UNDER DOE INSTRUMENT NO. DE-FC21-90MC27339

SEPTEMBER 1997

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GLOSSARY

ASME	American Society of Mechanical Engineers
BS&W	Basic Sediment & Water
Btu	British Thermal Units
CDL	Coal Derived Liquid
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
ENCOAL	ENCOAL Corporation, wholly-owned subsidiary of Bluegrass Coal Development Company
ESP	Electrostatic Precipitators
^0F	Degrees Fahrenheit
ft.	Feet
$ft.^2$	Square Feet
HP	Horsepower
H_2O	Water
H_2S	Hydrogen Sulfide
in.	Inches
Kellogg	The M. W. Kellogg Company
lb/hr	Pounds per Hour
LFC Technology	Liquid From Coal Technology
MM Btu/hr	Million British Thermal Units per Hour
Max	Maximum
MSHA	Mine Safety and Health Administration
NO_X	Nitrogen Oxides
O_2	Oxygen
PDF	Process Derived Fuel
PLC	Programmable Logic Controller
%	Percent
pH	Measure of alkalinity and acidity on a scale of 0 to 14
psia	Pounds per Square Inch Absolute
psig	Pounds per Square Inch Gauge
RPM	Rotations per Minute
SMC	SMC Mining Company, renamed Bluegrass Coal Development Company, wholly owned subsidiary of Zeigler Coal Holding Company
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
turnkey	Subcontracting method that includes design, furnishing and installation responsibility
vol	Volume

1.0 INTRODUCTION

The design, construction and operation Phases of the ENCOAL Mild Coal Gasification Project have been completed. The plant, designed to process 1000 ton/day of subbituminous Power River Basin (PRB) low-sulfur coal feed and to produce two environmentally friendly products, a solid fuel and a liquid fuel, has been operational for nearly five years.. The solid product, Process Derived Fuel (PDF), is a stable, low-sulfur, high-Btu fuel similar in composition and handling properties to bituminous coal. The liquid product, Coal Derived Liquid (CDL), is a heavy, low-sulfur, liquid fuel similar in properties to heavy industrial fuel oil. Opportunities for upgrading the CDL to higher value chemicals and fuels have been identified. Significant quantities of both PDF and CDL have been delivered and successfully burned in utility and industrial boilers. A summary of the Project is given below and in ENCOAL's "Final Project Report"[1].

The project has been cost-shared by the U.S. Department of Energy (DOE), under the Clean Coal Technology Program administered by the Morgantown Energy Technology Center under Cooperative Agreement number DE-FC21-90MC27339. A "Public Design And Construction Report"[2] was published in December 1994 that described the ENCOAL plant as-built, IE tested and ready for operation. This Design Modifications Report is intended to update the original design report for the major changes that have been implemented since the plant became operational in July 1992. Changes integral to the process have become part of the Liquids From Coal (LFC) Technology as it has been demonstrated by the ENCOAL plant.

2.0 BACKGROUND INFORMATION

Organization

ENCOAL Corporation is a wholly owned subsidiary of Bluegrass Coal Development Company, (formerly named SMC Mining Company), which in turn is a subsidiary of Zeigler Coal Holding Company. ENCOAL entered into a Cooperative Agreement with DOE in September 1990 as a participant in Round III of the Clean Coal Technology Program. Under this agreement, the DOE shared 50% of the cost of the ENCOAL Mild Coal Gasification Project. The Cooperative Agreement was extended in October 1994 for an additional $18,100,000 bringing the Project total to $90,600,000 through September 17, 1996. No-cost extensions have moved the Cooperative Agreement end date to July 17, 1997 to allow for completion of final reporting requirements. A license for the use of the LFC Technology has been issued to ENCOAL from the technology owner, TEK-KOL. TEK-KOL is a general partnership between SGI International of La Jolla, California, the original LFC Technology developer and Bluegrass Coal Development Company. Figure 2.1 shows the current Project organization. The M.W. Kellogg Company (Kellogg) was an active member in the early years as the Engineering, Procurement and Construction subcontractor.

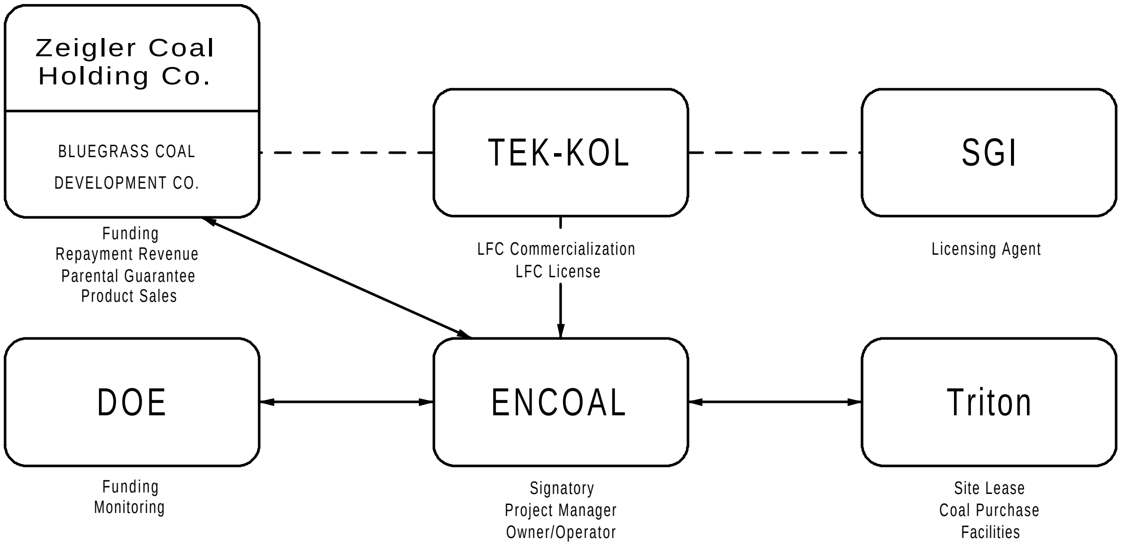


Figure 2.1: ENCOAL Project Organization

Location

The ENCOAL Project encompasses the design, construction and operation of a 1,000 TPD commercial demonstration plant and all required support facilities. The Project is located near Gillette, Wyoming at Triton Coal Company's Buckskin Mine. Figure 2.2 is a general location map. Selected in part because Triton is a sister company, existing roads, railroad, storage silos and coal handling facilities at the mine significantly reduced the need for new facilities for the Project. In addition, Triton could supply the raw coal for processing. Figure 2.3 shows the site layout for the existing Buckskin Mine facilities and the added ENCOAL Project facilities. The shaded areas are modifications to the original plot plan .

Objectives

The overall objective of the Project was to further the commercialization of the LFC Technology. This was to be done by demonstrating that the technology can reliably and economically convert low Btu PRB coal into superior, environmentally attractive low-sulfur, marketable products. In support of this overall objective, the following specific objectives were established that had a significant impact on the plant design:

(1) Provide products for commercial scale test burns
(2) Obtain data for the design of future commercial plants
(3) Demonstrate plant and process performance
(4) Provide capital and operating costs data
(5) Support future LFC Technology licensing efforts

Figure 2.2: **ENCOAL Project Location**

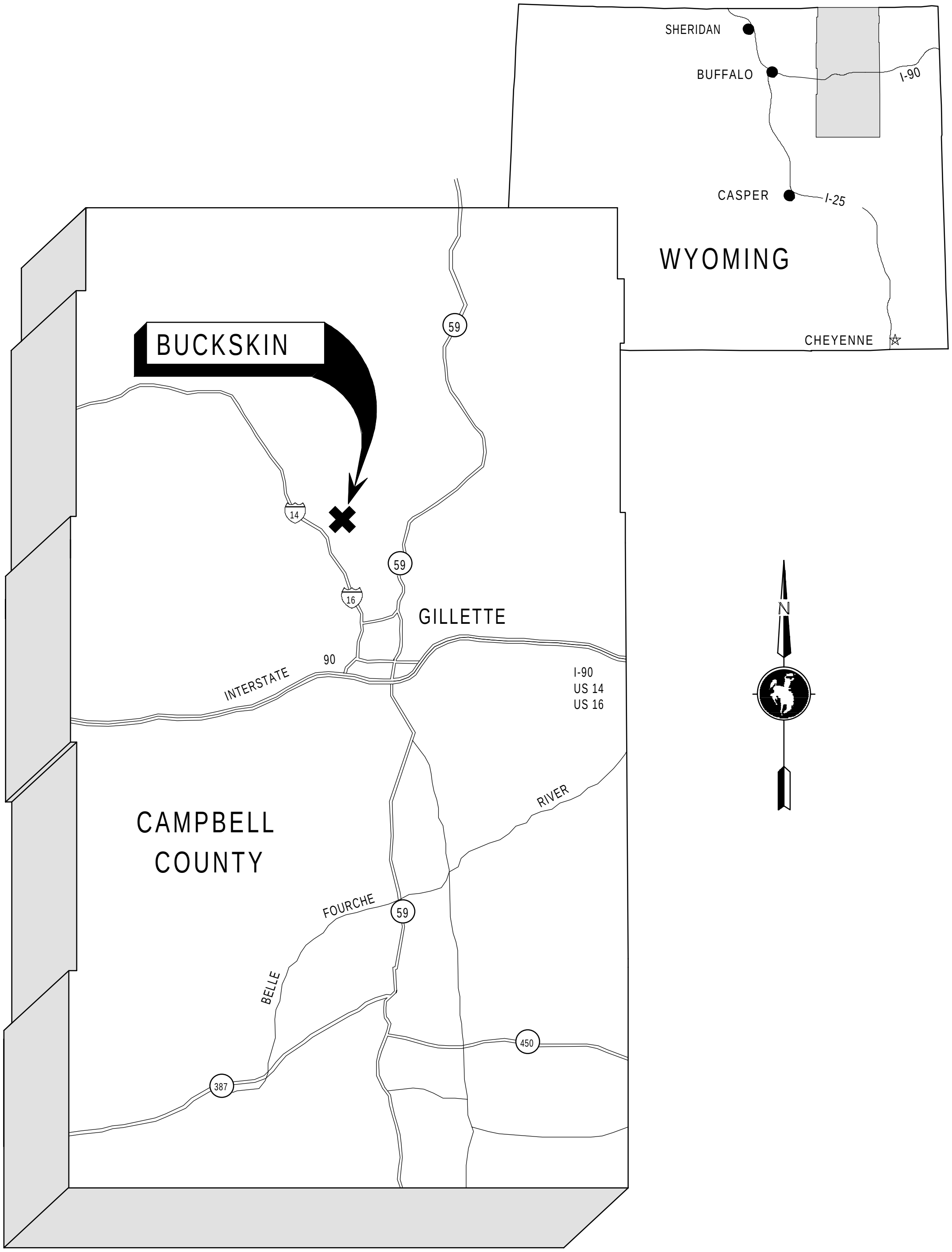
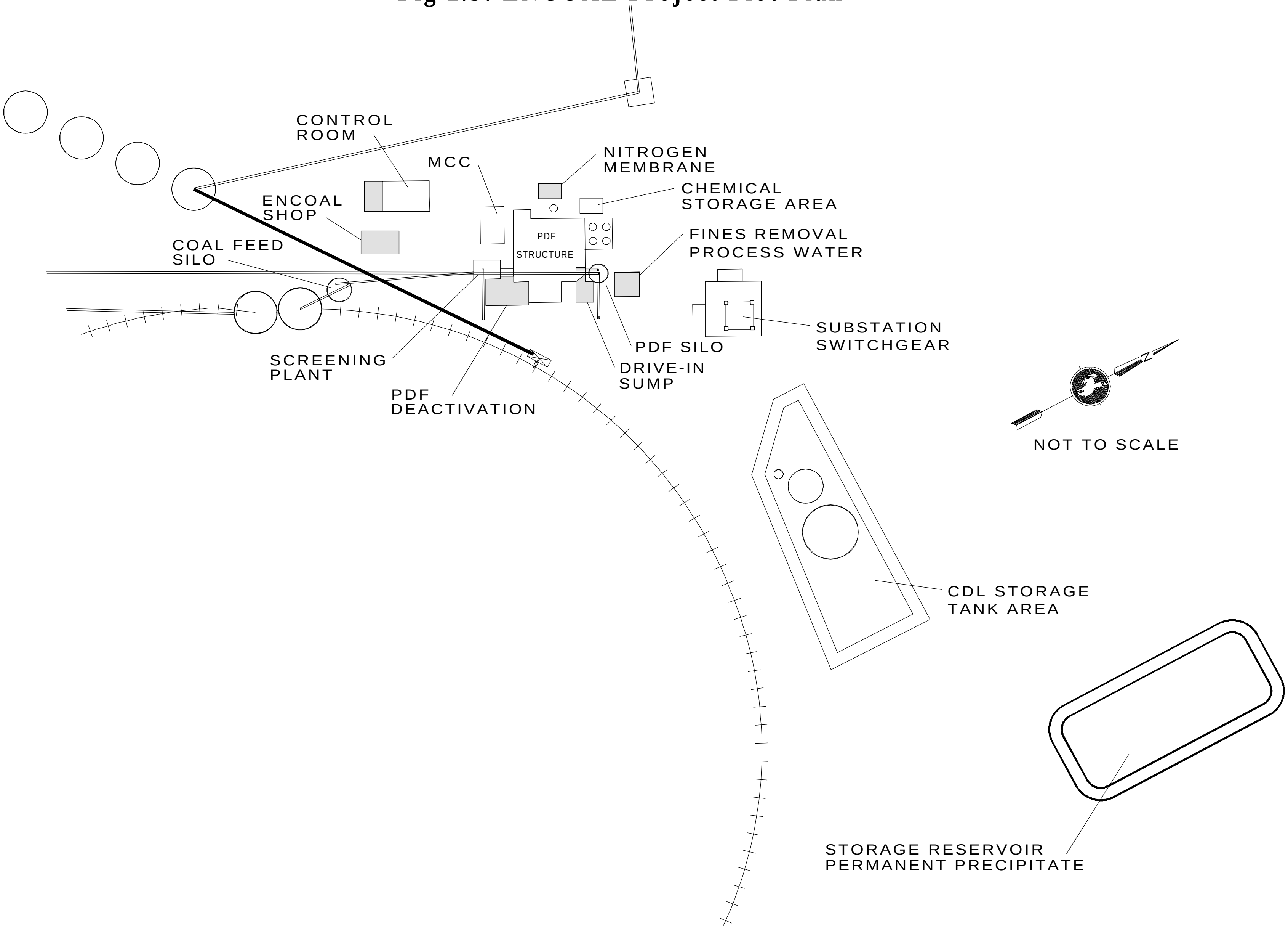


Fig 2.3: ENCOAL Project Plot Plan



Given these objectives, the project team charged with the responsibility of designing the facilities developed an additional set of guidelines to further define the requirements and aid in the design:

1. Keep scale-up from the SGI pilot plant reasonable.
2. Use currently available commercial equipment as much as possible.
3. Keep the process simple, postpone the refinement of CDL.
4. Match the products to existing markets.
5. Minimize all releases to the environment.

ENCOAL's processing plant was designed to commercial standards for a life of at least 10 years. It used commercially available equipment as much as possible, state-of-the-art computer control systems, BACT for air emissions, and environmental controls to minimize releases, and a simplified flowsheet to make only two products matched to existing markets. The intent was to demonstrate the core process and not make the project overly complicated or expensive. All plant modifications were designed with the same principles in mind.

Project History

ENCOAL's original parent company, SMC, worked on upgrading low rank coals from the early 1970's to the mid 1980's. SGI began working on their LFC Technology in 1980. In 1986 SMC and SGI held their first discussions. The TEK-KOL Partnership was formed in 1987 and joint development of the LFC Technology has progressed steadily since then. While some process as well as mechanical design was done by Kellogg in 1988 for permitting and financing purposes, the final design effort was started in ernest in July, 1990 in anticipation of the DOE contract. Civil construction was started in October, 1990; mechanical erection began in May, 1991. Virtually all of the planned design work was completed by July 1991. Most major construction was complete by April, 1992 followed by plant testing and commissioning. Plant operation began in late May, 1992 and the first 24 hour run producing both PDF and CDL occurred on June 17. This report covers the major modifications to the original design implemented since the plant became operational in July 1992.

Operating Experience

Table 2.1 summarizes the operating experience of the ENCOAL plant. The table is divided into two distinct periods; (1) the early runs before installation of the deactivation loop discussed below which concentrated on solving equipment and stabilization problems and (2) runs after the VFB installation which were primarily production runs for test burns. As the table clearly shows, the operating hours for the plant and average length of runs improved markedly after the 1993 shutdown due to all the modifications made during the outage, a primary focus of this report.

Pre-VFB			Post-VFB				
	1992	1993	1994	1995	1996	*1997	*SUM
Raw Coal Feed (Tons)	5,200	12,400	67,500	65,800	68,000	28,000	246,900
PDF Produced (Tons)	2,200	4,900	31,700	28,600	33,300	14,200	114,900
PDF Sold (Tons)	0	0	23,700	19,100	32,700	7,400	82,900
CDL Produced (Bbl)	2,600	6,600	28,000	31,700	32,500	14,700	116,100
Hours on Line	314	980	4,300	3,400	3,600	1,944	14,538
Average Length of Runs (Days)	2	8	26	38	44	81	

** Through May 31, 1997*

Table 2.1: ENCOAL Plant Performance

Although designed for 1000 TPD feed, the plant capacity is now held to 500 TPD due to limited residence time in the deactivation loop. Installation of a second VFB was planned to bring the plant back to full capacity if necessary. The plant now produces approximately 250 TPD of PDF and 250 barrels/day of CDL. The plant has performed increasingly better with respect to mechanical availability as the operations team has matured and equipment problems have been solved. Runs exceeding 120 days continuous operation are now routine with availability during the run at 90% or better, *(e.g. May 1997 achieved 100%).*

Even with the restricted capacity, the ENCOAL plant has now delivered 17 unit trains and one truck shipment of blended and straight PDF to seven different utility customers. Over 200 jumbo tank cars of CDL have been delivered to eight industrial customers. In all cases the PDF and CDL products have been handled in existing rail cars and material handling systems with no special handling requirements. Utility test burns have shown that the fuel products can be used economically in commercial boilers and furnaces to reduce sulfur and NO_x emissions significantly at utility and industrial facilities currently burning high sulfur bituminous coal or fuel oils. Ultimately, installation of commercial scale LFC plants should help reduce U.S. dependence on imports of foreign oil. The plant continues to operate and deliver products under private funding.

The ENCOAL Project has demonstrated for the first time the integrated operation of several unique process steps:

- Coal drying on a rotary grate using convective heating
- Coal devolatilization on a rotary grate using convective heating
- Hot particulate removal with cyclones
- Integral solids cooling and deactivation
- Combustors operating on low Btu gas from internal streams
- Solids stabilization for storage and shipment
- Computer control and optimization of a mild coal gasification process
- Dust suppressant on PDF solid fuels

3.0 OVERVIEW OF PROCESS

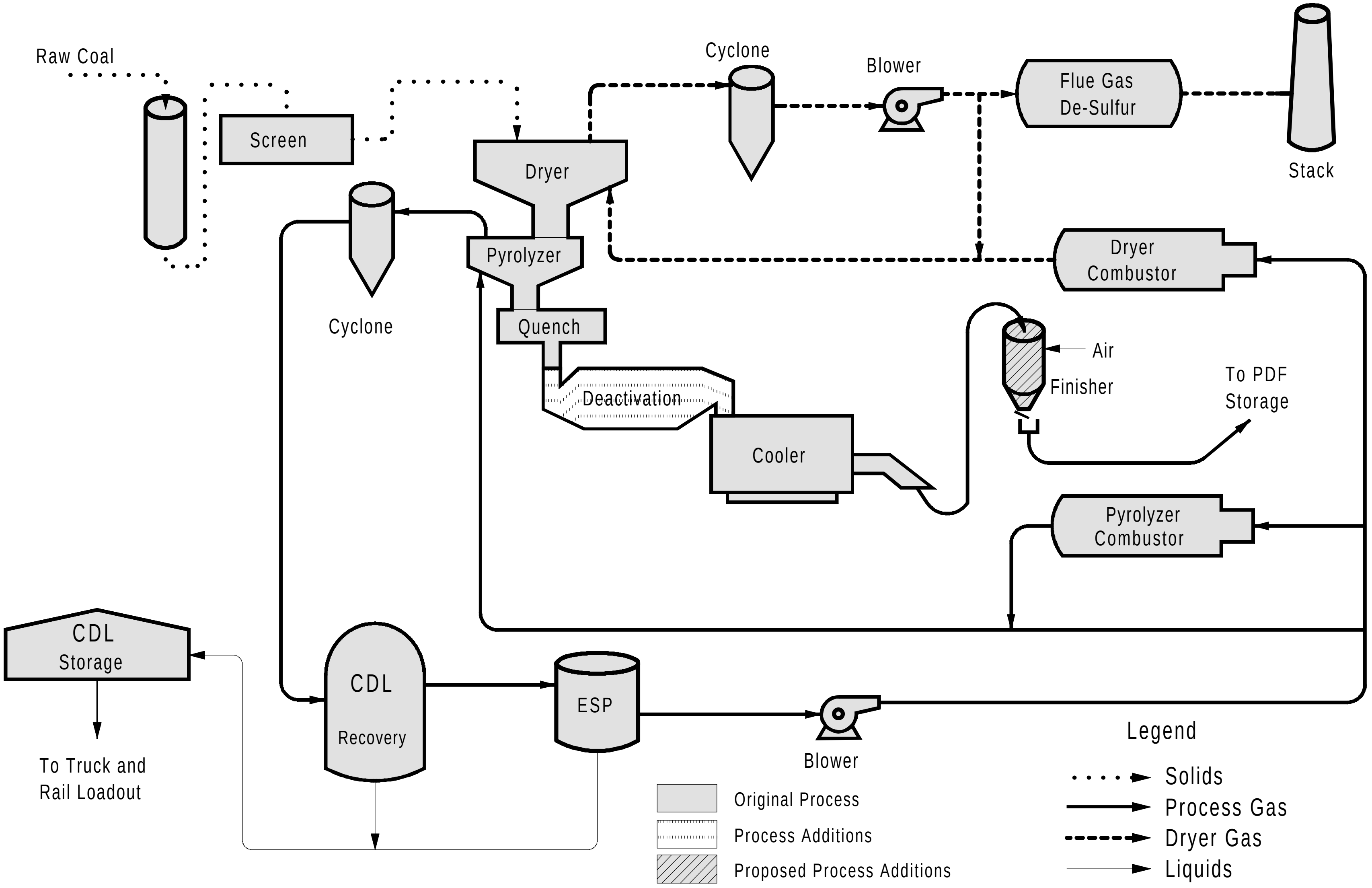
The LFC process is a mild gasification or mild pyrolysis process which involves heating of coal under carefully controlled conditions to produce gaseous compounds. It is termed mild because the temperatures are moderate and reactions take place at near atmospheric pressure. Figure 3.1 shows a fairly detailed flow diagram of ENCOAL's application of the LFC Technology. The shaded areas represent changes to the original process flow sheet.

Run-of-mine coal is conveyed from the Buckskin Mine to a storage silo. The coal from this silo is screened to remove oversize and undersize materials. The specification coal feed, 2" x _" size, is hand sampled to measure the moisture, ash, carbon, hydrogen, sulfur, and other contents of the feed coal (it once passed through a GAMMA-METRICS coal analyzer - now removed). The coal is then fed into a slotted rotary grate dryer where it is heated by a hot gas stream. The residence time of the coal and temperature of the inlet gas have been selected to reduce the moisture content of the coal without initiating chemical changes. The solid bulk temperature is controlled so that no significant amount of methane, carbon monoxide or carbon dioxide is released from the coal.

The solids from the dryer are then transferred to a second rotary grate , the pyrolyzer, where the temperature of the dried coal is raised to about 1000^0F by a hot recycled gas stream. The rate of heating of the solids i.e., the inlet temperature and flow rate of the hot recycled gas stream, is carefully controlled because it determines the properties of the solid and liquid products. In the pyrolyzer, a chemical reaction occurs which results in the release of volatile gaseous materials from the coal. Solids exiting the pyrolyzer are quickly quenched to stop the pyrolysis reaction, then transferred to a small surge bin that feeds the vibrating fluidized bed (VFB) deactivation unit - a major addition to the original plant.

In the VFB unit, the partially cooled, pyrolyzed solids contact a gas stream containing a controlled amount of oxygen. Termed "oxidative deactivation," a reaction occurs at active surface sites in the particles reducing the tendency for spontaneous ignition. The heat generated by this reaction is absorbed by a fluidizing gas stream which is circulated through a cyclone to remove entrained solids and a heat exchanger before being returned by a blower to the VFB. Oxygen content in the loop is

Figure 3.1: Simplified Flow Diagram



maintained by introducing the proper amount of air through a control valve. Excess gas in the loop is purged to the dryer combustor for incineration.

Following the VFB, the solids are cooled to near atmospheric temperature in an indirect rotary cooler. A controlled amount of water is added in the rotary cooler to rehydrate the PDF to near its ASTM equilibrium moisture content. This is also an important step in the stabilization of the PDF. The cooled PDF is then transferred to a storage bin. Because the solids have little or no free surface moisture and, therefore, are likely to be dusty, a patented dust suppressant called MK is added as PDF leaves the product surge bin.

At the present time, the PDF is not completely stabilized with respect to oxygen upon leaving the plant. The PDF must be "finished" by a short exposure to atmospheric conditions in a layered stockpile prior to being reclaimed and shipped. In addition to atmospheric stabilized PDF, a stable product can be made by blending run-of-plant PDF with either ROM coal or the atmosphere stabilized PDF , but there is a Btu penalty. ENCOAL has recently completed pilot-scale equipment tests that successfully perform this finishing step using continuous process equipment. The design uses commercially available equipment to be installed just downstream of the rotary cooler mentioned above, and will effectively stabilize PDF without the layered stockpile step. Installation of this equipment is currently scheduled for the second half of 1997.

The hot gas produced in the pyrolyzer is sent through a cyclone for removal of the particulates and then cooled in a quench column to stop any additional pyrolysis reactions and to condense the desired liquids. Only the CDL is condensed in this step; the condensation of water is avoided. Electrostatic precipitators recover any remaining liquid droplets and mists from the gas leaving the condensation unit.

Almost half of the residual gas from the liquid recovery unit is recycled directly to the pyrolyzer, while some is first burned in the pyrolyzer combustor before being blended with the recycled gas to provide heat for the mild gasification reaction. The remaining gas is burned in the dryer combustor, which converts sulfur compounds to sulfur oxides. Nitrogen oxide emissions are controlled via appropriate design of the combustor. The hot flue gas from the dryer combustor is blended with the recycled gas from the dryer to provide the heat and gas flow necessary for drying.

The unrecycled portion of the off-gas from the dryer is treated in a wet gas scrubber and a horizontal scrubber, both using a water-based sodium carbonate solution. The wet gas scrubber recovers the fine particulates that escape the dryer cyclone, and the horizontal scrubber removes most of the sulfur oxides from the flue gas. The treated gas is vented to a stack. The spent solution is discharged into a pond for evaporation. The plant has several utility systems supporting its operation. These include nitrogen, steam, natural gas, compressed air, bulk sodium carbonate and a glycol/water heating and cooling system.

4.0 PLANT EQUIPMENT MODIFICATIONS

The early operation of the ENCOAL plant facilities was typical of what would be expected from a first-of-its-kind technology application. Along with the many successful plant runs there were many more false starts. Valuable information was gained from every run, successful or not, and this information was carefully evaluated to define necessary equipment repairs, plant modifications and process adjustments.

In the last five years, numerous changes have been made to the ENCOAL plant facilities as well as to the computer programs that control its operation. These have taken place both during plant operation and during shutdowns. Planning for these changes starts during an operating mode in either case, sometimes involving contractors or operators on overtime making preparations for the modifications in a way that minimizes the length of a planned shutdown. The longest shutdown for modifications to date occurred from July 1993 to January 1994 for addition of the deactivation loop. Several shorter shutdowns were also required for other less involved modifications, some of which were remote to the main plant and work could proceed without interrupting plant operations, like the temporary process water handling system. The following sections describe the modifications made to the original plant equipment.

4.1 Solids Handling System

Problems in the solids handling systems in the ENCOAL plant were self inflicted in some areas, like spillage control. Dribble chutes, space for collection and clean-up and screw conveyors for the fines transfer were neglected in the original design. A means of removing raw coal from the feed coal silo without running through the plant became important during an unplanned lengthy shutdown. In the case of the flexible wall vertical plant feed and PDF conveyors (s-belts), the excessive spillage and fluid drive systems proved very troublesome. The GAMMA-METRICS on-line coal analyzers were eventually removed because of inferior software, cheap clone computers and a paucity of manufacturer’s support. Sampling for the extensive calibration testing needed for these analyzers also was a problem because it had to be done by hand. Drag conveyors in the plant, all of the single chain design with hardened flights, have been very high maintenance items.

S-belts

The Schultz Flex-O-Wall conveyors furnished with the original plant only had a few inches of clearance with the floor or nearest enclosure wall. High spillage is inherent because of the bucket design. The result was a maximum of a few hours run time before the material built up under the belts and began to be carried back, a fire hazard and thus causing a plant shutdown. During successive shutdowns, especially the VFB addition, dribble chutes were added, trenches jack-hammered into the floors and a screw conveyor added to eliminate the problems. The motors and fluid drive clutches ordered with these conveyors were sized too close to the nominal design and could not handle any surges.Eventually the motors were replaced and the fluid drives removed.

GAMMA-METRICS Analyzers

The original LFC Technology concept included a closed loop process control scheme that relied on rapid, reliable on-line feed coal analysis as well as PDF solid product analysis. GAMMA-METRICS nuclear analyzers were purchased for the plant feed and product streams at an installed cost of well over $1,400,000. The data from the analyzers was to provide feed forward and feed backward control of the process variables to allow optimization of the LFC process. Extensive efforts were made over the first four years of the project to calibrate these units so they would provide the needed process information. Hand sampling required for gathering the seemingly endless samples required by the manufacturer made the effort even more difficult.

Numerous 30 to 60 day sampling campaigns on a several-times-per-day basis were completed only to be thwarted by software or computer crashes that caused loss of all data. Plant shutdowns also caused some of the problems, but invariably the user unfriendly data gathering equipment furnished by GAMMA-METRICS would fail before the plant could be brought back on line. Manufacturers support was very poor. In the fall of 1996, both GAMMA-METRICS analyzers were removed to end the exorbitant cost of maintaining the nuclear sources. Samples of coal and PDF are now taken manually once per shift and analyzed on site to maintain process checks.

Miscellaneous

To solve the problem of removing raw coal from the storage silo without going through the plant, a by-pass chute was added in the screening building. In retrospect, this should be included with any PRB storage unit to handle hot coal or avoid potentially long storage times. A dribble chute was also added on the plant feed belt to catch spillage. Other dribble chutes, wear plates, flow diverters and cleanout doors were also added in several places. Today the system operates very well. The drag conveyors still are high maintenance but money and time has not been available to change them to the dual chain design that would be much more reliable (and costly to buy). Drag conveyors in general, and certainly single chain type, should be avoided in commercial plants.

4.2 Dryer and Pyrolyzer Modifications

Dryer and Pyrolyzer Internal Seals

ENCOAL's process uses convective heating in the Salem Furnace Company rabbled rotary hearth furnaces for the dryer and pyrolyzer units. This is accomplished by passing hot gasses through a slotted, rotating grate upon which rests a bed of coal. The seal between the rotating grate and the vessel wall, which prevents the hot gas below the grate from bypassing the coal bed, was a blade attached to the rotating member immersed in a stationary tub of sand. See Figure 4.2a for the details. This seal design proved to be very troublesome.

Besides the higher than expected wear, sand degradation, coal dust build-up and maintenance problems in both units, the sand seal in the pyrolyzer did not allow operation at full design differential pressure across the grate. In order to operate, the flow rate in the pyrolyzer loop had to be reduced to avoid blowing out the sand in the seal. The lower gas flow resulted in loss of efficiency in the cyclone, dust carryover in the piping, solids in the CDL product and plugging of lines. In addition, less heat was transferred to the coal resulting in less severe pyrolysis. Attempts were made to raise the on-gas temperature to compensate for the lower gas flow but this generated heavier CDL and raised the liquid dew point in the off-gas. Condensation of liquid then occurred ahead of the quench column where it combined with the dust in the system creating unacceptable ductwork plugging.

At significant expense, the manufacturer, working with ENCOAL, developed an alternate design using external water seals rather than the internal sand seal. Details of this design are shown in Figure 4.2b. With design and material furnished by the manufacturer, ENCOAL installed the pyrolyzer water seal during the VFB addition shutdown. Based on highly successful results during the following plant runs, a water seal was added to the dryer in January 1995. This revision was one of the major contributors to longer runs in the ENCOAL plant.

Clean up of the Salem grates became more of an issue once longer plant runs were possible. The manufacturer again was asked to assist with the problem and they came up with a steam broom, a series of nozzles located above the normal coal level directed toward the soaking pit outlet. During shutdown, steam is turned on and the nozzles blow the residual coal off the grate. The steam brooms are very helpful and are used during every shutdown to help avoid fires when opening up the process vessels.

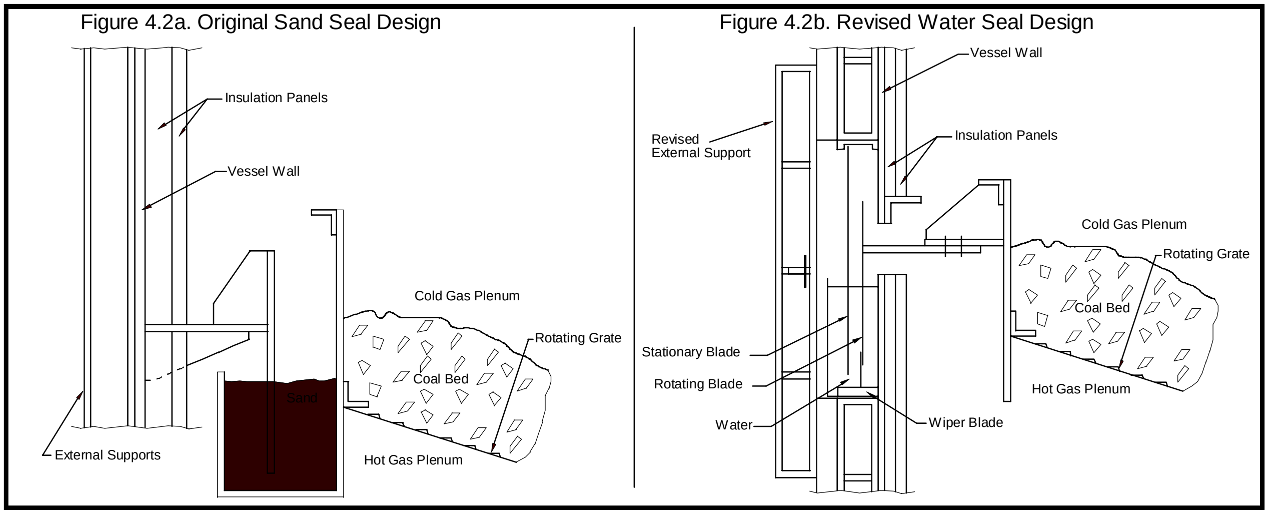


Figure 4.2a. Original Sand Seal Design

Figure 4.2b. Revised Water Seal Design

Figure 4.2. Comparison of Seal Designs - Dryer and Pyrolyzer

In addition, a steam blaster was added to both units that swings down near the grate to clean the slots in the grate without entering the dryer or pyrolyzer. These have been used successfully to extend a run when the plugging of the grates is moderate. Manual cleaning is still required after many months of operation. This buildup is not a major problem. It is easily removed, consisting mostly of coal dust, not coke. It can be handled during normal yearly turnarounds in a commercial plant.

4.3 Dryer and Pyrolyzer Cyclones

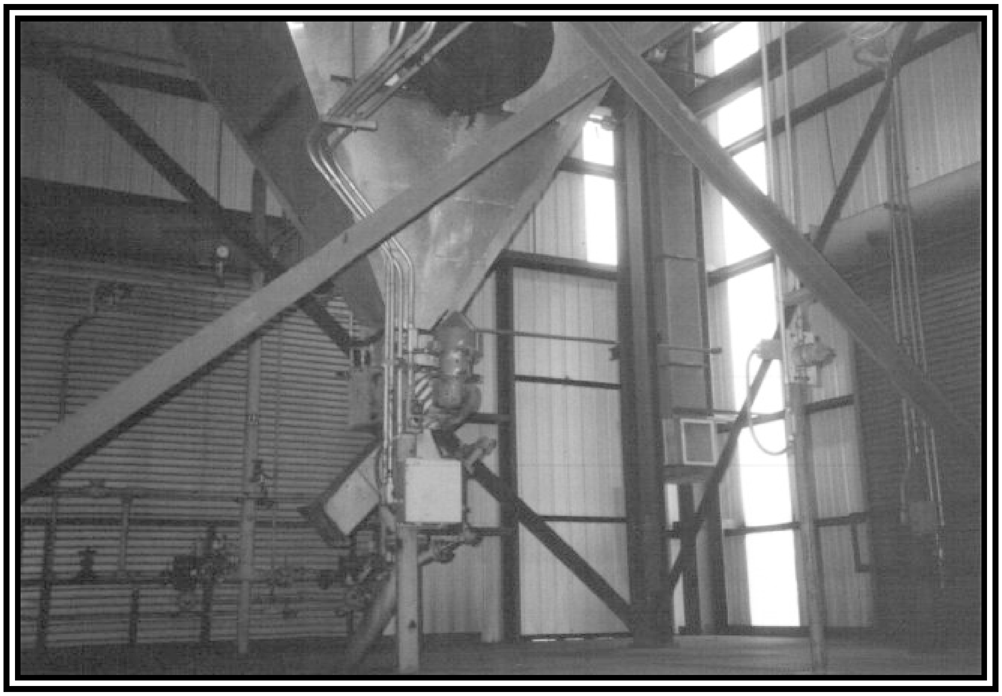
Dryer Cyclone

Operation of the dryer cyclone was very successful with no modifications being made to the cyclone itself. However, the fines handling system at the discharge of the unit was significantly changed. The original design included indirect heat exchange via a screw cooler prior to being slurried to the sump system. Because of maintenance and plugging problems with the screw cooler, this unit was removed. The final layout simply mixes the fines with water immediately under the rotary valve airlock prior to draining to the plant sump system. (See Figure 4.3a: Dryer Cyclone Fines Discharge)

Pyrolyzer Cyclone

Operation of the pyrolyzer cyclone was not as successful as the dryer. The pyrolyzer cyclone was originally designed to be 97% efficient; however, problems with limited loop flow rates, cyclone pressure drop, and the small size and quantity of fines made this cyclone only 75% efficient. The pyrolyzer water seal modification discussed earlier did allow for higher flowrates and pressure drop, but the cyclone still did not perform as designed. This resulted in high sediment concentrations in the CDL. The gas inlet and the vortex finder were then modified to aid in flow direction and pressure drop increase. These modifications were somewhat successful yielding a CDL with an average sediment of 3 wt%. Although not 97% efficient, the pyrolyzer cyclone operation is now acceptable.

Other modifications to the pyrolyzer cyclone include extensive changes to the fines handling system. The fines slurry mix tank and pump system originally designed for handling the pyrolyzer cyclone fines continually plugged and experienced high wear. This system was therefore removed. Like the dryer cyclone, the present fines handling system is a simple water-fines mixing box immediately under the rotary airlock prior to gravity draining to the sump system. This arrangement is easy to maintain and does not utilize any motorized equipment to operate. (See Figure 4.3b: Pyrolyzer Cyclone Fines Discharge)



4.3a: Dryer Cyclone Fines Discharge.

4.3b: Pyrolyzer Cyclone Fines Discharge.

4.4 Pyrolyzer Quench Table and Quench Steam Condensing System

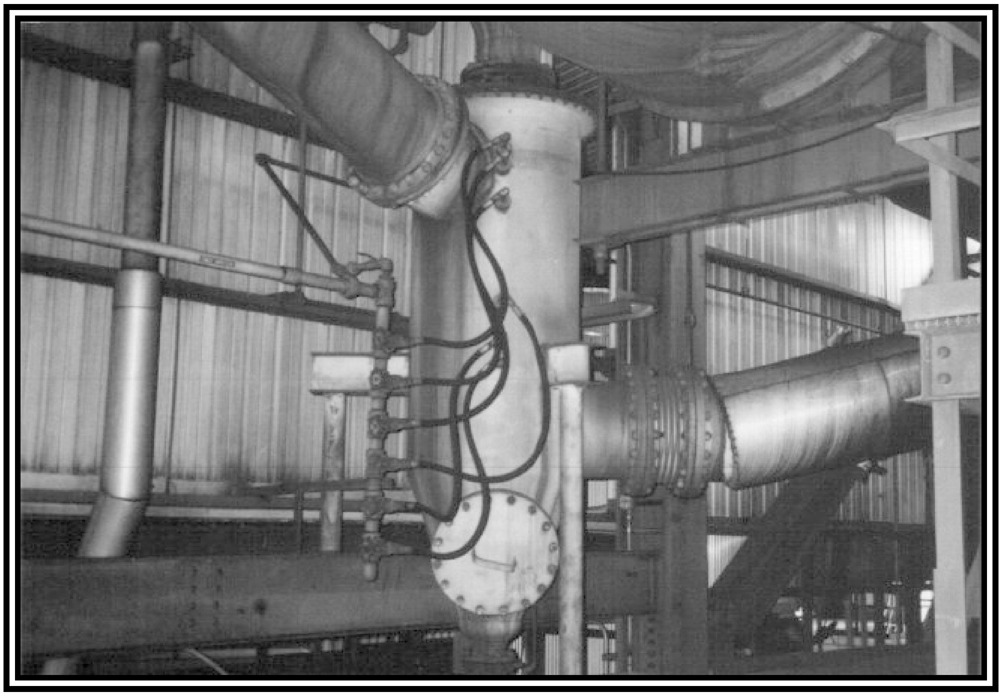
Pyrolyzer Quench Table

Few problems were encountered in the operation of the pyrolyzer quench table. The upper water seal was adjusted to keep from flooding the process during minor plant upsets, and the process water supply piping was modified for ease of maintenance. The quench table spray nozzle system supplied with the original equipment frequently plugged and could not be maintained while the plant was on-line. The nozzle assemblies were modified to be removable on-line for unplugging, and a supply header was fabricated to simplify the supply piping and organize the nozzles. This new arrangement was very successful in reducing the maintenance of the system and increasing operator understanding of the quench table operation. (See Figure 4.4a: Pyrolyzer Quench Table Water Supply Header)

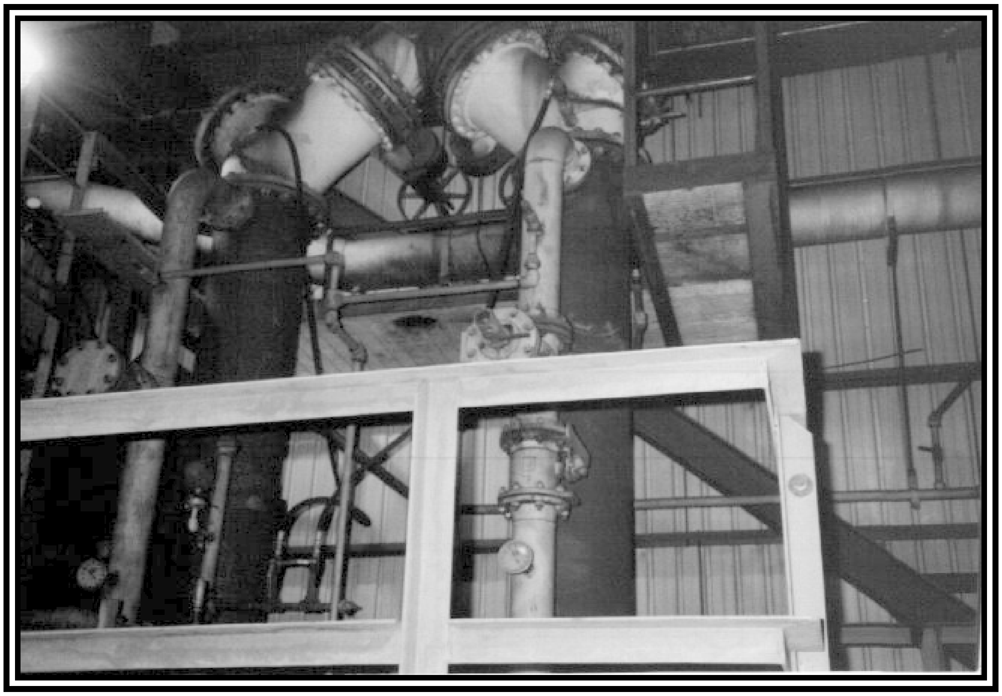
Pyrolyzer Quench Steam Condensing System

Several problems were encountered with the operation of the quench steam condensing system. Excessive coal fines build-up was experienced in both the piping to the condenser and in the condenser tubes themselves. Plugging of the condenser caused over pressuring of the quench table, which in turn required the opening of a pressure relief valve. Many plant shutdowns were attributed to this phenomenon. A fines knock-out drum and piping wash nozzles were installed between the quench table and the condenser to strip the coal fines from the steam. (See Figure 4.4b: Quench Steam Fines Knock-out Drum) The knock-out drum addition was successful in allowing the plant to run for longer periods; however, extended plant operation would eventually foul the single condenser and cause a plant shutdown. A second, redundant condenser was then installed to allow for on-line switching between condensers without requiring a plant shutdown for cleaning. (See Figure 4.4c: Dual Quench Steam Condensers) With these modifications, the operation of the quench steam condensing system became routine.

Figure 4.4a: Pyrolyzer Quench Table Water Supply Header.



4.4b: Quench Table Steam Fines Knock-Out Drum.



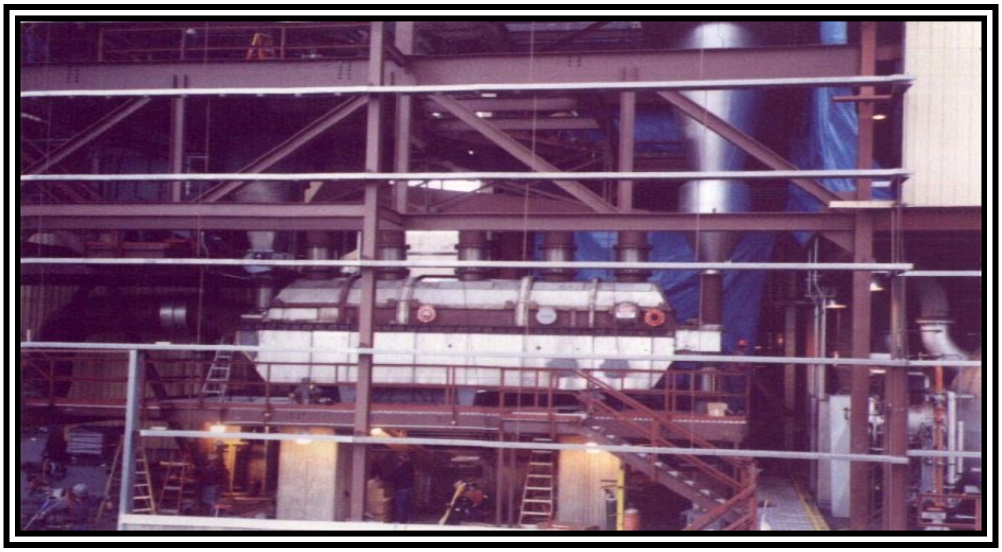
4.4c: Dual Quench Steam Condensers.

4.5 PDF Deactivation System

Problems with PDF product self heating in 1992 and 1993 led to several minor plant modifications and extensive testing in hopes of using original plant equipment to produce stable PDF. Results of a January 1993 test run, however, indicated that PDF deactivation would require a separate, sealed vessel. Subsequent plant and laboratory tests were run in February and March of the same year in order to establish effective criteria for deactivation. Based upon the results of these tests, an option for PDF deactivation was chosen. The deactivation process is discussed below. For the modification, a 6' x 30' vibrating fluidized bed unit and support equipment, the first of two planned systems, were installed in series with the original plant equipment to deactivate PDF. The system was designed to handle half plant throughput; when it had proven itself, a second VFB system would be installed. Installation of the PDF deactivation facilities, *(ie VFB project),* began in June 1993 adjacent to theENCOAL plant. Construction and start-up of the facilities was completed in January 1994 and the new equipment is currently in operation. (See Figures 4.5a and 4.5b: PDF Deactivation System Construction, and Figure 4.5c: PDF Deactivation Building Completed)

PDF Deactivation Loop Process Description

Quench table processed coal is fed into the deactivation loop by a sealed drag conveyor where it is partially fluidized and treated with a controlled temperature and oxygen gas stream in a VFB unit. The deactivation gas stream consists of a fan to move the gas stream, a cyclone to remove entrained solid fines, a heat exchanger to control gas temperature, and a booster fan to bleed off gas to the dryer combustor. The residence time, oxygen content, and temperature of the gas stream were selected to deactivate the coal within the VFB unit. (See Figure 4.5d: PDF Deactivation Loop Simplified Process Flow Diagram)

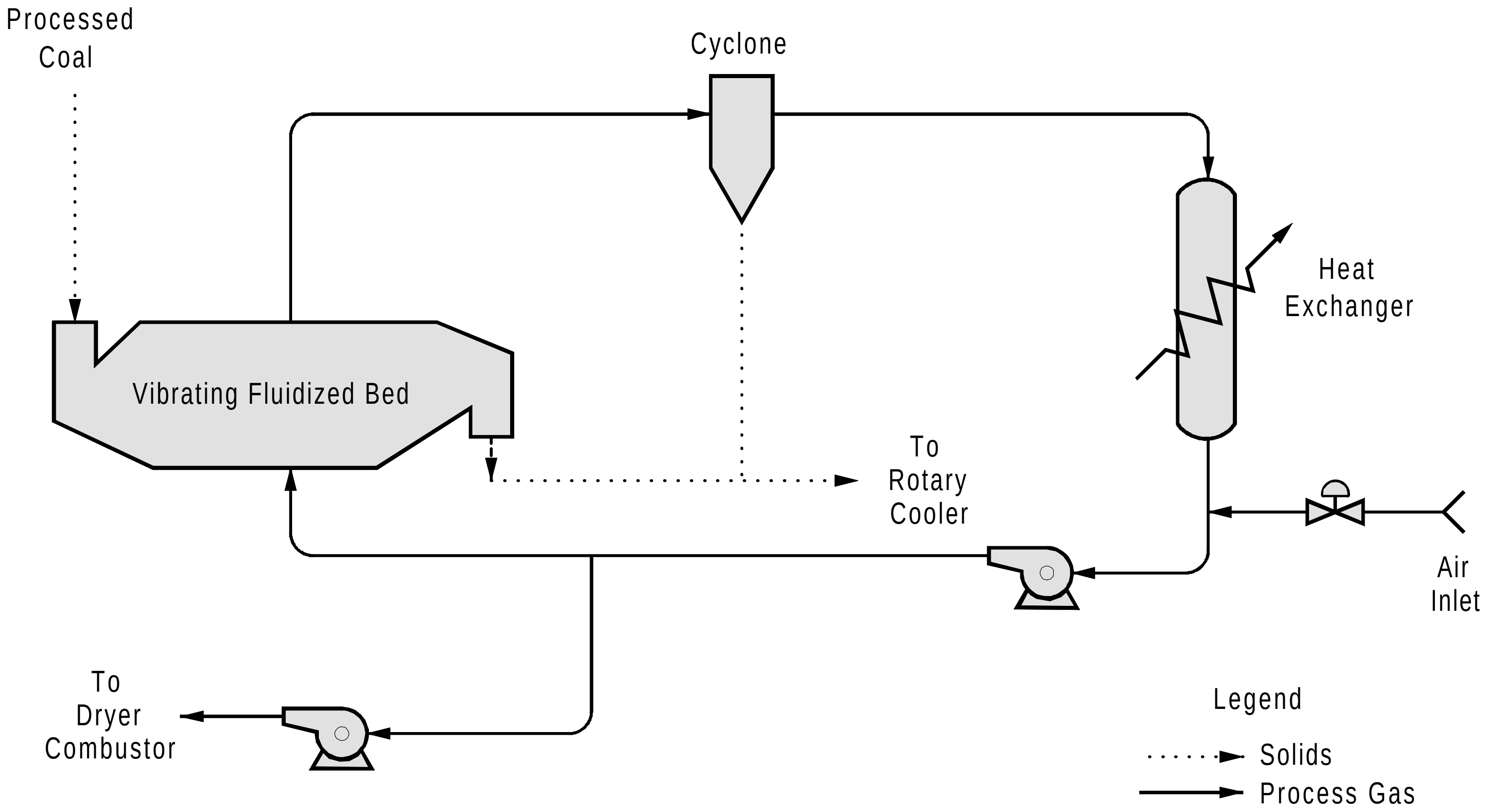


4.5a: Vibrating Fluidized Bed Unit.

4.5b: PDF Deactivation System Under Construction.

4.5c: PDF Deactivation Building Completed.

Figure 4.5d: PDF Deactivation Loop Simplified Process Flow Diagram



VFB System Operation

By the spring of 1994, plant production runs were considerably smoother and longer. The new deactivation system allowed for shipment of PDF to utility customers for the first time; however, even as PDF stability was notably improved with the addition of the VFB, deactivation of PDF still required additional oxygen prior to shipment. Over 20 different operating conditions were varied and evaluated to enhance the amount of oxygen absorbed in the VFB system, but were not entirely successful. The decision was made to "finish" the oxidation deactivation of the solids by laying the PDF on the ground outside the plant. This process, which came to be known as "pile layering", involves spreading the PDF in 12-inch layers thus allowing PDF particles to react with oxygen and become stable. As each thickness is stabilized, more PDF may be layered on top. This method of stabilization, (combined with blending with ROM coal, increased silo retention times, and slightly higher rehydration rates), has been used to deactivate PDF for all shipments to date.

In-plant stabilization of PDF, however, still required more evaluation. This evaluation process was conducted in 1995 and 1996 in series with the plant operation, and discussion of this work is found below in Section 4.14: PDF Finishing.

4.6 PDF Cooler and Rehydration

The cooler is a rotating cylindrical vessel which measures 11 feet diameter and 50 feet in length, and is used to cool PDF to atmospheric temperature in the LFC Process. The unit indirectly cools the PDF using internal cooling water tubes and tumbling action to accomplish the heat exchange. This unit was found to be a very efficient heat exchanger, and little mechanical or operating problems were encountered. In fact, concerns of external tube fouling with dust were alleviated as the tumbling action of the PDF kept the tube surfaces clean during operation.

Several temporary modifications were made to the PDF cooler in late 1992 in an effort to improve PDF stability using in-plant equipment. These modifications included the addition of a fan, ductwork, and entrained fines removal equipment to circulate a controlled oxygen atmosphere through the cooler. These modifications proved unsuccessful, and it was determined that a separate, sealed vessel would be required to deactivate PDF as discussed in Section 4.5 above. The gas circulation system was therefore removed from the cooler.

Rehydration

Other modifications made to the unit, however, were more successful. The original design of the ENCOAL plant placed the rehydration step in the process at the top of the PDF silo, spraying water on the PDF as it dropped vertically into storage. This rehydration technique proved to be inconsistent as it was difficult to obtain uniform distribution of water on the PDF, and there was not adequate mixing as PDF entered the silo. In addition, as PDF rehydrates to equilibrium moisture, the resulting heat of reaction necessitates heat removal, or the PDF overheats and becomes unstable.

The cooler was modified to include a small water lance and spray nozzle to inject rehydration water into the interior of the unit. The nozzle placement in the cooler was designed to be adjustable to ensure the proper amount of water could be injected without flashing to steam. The tumbling action of the cooler was found to provide more than adequate mixing, and the heat of reaction due to rehydration is taken away by the indirect heat exchange with cooling water. With the relocation of the rehydration spray to the interior of the cooler, the distribution of rehydration water and the consistency of PDF moisture quality greatly improved. (See Figure 4.6: PDF Cooler with Rehydration Spray Addition)

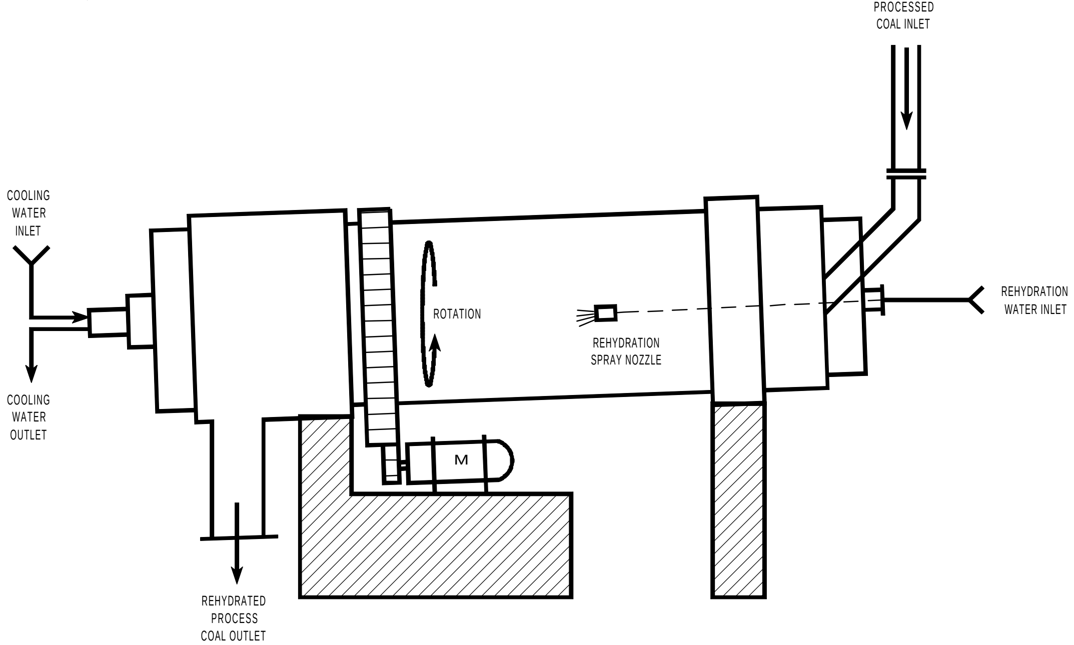


Figure 4.6: PDF Cooler With Rehydration Spray Addition.

4.7 Quench Tower

The quench tower in the ENCOAL plant is a 12.5' diameter by 90' tall condensation unit where the overhead gas from the pyrolyzer is cooled to form CDL. It has 12' of Glitch Grid Tray packing giving approximately two theoretical stages to reach equilibrium. A distributer bar with nozzles at the top of the packing breaks the refluxed CDL cooling oil into droplets that cool the gas and absorb the condensible hydrocarbons. This column has worked very well during its five years of operation. No buildup of solids on the walls or in the packing has ever been observed even though it was predicted by some that cokingwould occur.

One problem did occur in the column inlet piping and gas distributor. An oily mixture of coal fines and heavy pitch would build up at the column inlet distributor as shown in Figure 4.7a. This accumulation caused several plant shutdowns and many hours of cleanup in the piping, (and general area when the oils were inadvertently spilled). After several attempts to make larger and larger weep holes work in the distributor, it was completely removed. The revised distributor is depicted in Figure 4.7b has eliminated the problem and the plant has operated for nearly two years without measurable buildup. In the preceding two years the piping had to be cleaned out about every three months.

4.8 Electrostatic Precipitators

Much time was spent in repairing the ESP's in 1992 and 1993. Numerous plant shutdowns were caused by failed insulators in all three units. ENCOAL worked in conjunction with the ESP manufacturer to establish the cause of the insulator failures. As a result of this effort, several modifications were implemented and are listed as follows:

1) New non-glazed, ceramic insulators were fabricated and installed in the units. These new insulators are made of a material that is resistant to cracking and are of a slightly different design than the originals.

2) Heating blankets and external insulation were added on the insulator cans and the blankets were set to a temperature that maintain 250°F at the insulator. The high temperatures keep the surface of the insulator hot and do not allow liquids to condense on the insulator surface.

3) Thermocouples were installed on all of the insulator cans to monitor the can temperature during plant operation. An operator alarm is activated if the can temperature falls below the set temperature.

4) The gas flows through the three ESP units were balanced. A balanced flow ensures that process gas is distributed equally and not concentrated through one ESP.

5) A nitrogen purge was added to all insulator mounts to keep CDL from condensing on the insulator surface, and thereby avoiding an insulator failure.

These modifications were very successful in solving the operational difficulties with the ESP's. Once the initial insulator failures were overcome, the ESP's operated very well for the remaining 3½ years of operation.

Figure 4.7: Quench Tower Gas Distributor Modification

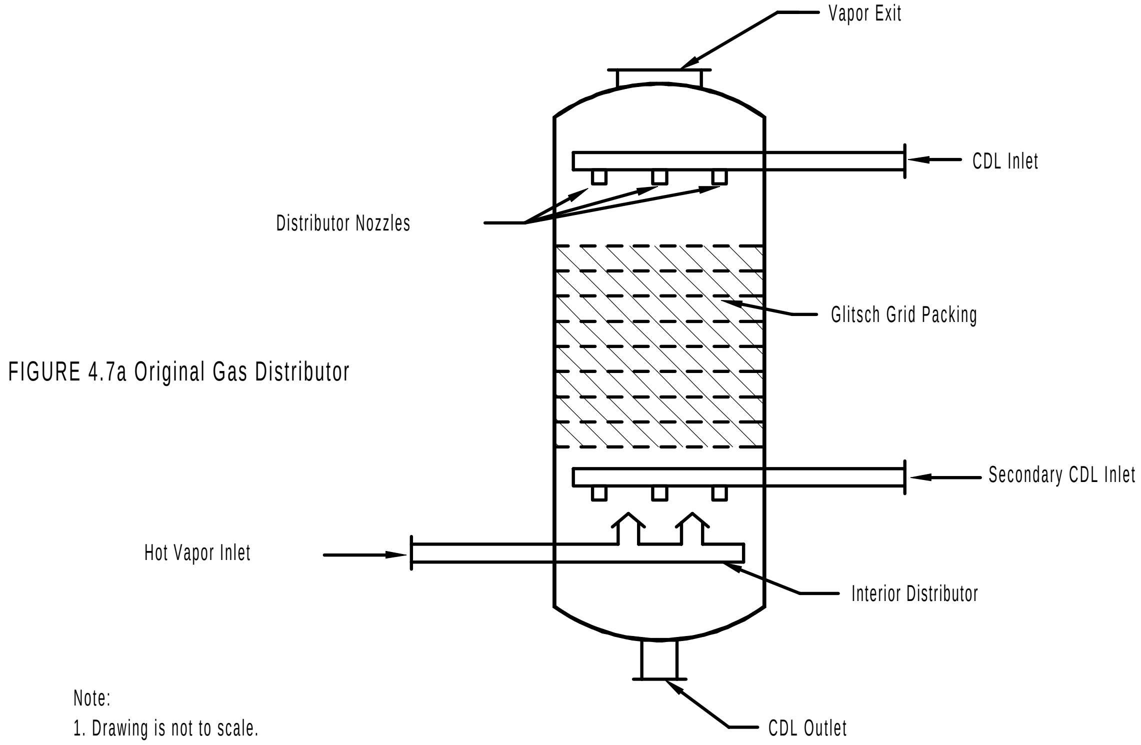


FIGURE 4.7a Original Gas Distributor

Note:
1. Drawing is not to scale.

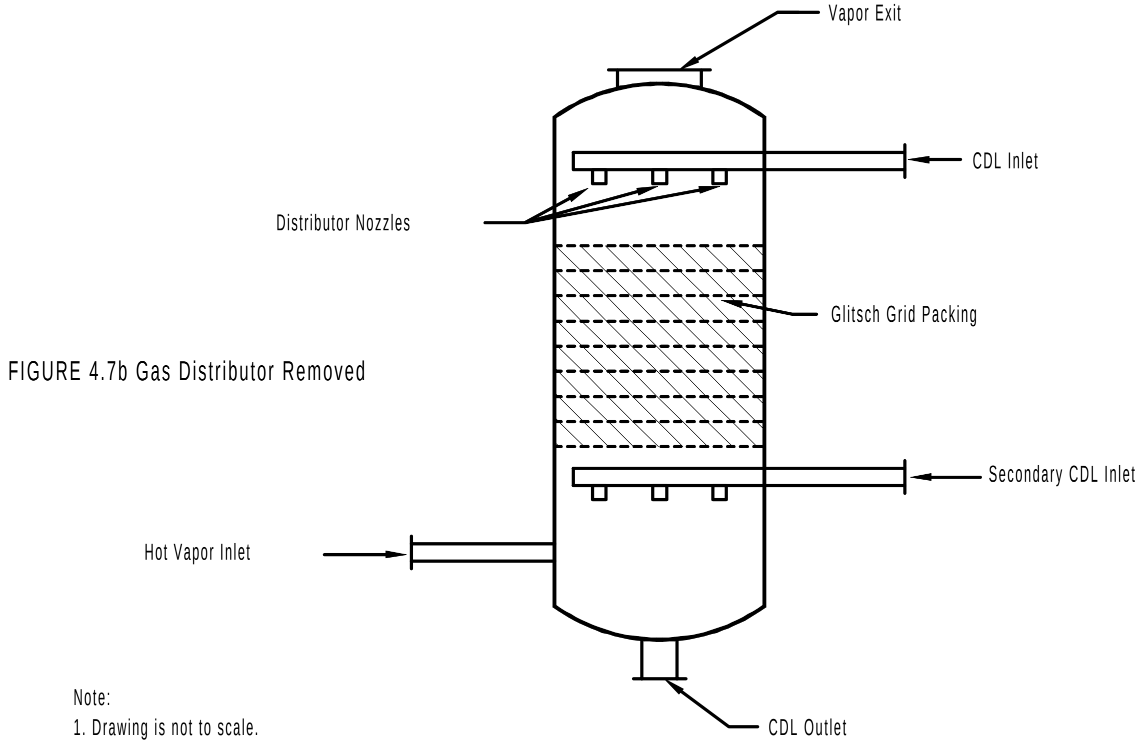


FIGURE 4.7b Gas Distributor Removed

Note:
1. Drawing is not to scale.

4.9 CDL Handling and Storage

Essentially no modifications were made to the original CDL handling and storage systems with the exception of the loadout facilities. The CDL loadout flow meter was removed after loading the first rail car. The meter fouled with CDL and became inoperable. It was decided that maintenance of this instrument would be high and a system of tank car measurement and weighing of the cars was utilized for all further shipments. The loadout pump was also relocated from the loadout area to the CDL storage tank. Insufficient suction head of the pump necessitated its relocation to be closer to the main storage tank. Overall, the CDL handling system operated quite well and was one of the least modified systems in the plant. In particular, the glycol/water heat tracing of the CDL lines proved to be ideal even during the extreme winter temperatures of Wyoming. The CDL system could be started from a "cold" stop, with little or no impact on the system operation.

Independent of the plant operation, sediment removal from CDL was tested in late 1996 in an attempt to reduce the solids content of the oil and expand CDL market opportunities. A small centrifuge was installed and tested at various conditions. From these tests, it was determined that a centrifuge could be used to remove 95% of the sediment with less than a 5% loss of CDL by weight. A conceptual design was made to implement a CDL solids removal system using the results of this test. The system would consist of a feed surge tank, pump, and a centrifuge to handle the CDL, and a fines bin, mixer, and a pelletizer to handle the sludge generated by the removed solids. Dryer or pyrolyzer cyclone fines can be blended with the sludge and agglomerated to produce a pellet PDF product. This agglomeration step was tested in early 1997, and fines to sludge ratios of 85% to 15% were successful in producing an acceptable pellet. Further CDL solids removal testing is ongoing and implementation of a full-scale system depends on market response to the "cleaned" CDL.

4.10 Process Fans

Both the dryer and the pyrolyzer fans were found to operate acceptably as designed for the process flow and temperature conditions, but were grossly inadequate in terms of sealing the process gases. In both units, the casing gaskets were replaced, and the casings themselves had to be modified and seal welded in the field to correct poor quality fabrication. The vendor supplied shaft seals were also found to be inadequate. Major modifications were made to the dryer fan in particular to accommodate a new mechanical carbon gland seal on a casing that was not designed to be gas tight. Once installed, the new carbon seals were more effective, but would eventually leak due to accelerated wear by fines in the process gas. Even with nitrogen purges, the fines in the process gas would contaminate the seal surface and excessively wear the carbon rings after only a few weeks of operation. Several iterations were made on sealing the units, and finally an ENCOAL "home-made" packing gland type seal with high temperature grease was found to be the best and longest lasting seal. Today, a carbon gland seal with a nitrogen purge is used on the suction side of the fan and a packing gland-grease seal is used on the pressure side.

4.11 Combustors

Control of the combustors was found to be difficult during start-up. The combination of oxygen excursions in the dryer loop and oscillation of the air to fuel ratios plagued the operation. In particular, the transition from secondary air to primary air in the combustor ramping sequence was not smooth. The original design primary air control valves did not regulate flows well under low flow conditions. Once the combustors were ramped past the transition point, the air control would improve, but the fuel to air ratios would fluctuate. An eight inch trim control valve was therefore added to both the pyrolyzer and dryer primary air intakes, and much improved stability of the combustor air flows was obtained. Programming changes were also made to both combustors that allowed natural gas flow to follow the combustion air flow rates. This change was necessary to dampen oscillations and prevent oxygen excursions due to improper air to fuel ratios.

Since the initial control problems were overcome, operation of the combustors has been generally uneventful. Minor adjustments to the programming occurred during the remaining 4½ years of use, and the combustion of the 30-50 Btu/scf plant recycle gas was very successful.

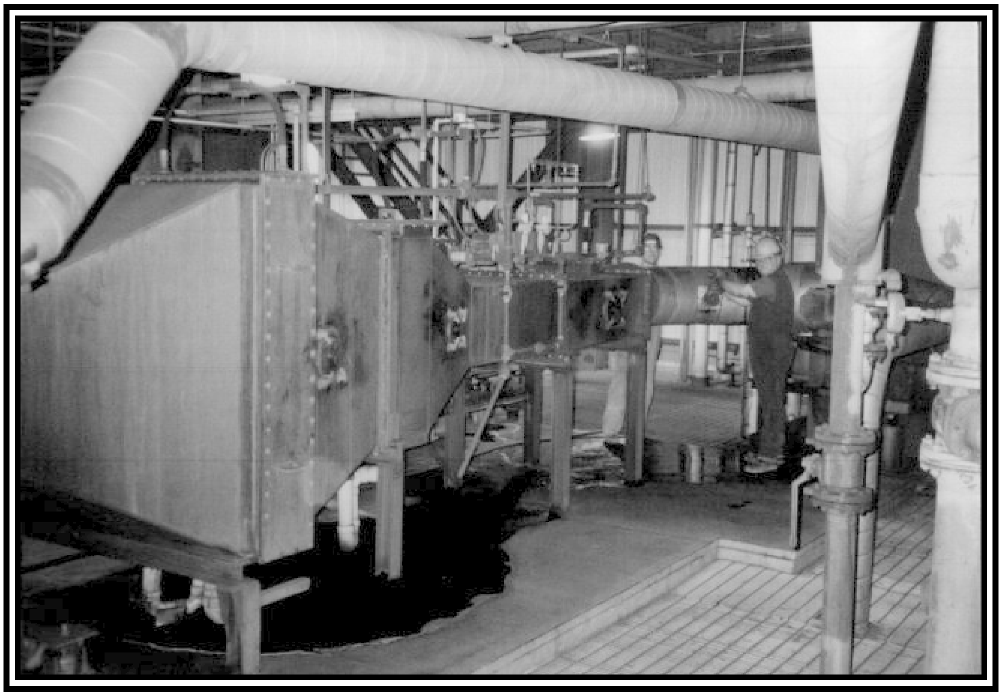
4.12 Purge Gas Treatment

The sodium carbonate solution sulfur recovery scrubber system in use at the ENCOAL plant is another system that has worked very well and has not required major modifications. This system first uses a venturi scrubber of the same patented design as the dust scrubbers to remove particulates from the purge gas stream. A Kellogg patented wet gas scrubber with three water curtains follows the venturi. Sodium carbonate solution used in both scrubbers removes 97% or more of the sulfur compounds in the purge gas stream.

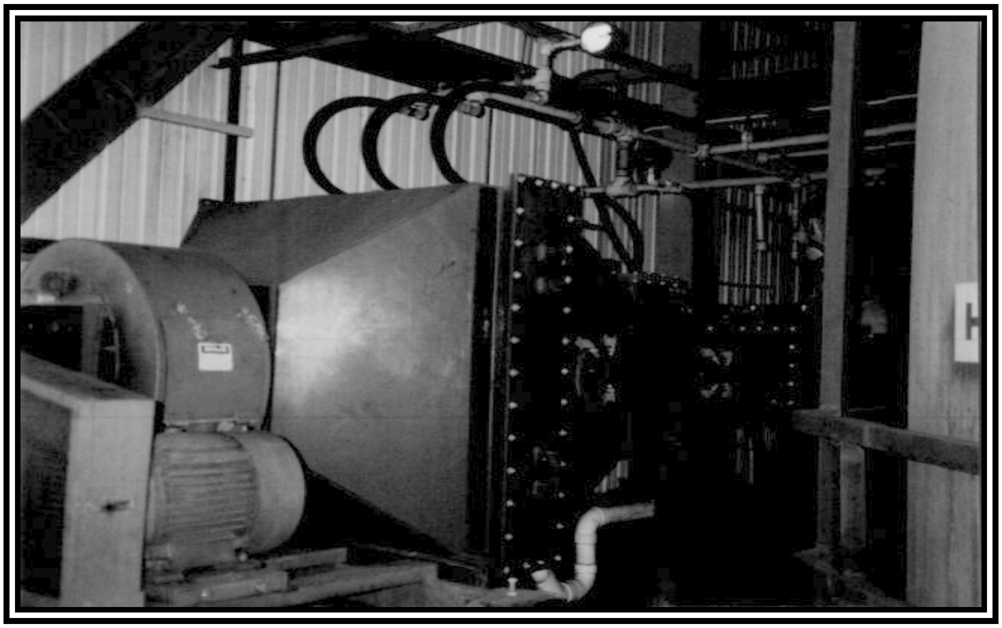
Because the scrubber system is handling water, SO_2 and SO_3 at temperatures well below the dew point of sulfuric acid, the material of construction selected was fiberglass reinforced plastic. The temperature limit for this material is 170° F. To protect the purge gas piping water sprays were added ahead of the venturi scrubber with firewater backup to insure they would work. In addition, to provide over temperature protection to the whole dryer loop, an emergency cooling water spray system was added in the dryer on-gas ductwork. These systems have performed very well and no purge gas equipment has ever been damaged, or subjected to temperatures exceeding design.

4.13 Dust Scrubbers

Operation of the original two raw coal dust scrubbers proved that the patented design of these units worked very well to collect dust from conveyor transfer points. However, during start-up and shutdown conditions, there are times when the facilities are not operating at design conditions, and dried, underpyrolyzed coal (off-spec PDF) is produced. This condition led to excessive amounts of dust at the PDF transfer points early on in plant operation. Two additional dust scrubbers were therefore installed to gather dust from the PDF s-belt, PDF cooler, and the PDF silo transfer points. (See Figures 4.13a and 4.13b: PDF Transfer Points Dust Scrubbers)



4.13a: PDF Cooler Dust Scrubber.



4.13b: PDF Silo Dust Scrubber.

4.14 PDF Finishing

Background

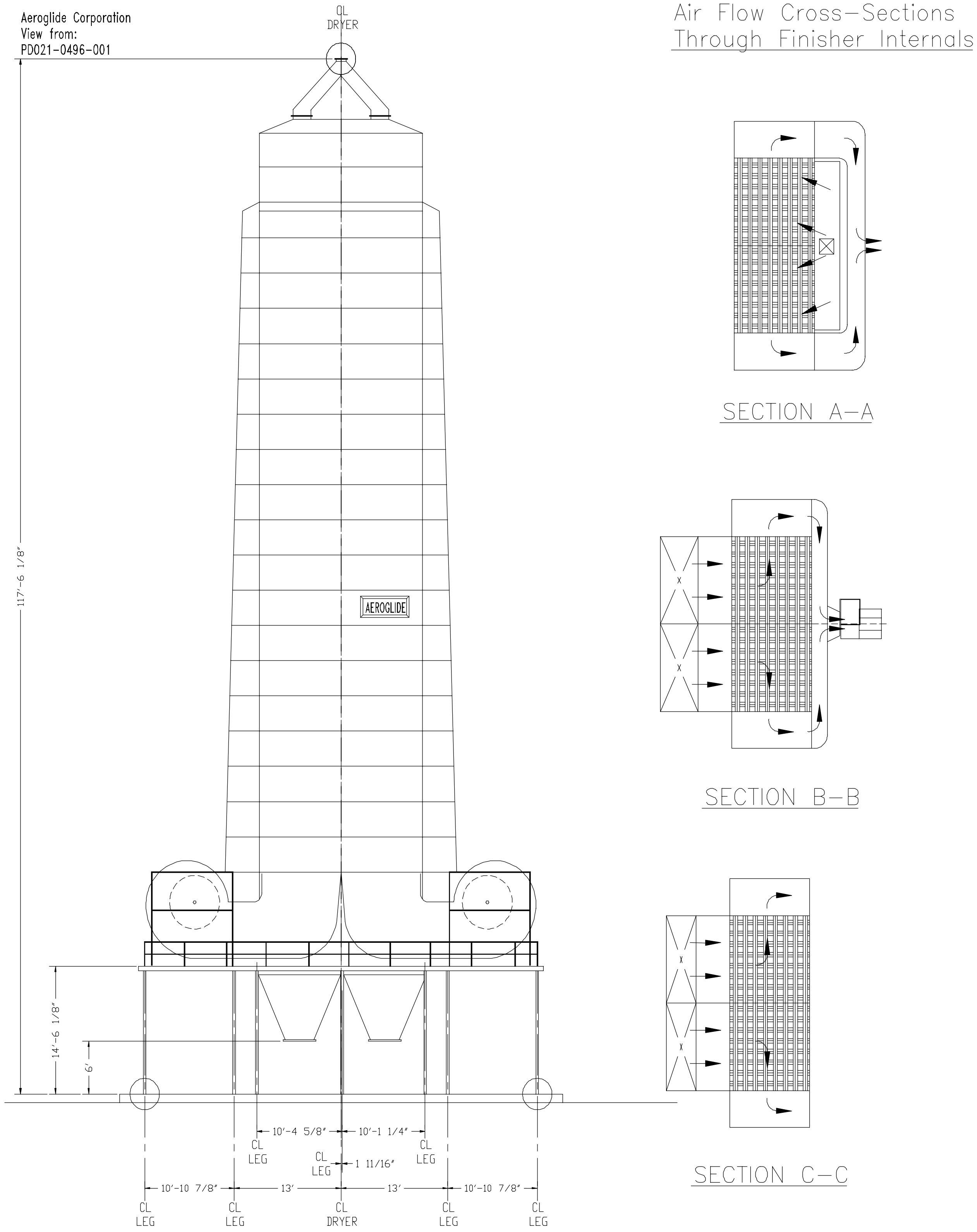
As discussed in Section 4.5 above, extensive testing and plant modifications were made in an effort to stabilize PDF using in-plant equipment. The addition of the PDF Deactivation (VFB) system in 1993 was designed to accomplish this task, however it was determined that additional oxidative deactivation of the PDF was necessary. In order to produce shipments of PDF for utility test burns, "pile layering" of PDF on the ground was utilized. This method of stabilization is labor intensive and negatively impacts PDF quality by degradation of size, moisture, and ash content by being handled outside the plant.

A PDF stability task force was assembled in late 1994 to develop an acceptable in-plant stabilization method and test this design in the ENCOAL plant. Several avenues were pursued including spray-on additives, additional plant equipment, and changes in plant operation. The task force met with engineers and scientists from the Pittsburg Energy Technology Center (PETC) and the Morgantown Energy Technology Center (METC) to identify areas where assistance was needed in solving stability problems. As a result of the meeting, a Cooperative Research and Development Agreement (CRADA), a separate, research-oriented accord with PETC, was developed, and a project combining the applied research efforts of ENCOAL, Western Syncoal, PETC, and METC was formed. These entities would develop measurement methods, define reaction kinetics and mechanics, and evaluate new stabilization techniques. As a result, a Bureau of Mines test, nicknamed “Jar-O-R,” was modified to measure product reactivity and is still used to measure the oxygen appetite of upgraded Powder River Basin coal.

By July 1995, the stabilization task force, working with the resources represented by the CRADA, performed sucessful bench scale tests for oxidizing PDF at low temperatures, and the team recommended the construction and testing of a Pilot Air Stabilization System (PASS) to complete the oxidative deactivation of PDF without drying the product. At this time, the CRADA completed its contributions to the stabilization research.

Design and installation of the Pilot Air Stabilization System (PASS) was completed in November 1995, and the unit operated from late November through January of the next year. PASS testing was successful: the PASS unit processed ½ to 1 ton of solids per hour, 24 hours a day, for 2½ months. Even more important, stable PDF was produced for the first time and stable, uncompacted piles were made without ground stabilization techniques. The data obtained were used to develop specifications and design requirements for a full-scale, in-plant PDF finishing unit based upon an Aeroglide tower dryer design. (See Figure 4.14a: Aeroglide Tower Dryer) As part of the commercialization effort, these same data were then scaled up for application to a larger plant. Financial restrictions have delayed the fabrication and installation of the ENCOAL plant full-scale finishing unit, but ENCOAL will continue to seek private funding for this project.

Figure 4.14: Proposed PDF Finisher; Aeroglide Tower Dryer.



5.0 PLANT UTILITY MODIFICATIONS

In most cases, the original ENCOAL plant utility systems required few modifications during the last 5 years of operation. Systems such as glycol/water, natural gas, potable water, and firewater were essentially unchanged from the original design. In other cases however, changes were necessary to make a system more reliable and easier to operate. Utility modifications took advantage of plant shutdowns whenever possible, involving contractors or plant operators for implementation. The longest plant shutdown for utility modifications to date occurred from mid-March 1995 to May 1995 for the addition of the permanent process water fines removal system. Several shorter shutdowns were also required for other less involved modifications, some of which were remote to the main plant and work could proceed without interrupting plant operations. The following sections describe the changes made to specific plant utility systems.

5.1 Nitrogen

Capacity limitations with the original natural gas fired nitrogen vaporizer lead to an eventual equipment exchange with the vaporizer vendor. The new vaporizer utilizes a glycol/water pump, a shell and tube heat exchanger, and a separate glycol piping system to vaporize the required nitrogen for plant start-up and purging needs. A separate glycol system was placed in parallel with the plant system to ensure consistent flow of glycol even during power outages for safety reasons.

Other changes to the nitrogen system included the addition of a centralized distribution header for ease of operation and system isolation, and a nitrogen membrane package to generate nitrogen on-site. The membrane system includes an air compressor, membrane filter skid, and a surge tank to provide plant nitrogen. The membrane skid has sufficient capacity to support all normal plant operations. The original liquid nitrogen system remains on-line in parallel, and supplants the membrane system during start-up and plant upsets. The system has reduced the overall plant operating costs and is maintained under contract by the nitrogen supplier.

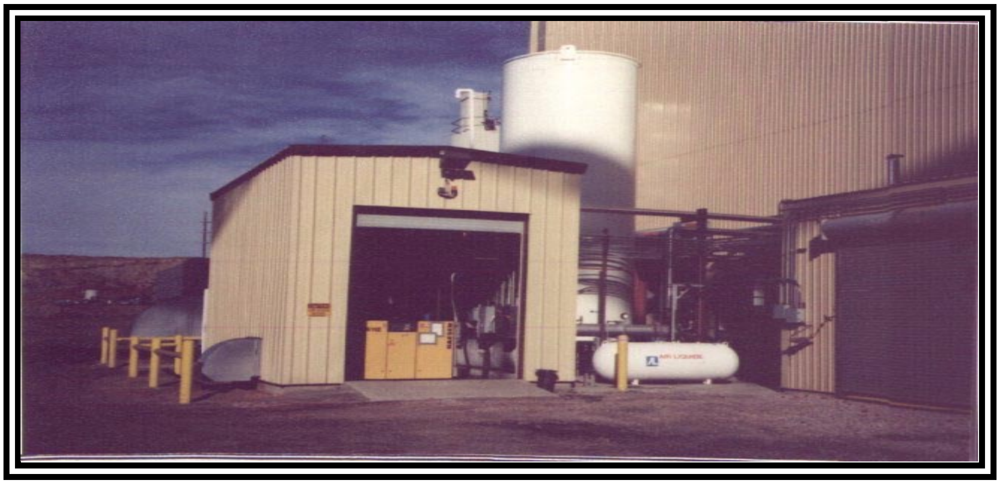


Figure 5.1: Nitrogen Membrane Building.

5.2 Instrument and Utility Air

Few changes were made to the instrument and utility air distribution piping system during the operation; however, some changes were made to the air compressors and air dryers to increase equipment reliability. The air compressor coolers were raised approximately three feet to aid flow of compressor oil to and from the coolers, and the piping outside the main structure was glycol/water heat traced to prevent freezing during extreme winter temperatures.

Occasional problems with condensed water in the instrument air system in early runs caused delays in start-up and hindered plant operation. The problem was found to be in the regeneration of the instrument air dryer desiccant. The original dryer used "warm dry air" for desiccant regeneration, and the efficiency of this dryer was therefore greatly dependent upon the temperature of the purge air. If the purge air was too cool, the desiccant would remain "damp" and the instrument air would not be thoroughly dried. A new heated air dryer was installed in October 1993 that uses electric heat coils instead of "warm dry air" for desiccant regeneration. This system has proven to be more reliable and consistently keeps the instrument air dry. (See Figure 5.2: Instrument Air Dryer)

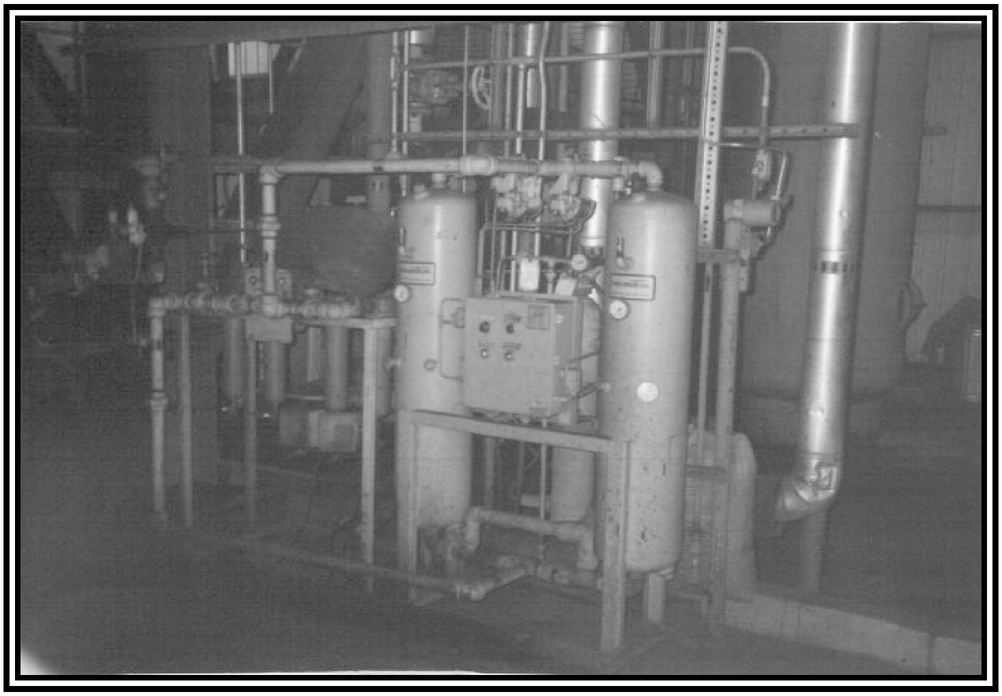


Figure 5.2: Instrument Air Dryer.

5.3 Steam System

Utility steam is generated by a 10,000 lb/hr 135 psig boiler to supply steam for clean-up, emergency VFB system purging, analyzer heat tracing, and steam/glycol heat exchange during plant outages. This boiler was found to be of proper capacity for plant outages when major cleaning and glycol/water system heat exchange was necessary. However, while the plant was on-line, the capacity of the boiler was too large for the light steam duty, causing the boiler to cycle excessively. A second 1,000 lb/hr boiler was installed in 1995 to be used during plant operating periods when the steam requirements were small. This boiler was installed in parallel with the original boiler, and allowed for the large boiler to be shut down during long plant runs. This operation allowed for more efficient use of boiler feed water chemicals, and was less demanding on boiler maintenance. (See Figure 5.3: Small Utility Boiler)

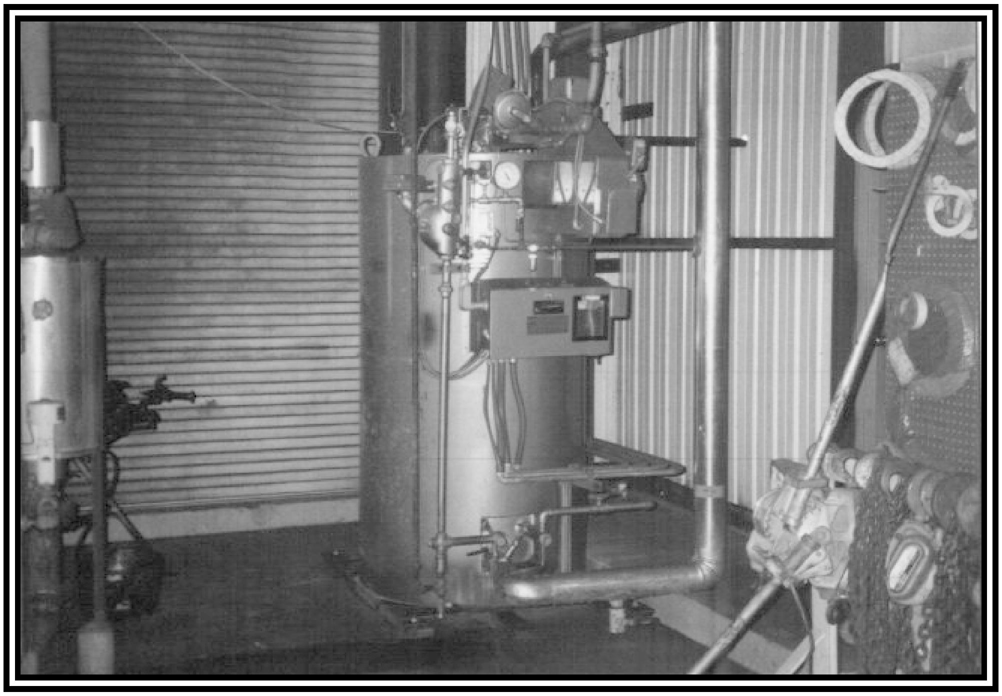


Figure 5.3: Small Utility Boiler.

5.4 Cooling Water

Several modifications or additions were made to the plant cooling water circulation system during the 5 years of operation. Early in the project, a chlorination system was added to control algae growth, and a scale inhibitor was added to reduce scale deposits in the piping and heat exchangers. Once the chlorine and anti-scalant systems were added, problems with strainer blinding and reduced flows were overcome.

As major plant equipment was added to the ENCOAL plant, such as the PDF deactivation and process water fines removal systems, additional demands were placed on the cooling water system. In order to increase overall cooling water flows, the impellers in the main cooling water pumps were exchanged for larger diameter models in 1993. These pumps were modified again in 1995, increasing the impeller size and repowering from 75 hp to 100 hp. These two changes almost doubled the flow rate capacity of the pumps, and allowed for proper cooling water supply for all the present day plant needs.

The plant high pressure water system was also extensively modified from the original design. The original cooling water booster pump was found to be undersized very early in plant operation. This pump was replaced and a main distribution header installed to ease plant operation and system isolation. A second redundant pump was later installed to enhance system reliability and to ensure emergency back-up water could be supplied at all times. (See Figure 5.4: Cooling Water Booster Pumps and Distribution Header)

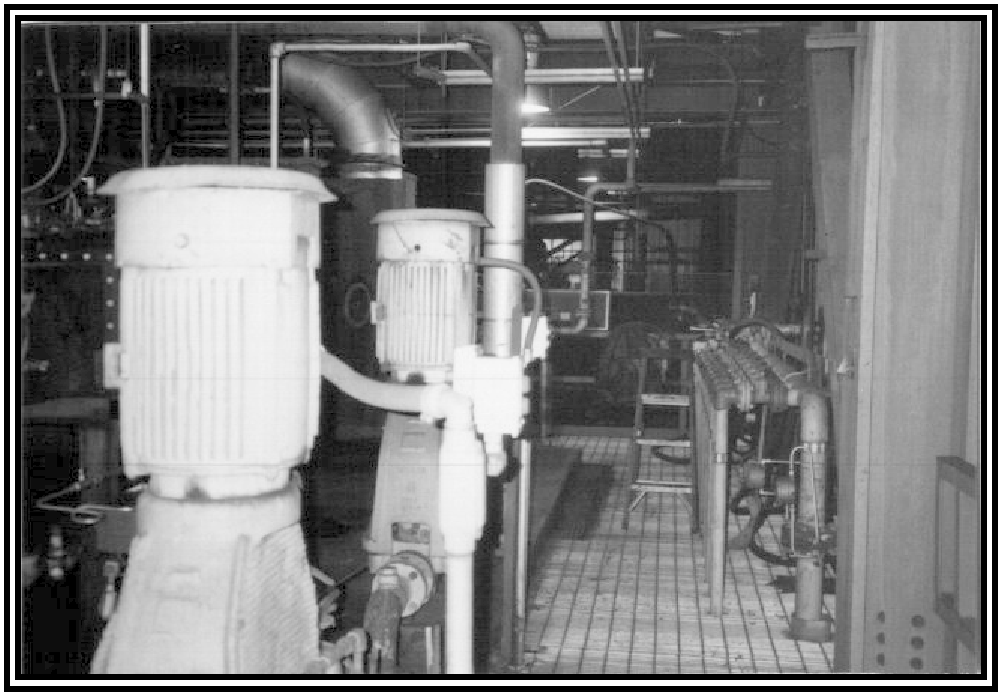


Figure 5.4: Cooling Water Booster Pumps and Distribution Header.

5.5 Sump System

The ENCOAL plant contains several sumps to collect the various washdown water, dust scrubber effluent, and equipment drains prior to being pumped to the site waste water treatment pond for settling of fines. The original plant sump system routed these individual sump discharges to the screening building sump prior to being pumped the Buckskin mine underground piping network. This routing was immediately determined to be inadequate and unreliable due to extensive plugging problems and overloading of the Buckskin Mine underground piping system. Major modifications were made to the plant sump system piping to remove bends wherever possible, and pipes were routed above ground inside the plant to ease maintenance of the lines. A new, large drive-in sump was constructed adjacent to the PDF silo to serve as the ENCOAL plant main sump collection point. All plant sumps and equipment drains were rerouted to this centralized collection area. The new sump design uses a sloped bottom sump and overflow weir plate to collect and settle out large fines and trash prior to "cleaned" water being pumped directly to the mine waste water pond. The settled fines and trash may be removed by a loader and dump truck, and a new direct line to the waste water pond eliminated problems with overloading the Buckskin Mine piping system. Once the sump modifications were completed, delays in plant start-up were avoided and operation became much more reliable. (See Figure 5.5: Drive-in Sump Under Construction)

Figure 5.4: Drive-in Sump Under Construction.

5.6 Car Topper

Not included in the original ENCOAL plant design, the car topper system was developed to aid in the transport of PDF in conventional coal cars. Due to the average size of the PDF product being ¼", a rail car topping system was installed to apply a coat of MK, ENCOAL's patented dust suppressant, on the PDF in the rail cars to stop small particles from blowing out during transport. This system was first utilized in 1995, and was found to be very effective in preventing PDF loss. The system consists of an MK storage tank, pump, and adjustable spray bar to apply the MK as the train is being loaded. (See Figure 5.6: Car Topper System).

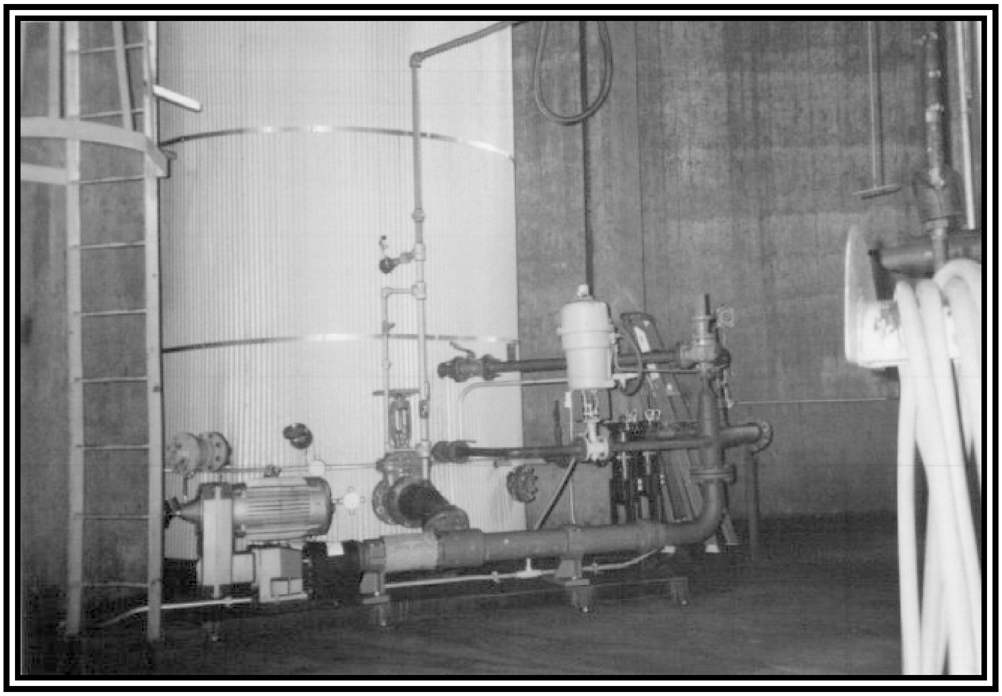


Figure 5.6: Car Topper System.

5.7 Vapor Recovery

Excessive odor from the plant process water circulation and sump system in early plant operation lead to the design and installation of another new utility system called vapor recovery. Extensive ambient air testing was done to ensure there were no harmful levels of toxic materials in the ENCOAL plant. However, odors did hava a nauseating effect on some people working in the plant for extended periods. Therefore the vapor recovery system was added. The system uses a small blower and an activated carbon filter to collect and filter odorous air from the process water containment areas in the plant. Once filtered, the gases are exhausted to atmosphere outside the plant. This system has proven to be very successful in reducing plant odors. (See Figure 5.7: Vapor Recovery System)

5.8 Process Water

The ENCOAL plant process water system was the most modified and changed utility during the 5 years of operation. The original design used a very small capacity pump and circulation system called "oily water". Its purpose was to gather and contain all washdown and seal water that could include dissolved hydrocarbons, and used this water to slurry fines from the pyrolyzer cyclone to be injected as rehydration water on PDF. While the system did work well to contain the water, the surge capacity and circulation system was found to be undersized and could not effectively handle the quantities of slurried fines in the water. In addition to these problems, two other small utility systems called quench spray water and seal water were also found to be inadequate. The entire quench table spray system and a portion of the seal water system were combined with the "oily water" system, and renamed process water. Temporary surge tanks were used to increase capacity, and new pumps were installed to increase flow.

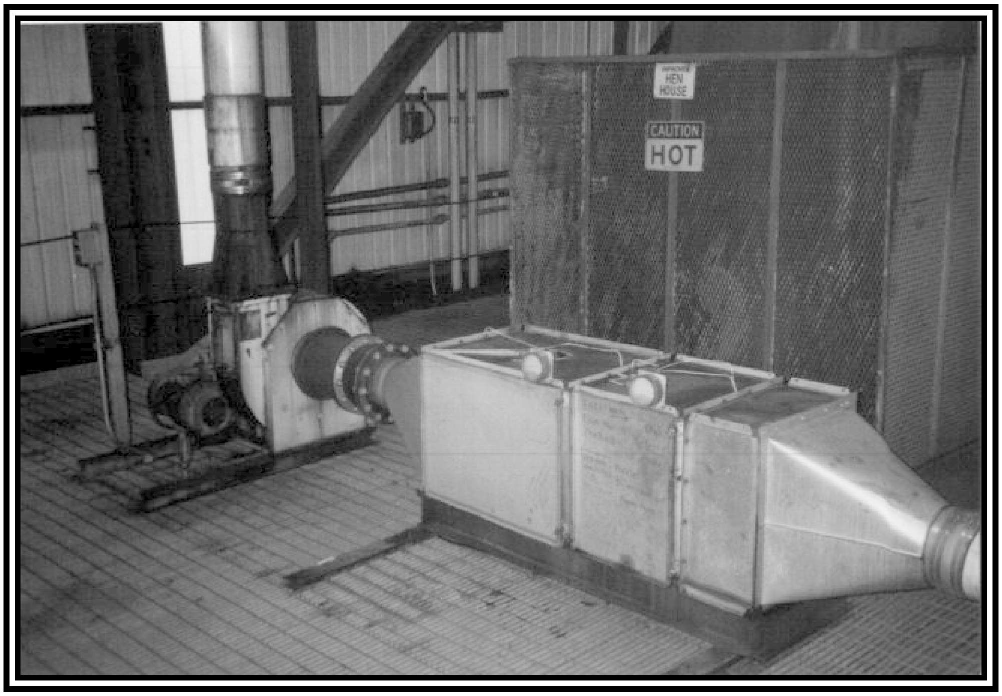


Figure 5.7: Vapor Recovery System

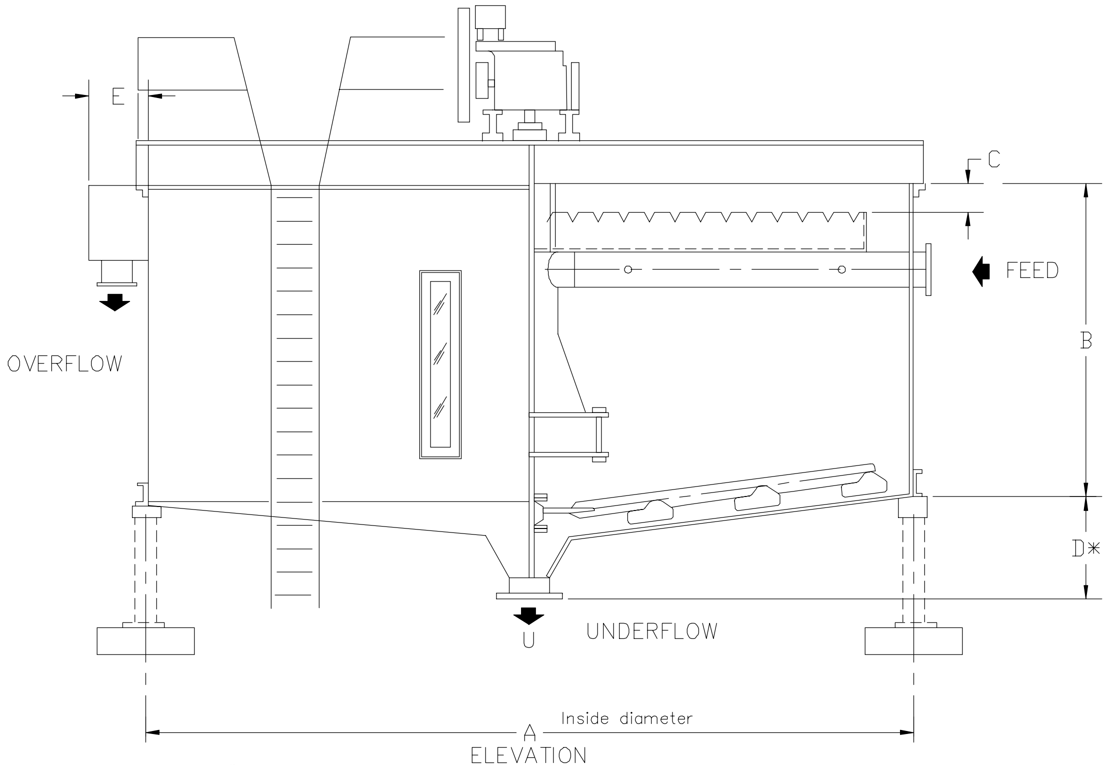
Problems with fines accumulation in the system continued to plague the plant however, and numerous shut-downs were attributed to plugging the quench table nozzles and Salem water seals. A temporary process water fines removal system was installed in 1994 that utilized a large decanter tank and flocculent injection to settle fines from the system. This system allowed the plant to operate for longer periods of time while necessary data was collected for permanent fines removal equipment.

The permanent process water fines removal equipment was procured and installed in early 1995. This system consists of a process water collection system, clarifier, vacuum drum filter, heat exchanger, and two new slurry pumps that effectively removes the entrained fines while maintaining a reliable circulation of process water throughout the facility. The fines removal equipment was housed in a separate, contained building near the PDF silo. Filter cake discharged from the vacuum filter is hauled to the ENCOAL land farm for hydrocarbon treatment as discussed in Sections 6.0 and 6.2 below. (See Figures 5.8a, b, and c: Process Water Fines Removal System). Appendix A includes floor plans for the process water fines removal building.

Figure 5.8a: Process Water Clarifier.

Figure 5.8b: Process Water Fines Removal Building.

Figure 5.8c: Process Water Clarifier General Arrangement Drawing



* D based on bottom slope of 1 1/2" in./ft.
Adjust for other slopes.

ENVIRO-CLEAR MODEL NUMBER	PRINCIPAL DIMENSIONS					SUBJECT TO CHANGE DEPENDING ON FLOW AND SOLIDS FEED				FILLED WITH WATER TO OPERATING LEVEL		AREA
						PIPE CONNECTIONS NOMINAL PIPE SIZE			MOTOR DRIVE MAXIMUM	NO. OF SUPPORT	LOAD PER SUPPORT	
	A	B	C	D	E	S	T	U	H.P.	NO.	KIPS	SQ. FT.
C-3	3'-0"	3'-6"	6"	11"	6"	2"	2"	2"	3/4	4	1	7
C-5	5'-0"	3'-6"	6"	1'-3"	9"	2"	3"	2"	1	4	2	20
C-7	7'-0"	4'-6"	6"	1'-6"	1'-10"	4"	4"	3"	1 1/2	4	4	38
C-9	9'-0"	4'-6"	6"	1'-8"	1'-10"	4"	4"	3"	1 1/2	4	7	64
C-11	11'-0"	4'-6"	6"	1'-10"	1'-10"	6"	6"	4"	1 1/2	4	10	95
C-12.5	12'-6"	4'-10"	6"	2'-1"	1'-10"	10"	10"	8"	1 1/2	4	12	123
C-15	15'-0"	5'-5"	6"	2'-3"	1'-10"	12"	12"	8"	2	4	18	177
C-17	17'-0"	6'-0"	6"	2'-4"	1'-10"	12"	12"	8"	2	4	27	227
C-20	20'-0"	6'-6"	6"	2'-6"	1'-10"	12"	12"	8"	2	4	24	314
C-23	23'-0"	7'-0"	6"	2'-9"	1'-10"	14"	14"	8"	3	8	28	415
C-26	26'-0"	7'-0"	6"	2'-11"	1'-10"	14"	14"	8"	3	8	35	531

6.0 ENVIRONMENTAL MODIFICATIONS

ENCOAL's policy is to always operate in an environmentally responsible manner. The goal is to have no citations or Notice Of Violations (NOV's). The original plant was designed to have no effluents other than normal coal washdown water and no solids waste streams. Emissions were designed to be less than 100 tons per year of SO_x, NO_x, methane, particulates or CO. As expected, the demonstration plant has provided a great learning experience in the control of environmental releases.

The following list includes some of the more significant environmental modifications to the ENCOAL facilities;

1) Solids collected in the process water stream as described above can not be recovered in the product stream via rehydration as originally conceived. They are very expensive to recover in the quantities produced so a biological disposal method or landfarm was developed.

2) The requirement of atmospheric exposure for finishing PDF has led to the need for longer term laydown and storage areas than envisioned for PDF pile testing in the original plant concepts.

3) Production at less than design capacity resulted in modifications to the operating permits requested from the State of Wyoming.

4) Low production totals delayed the need for installation of the Permanent Precipitate Storage Reservoir. This resulted in permit revisions and addition of an evaporation system to the temporary reservoir.

5) Odors in the processing plant proved to be very objectionable for many operators. Extensive ambient air monitoring work revealed no EPA listed toxins in concentrations anywhere close to Federal limits. However, it was decided to install a vapor recovery system on all process water holding vessels as described in Section 5.7.

6.1 Air Quality Issues

Late in 1992, ENCOAL staff members met with the WDEQ to discuss the status of plant operation, notification requirements and the status of stack gas monitoring. As a result of this meeting, a letter was sent to the WDEQ confirming the stack gas monitoring schedule and explaining ENCOAL's temporary noncondensible gas venting arrangements installed for the PDF quench table. The letter, which also discussed the quench table steam condenser tests scheduled for January 1993, was approved in December 1992.

In mid-1993, ENCOAL submitted a permit application for the vapor collection system exhaust on the process water system. Although a permit was not required by current regulations, it was agreed that a permit would be prudent, and data were collected from plant runs to support a permit application.

Stack Gas Emissions

In October 1995, a third-party testing firm mobilized to perform emission testing necessary to obtain ENCOAL's permit to operate from the WDEQ. The stack and emissions testing using DEQ-approved protocol was successfully completed in November 1995, and indicated that the plant is operating within permitted limits for NO_x, sulfur oxides, carbon monoxide, volatile organic compounds, and particulates. The SO_2 Continuous Emission Rate Monitoring System for the ENCOAL plant stack gas was certified as a result of the testing.

Air Quality Permit

Revisions to the AQ permit, delayed since the beginning of Phase III by interruptions in plant operation, were reviewed by the WDEQ in March 1996, and ENCOAL responded to the Department's questions. In mid-1996, ENCOAL received a notice of completeness for its application for Section 21 AQ permit from the WDEQ. The permit included a 5-acre laydown area that was not anticipated in the original application. The application proceeded smoothly through the technical review and was formally approved in November 1996.

6.2 Land Quality Issues

Permanent Precipitate Storage Reservoir

A permanent storage reservoir was part of ENCOAL's original plan, but because the WDEQ questioned the location of the permanent precipitate disposal pond, an alternative permit application was submitted, modifying an existing mine sediment pond. Because the temporary pond proved adequate far longer than originally believed, ENCOAL was allowed to defer permitting and construction of the permanent disposal pond until 1995, when geotechnical survey holes were drilled on a secondary site for the permanent precipitate storage reservoir. After core sample testing indicated that soils were acceptable at the construction site, the design for the pond was completed in cooperation with the WDEQ, and the permit application was finalized in June 1995. When the WDEQ determined that public notice would be required, construction was deferred, this time until 1996, and options to extend the life of the temporary pond were again evaluated. After weighing several options, a system designed to improve the evaporation rate was installed. The system included a portable diesel powered pump, floating platform and a nozzle bank to spray the effluent into the air. It was approved by the WDEQ and started up in September 1996. (See Figure 6.1: Portable Evaporation System)

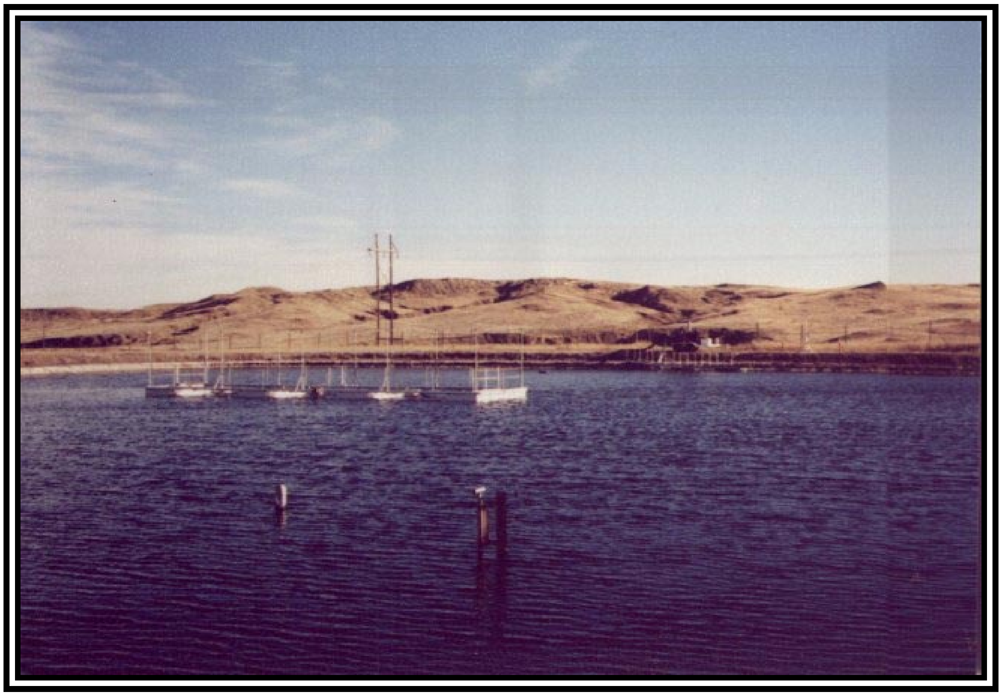


Figure 6.1: Portable Evaporation System.

The WDEQ reviewed the application for revisions to the permanent pond, and ENCOAL responded to WDEQ questions in March 1996. At that time, a bid package for construction of the permanent reservoir was sent to potential contractors. The permit for construction cleared public comment and was sent to WDEQ's head office; final approval for the reservoir was received in June. Reservoir construction began the first week in July and continued through 1996. This reservoir is scheduled to be commissioned for use in July 1997. (See Figure 6.2: Permanent Precipitate Storage Reservoir)

Land Farm

Early in 1993, ENCOAL initiated discussions for construction and permitting of an onsite land farm. The land farm, conceived in response to the collection of greater amounts of process water fines than originally anticipated, would biologically eliminate hydrocarbons from process fines prior to onsite disposal. It was intended as a temporary facility, since the ultimate plan was to recover fines back into the PDF solid product.

The first step in the development of the land farm was the collection and testing of fines samples and the gathering of information from plant runs. In the fall of 1993, ENCOAL reviewed a preliminary design for the land farm before submission to the WDEQ, and construction began when informal approval from the WDEQ was received. The earthwork and underground piping were completed in November 1993, and commissioning was scheduled for mid-January of the following year. Final approval was received in August 1994.

In the fall of 1995, the LQD of the WDEQ approved a permit for revisions to the land farm that included a new concrete holding area for wet fines, a higher retaining dike to increase capacity, and provisions for continuous operation with pit disposal of treated fines. Specifications to complete the modifications were developed, and a bid package was issued. Modifications began in July 1996 and were completed 2 months later, and the facility was commissioned in October of the same year. (See Figure 6.3: ENCOAL Land Farm)

Figure 6.2: Permanent Precipitate Storage Reservoir.

Figure 6.3: ENCOAL Land Farm.

7.0 SAFETY AND ADMINISTRATIVE ITEMS

One of ENCOAL's most important accomplishments during the life of the project is its safety record. Since October 1990, only nine reportable accidents and four lost time accidents were reported for all personnel, including contractors and associated workers. This lost time accident rate is less than one-third the most recent available rate for petroleum and coal processing industries, while the number of reportables is less than one-fifth.

ENCOAL achieved this by consistently supporting a policy that encouraged operator and contractor involvement in plant operations to ensure proper safety awareness. Modifications that reduced or removed the potential for injury were continually made to the facility as a result of this policy. Some of these modifications included installation of platforms, handrails, stairways, guards, blinds, and man-ways all oriented to ease maintenance of the plant while providing safe access to the equipment. Other modifications made to the facility for administration purposes are discussed below.

1) A 40 foot by 80 foot maintenance shop and warehouse was constructed in 1992. This facility is used for a welding shop, tool storage, and commonly used parts warehouse. (See Figure 7.0a: ENCOAL Maintenance Shop)

2) A 25 foot by 45 foot addition to the original control room building was constructed in 1995. The expansion was necessary to provide storage space, a larger training/lunchroom, a maintenance office/library, and additional offices. (See Figures 7.0b and c: ENCOAL Control Room Building Expansion)

8.0 CONCLUSIONS

The goals of the ENCOAL Project have not only been met, but exceeded. Sixteen unit trains of PDF have been shipped and successfully burned at seven utilities. PDF has also been tested as a reductant (combined with iron ore) in the DRI process, and holds promise as a blast furnace injectant. The LFC process has been demonstrated and improved through the modifications discussed in this report. *(Table A.1 in Appendix A summarizes the changes and additions to the ENCOAL plant equipment list over the 5 year period).* Almost 5 years of operating data have been collected as a basis for the evaluation and design of a commercial plant. Finally, the licensing effort has reached the international level: agreements have been signed, and many opportunities are being developed.

Although major DOE objectives have been reached, some issues need to be resolved before a commercial plant project can proceed. The ENCOAL Demonstration Plant must continue to test the viability of alternate commercial-scale equipment, deliver additional test burn quantities of products, train operators for the commercial plant and provide additional design and economic data for the commercial plant. ENCOAL also needs to install an in-plant finisher that will substantiate the large-scale testing of PDF finishing, the final stage of stabilization.

Efforts to license the technology will proceed under the auspices of TEK-KOL, both domestically and internationally. These activities are in progress as further described in other reports.[1,3]

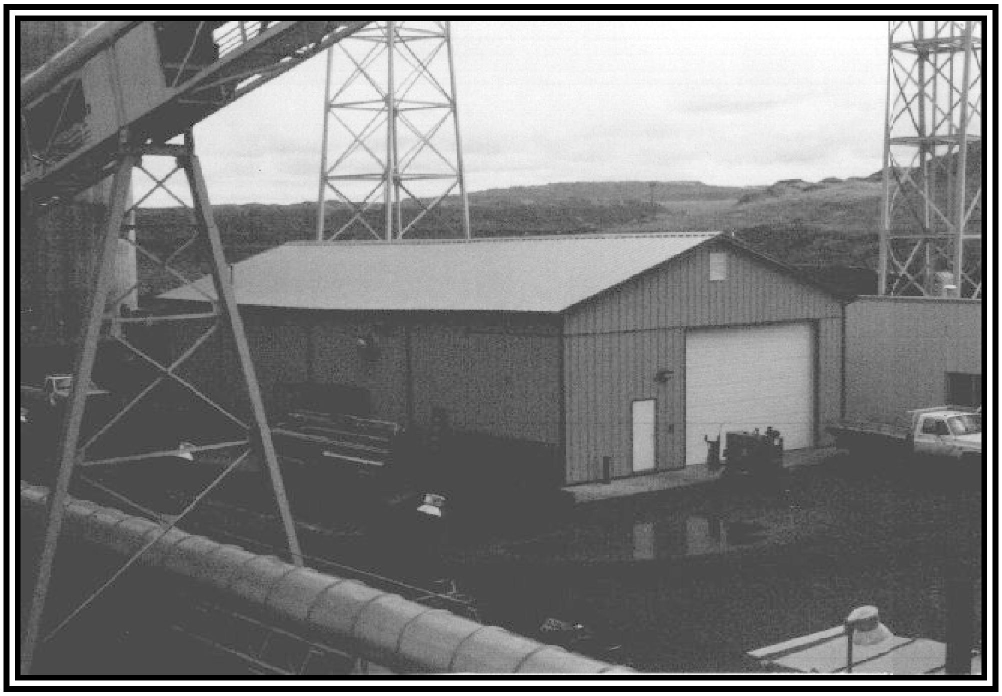
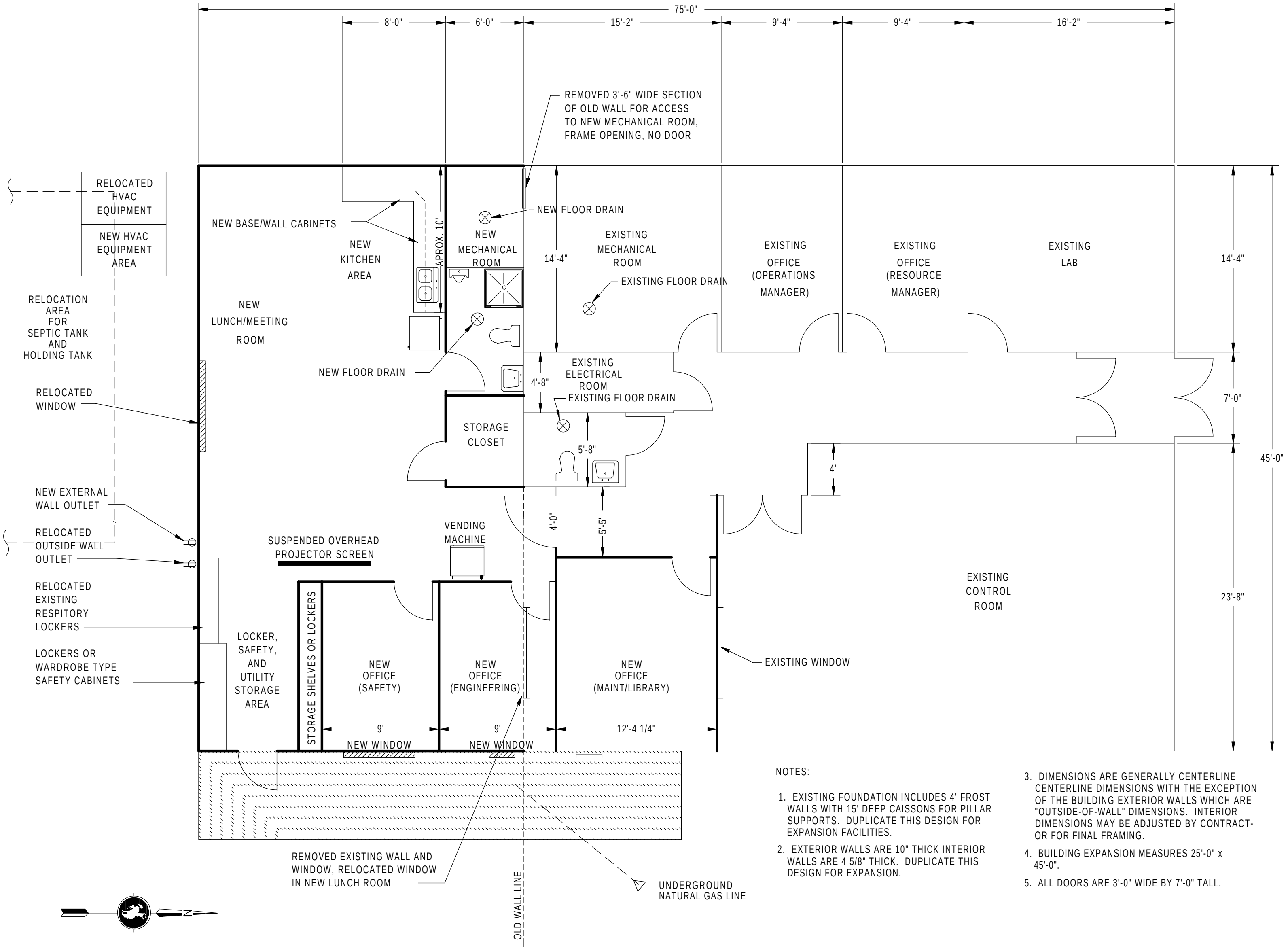


Figure 7.0a: ENCOAL Maintenance Shop.

Figure 7.0b: ENCOAL Control Building.

Figure 7.0c: ENCOAL Control Room Building Expansion Floor Plan



NOTES:

1. EXISTING FOUNDATION INCLUDES 4' FROST WALLS WITH 15' DEEP CAISSONS FOR PILLAR SUPPORTS. DUPLICATE THIS DESIGN FOR EXPANSION FACILITIES.
2. EXTERIOR WALLS ARE 10" THICK INTERIOR WALLS ARE 4 5/8" THICK. DUPLICATE THIS DESIGN FOR EXPANSION.
3. DIMENSIONS ARE GENERALLY CENTERLINE CENTERLINE DIMENSIONS WITH THE EXCEPTION OF THE BUILDING EXTERIOR WALLS WHICH ARE "OUTSIDE-OF-WALL" DIMENSIONS. INTERIOR DIMENSIONS MAY BE ADJUSTED BY CONTRACTOR FOR FINAL FRAMING.
4. BUILDING EXPANSION MEASURES 25'-0" x 45'-0".
5. ALL DOORS ARE 3'-0" WIDE BY 7'-0" TALL.

REFERENCES

1. "ENCOAL Mild Coal Gasification Project: ENCOAL Project Final Report," U.S. Department of Energy Report, July 1997.

2. “ENCOAL Mild Coal Gasification Public Design and Construction Report,” U.S. Department of Energy Report, December 1994.

3. “ENCOAL Mild Coal Gasification Project: Commercial Plant Feasibility Study,” U.S. Department of Energy Report, July 1997.

APPENDIX A

Table of Contents

TABLE A. 1 : ENCOAL MILD COAL GASIFICATION PLANT
UPDATED EQUIPMENT LIST

AS OF 2/28/97

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STATUS	TAG #	DESCRIPTION	VENDOR
	AT101	Dryer 02 Analyzer	AMETEK
	AT102	Dryer 02 Analyzer	Servomex
DELETED	AT107	Feed Coal Analyzer	Gammametrics
DELETED	AT140	PDF(tm) Analyzer	Gammametrics
	AT220	Pyrolyzer O2 Analyzer	Rosemount (Pastech)
	AT221	Pyrolyzer 02 Analyzer	Rosemount (Pastech)
	AT222	Pyrolyzer Hydrocarbon Analyzer	Rosemount
	AT223	Pyrolyzer CO Analyzer	Horiba
	AT224	VFB CO2 Analyzer	Horiba
	AT841	Finishing 02 Analyzer	AMETEK
	AT842	Finishing 02 Analyzer	Servomex
	AT843	Finishing 02 Analyzer	Horiba
	AT844	Finishing 02 Analyzer	Horiba
	AT845	Finishing 02 Analyzer	AMETEK
	AT3042	Dryer Combuster Analyzer	AMETEK
	AT.7542	Pyrolyzer Combuster Analyzer	AMETEK
	LElO5	Dryer YO-YO	Enders & Hauser
	LE106	Pyrolyzer YO-YO	Enders & Hauser
ADDED	EF1	N-West 5”” Floor (3’7.500 CFM)	Prop Master
ADDED	EF2	N-East 5th Floor (37.500 CFM)	Prop Master
	EF3	S-East 5th Floor (37,500 CFM)	Prop Master
	EF4	S-West 5th Floor (37.500 CFM)	Prop Master
	EF5	S-West 9th Floor (23,100 CFM)	Prop Master
	EF6	N-East 9th Floor (23,100 CFM)	Prop Master
	EF7	North 10th Floor (6,200 CFM)	Prop Master
	EF8	South 10” Floor (6,200 CFM)	Prop Master
	EF9	Elevator Shaft (2,500 CFM)	Prop Master
	EF10	Screwing Building (15,600 CFM)	Prop Master
ADDED	EF11	VFB Building (23,000CFM)	Prop Master
ADDED	EF12	Drive-in Sump (15.600 CFM)	Prop Master
ADDED	EF13	Oily Fines Building (15,600 CFM)	Prop Master
	MOV101	Above 101V Dryer	State Wide
	MOV102	Above Pyrolyzer	State Wide
	MOV120	Below 104V	State Wide
	HU1	Main Heating Unit (61.OOO CFM)	Weather-Rite
	HU2	Head HSE Heating Unit (19.160 CFM)	Weather-Rite
	HU3	Screen Building Heating Unit (10.600 CFM)	Weather-Rite
	HU4	VFB Heating Unit	Weather-Rite
ADDED	HU5	Oily Fines Building Heating Unit	Weather-Rite
DELETED	101F	Fines Slurry Mix Tank	J. W. Williams. Inc.
DELETED	101FC	Fines Slurry Mix Tank Cooler	J. W. Williams, Inc.
	101J	Dryer Off Gas Blower	Novenco Sheldons, Inc.
	101JC	Voith Coupling for 101 J Blower	Voith Transmissions, Inc.
	IO1V	Coal Dryer (Included W/l 20V)	Salem Furnace Company
	101VF	Coal Dryer Feed Hopper	Salem Furnace Company
	1021,	Stub Axle Idler Wheels for AT-107	Irwin Car & Equipment
	102V	Dryer Cyclone (With 101V) (4ea)	Salem Furnace Company
DELETED	1035	Fines Slurry Transfer Pump	Kirst Engineering
	103L	Stub Axle Idler Wheels for AT-140	Irwin Car & Equipment
	104N	Adjust. Frequency Drive/Pyrolyzer	Specialty Control Systems
	104V	Pyrolyzer	Salem Furnace Company
DELETED	105F	Seal Water Surge Tank (W/Cooling Coil)	J.W. William, Inc.

UPDATED EQUIPMENT LIST
AS OF 2/28/97
Page 2 of 6

STATUS	TAG #	DESCRIPTION	VENDOR
DELETED	105.1	Seal Water Circulation Pump W/Motor	Kirst Engineering
	105V	Pyrolyzer Cyclone	Mark Steel Corporation
CHANGED	106CA	Pyrolyzer Quench Steam Condenser A	Chico
ADDED	106CB	Pyrolyzer Quench Steam Condenser B	Chico
	106F	Pyrolyzer Quench Water Tank	Paragon Fabricators, Inc.
DELETED	106J	Pyrolyzer Quench Water Circ Pump W/Motor	Ingersoll Rand
ADDED	107C	Pyrolyzer Quench Steam Fines Knout-out Drum	ENCOAL
MOVED	1075	Fines Slurry Feed Pump W/Motor	Falcon Pump & Supply
	107V	PDF Cooler	Heyl & Patterson, Inc.
DELETED	109V	Dryer Fines Screw Cooler	Christian Engineering
	110V	Rotary Valve Below 102V	Smoot Company
CHANGED	112V	Rotary Valve Below 105V	W.M. Meyer
	120V	Pyrolyzer Quench Chamber	Salem Furnace Company
MOVED	121V	PDF Rotary Valve	W.M. Meyer
ADDED	128V	Char Drag Conveyor	Wolf & Assoc., Falk. Woods
ADDED	129F	VFB Char Surge Bin	Brewer Steel
ADDED	130V	Vibrating Fluid Bed	Carrier
ADDED	131V	Finishing Cyclone	Ducon Environmental Sys.
ADDED	132C	VFB Heat Exchanger	Thermal Transfer
ADDED	133V	Char Rotary Valve	W.M. Meyer
ADDED	134V	VFB Fines Rotary Valve	W.M. Meyer
ADDED	135V	PDF Drag Conveyor	Wolf & Assoc., Falk. Woods
ADDED	136V	PDF Diverter Gate	Raco International
ADDED	137V	VFB Diverter Rotary Valve	Rotolok, Inc.
	201C1	Quench Oil Cooler	Superior Hard Surfacing
	201c2	Quench Oil Cooler	Superior Hard Surfacing
	201E	Quench Tower W/Internals	Eaton Metals
	2015	Quench Tower Circulation Pump	Union Pump Company
	201JA	Spare for 2015	Union Pump Company
	201VA	Coal Liquid Electrostatic Precipitator	Lodge-Cottrell
	201VB	Coal Liquid Electrostatic Precipitator	Lodge-Cottrell
	201vc	Coal Liquid Electrostatic Precipitator	Lodge-Cottrell
ADDED	202J	CDL Strainer Clean-up Pump	Roper
	203F	Wash Oil Surge Drum (W/Heating Coil)	J. W. Williams, Inc.
	203J	ESP Wash Oil Pump	Goulds Pumps, Inc.
	301B	Dryer On-Gas Combustor	IT-McGill
	301J	Recycle Gas Blower	Novenco Sheldons, Inc.
	302B	Pyrolyzer On-Gas Combustor	IT-McGill
	302J	Forced Draft Air Blower to 302B	Robinson c/o Longhorn
	303J	Forced Draft Air Blower to 301B	Robinson c/o Longhorn
CHANGED	304J	PDF Air Cooler Fan W/Motor	Buffalo Forge
ADDED	305J	VFB Finishing Blower	TLT Babcock
ADDED	305JC	Voith Coupling for 305J	Voith
ADDED	307J	VFB Booster Blower	Illinois Blower,Inc.
ADDED	308J	VFB Cooling Blower	Buffalo Forge
ADDED	309J	Oily Fines Vapor Fan	Buffalo Forge
ADDED	309L	Oily Fines Vapor Filter	Powder River Heating
	401c	MK Application Heater	Alco Products
	403J	MK Appl Pump W/Var. Freq. Mtr., Dr. Jacket	Bullen Pumps
	SO1E	Horizontal Scrubber	Dust Technology
	501F	Scrubber Surge Tank	Dust Technology
	501J	Scrubber Circulation Pump W/Mech. Seal	Kirst Engineering

UPDATED EQUIPMENT LIST

AS OF 2/28/97

STATUS	TAG #	DESCRIPTION	VENDOR
	501L	Sodium Carbonate Mix Tank Agitator	The Eads Company
	502F	Sodium Carbonate Mix Tank	J. W. Williams, Inc.
	502J	PPSR Sodium Carbonate Pump	Kirst Engineering
	502JA	PPSR Sodium Carbonate Pump (Spare)	Kirst Engineering
	503F	Wet Gas Scrubber	Dust Technology
CHANGED	503J	Solution Makeup Pump with Motor	Roper
	504V	Sodium Carbonate Storage Silo	The Datum Company
	505V	Bin Vent Filter for 504V	The Datum Company
	506V	Sodium Carbonate Rotary Feeder	The Datum Company
ADDED	2000U	2,000Lb/Hr Steam Boiler Package	
	2001C	Steam/Glycol Heat Exchanger	High Country Fabrication
	2001F	MK Storage Tank	J. W. Williams, Inc.
	2001FC	MK Storage Suction Heater	Alco Products
	2001U	10,000Lb/Hr Steam Boiler Package	York Shipley
	2002F	Coal Derived Liquid Storage Tank	J. W. Williams. Inc.
	2002FC	CDL Tank Heating Coil	J.W. Williams, Inc.
	2002J	Coal Liquid Prod Transfer/Load Out Pump	Union Pump Company
	2002LA	Miser for 2002F	The Eads Company
	2002LB	Miser for 2002F	The Eads Company
CHANGED	2002UJ	BFW Pump	Grundfus
CHANGED	2002UJA	Boiler Feedwater Pump Aux.	Grundfus
	2002UL	DC-Aerator	York Shipley
	2003C	Glycol-Water Air Cooler	Ecodyne Corporation
	2003CA	Glycol-Water Air Cooler	Ecodyne Corporation
	2003CB	Glycol-Water Air Cooler	Ecodyne Corporation
	2003CC	Glycol-Water Air Cooler	Ecodyne Corporation
	2003CD	Glycol-Water Air Cooler	Ecodyne Corporation
	2003F	Offspec Oil Storage Tank	J.W. Williams, Inc.
	2003FC	Heating Coil for 2003F	J.W. Williams. Inc.
CHANGED	2003J	Coal Liquid Offspec Transfer Pump	Blackmer
	2003L	Offspec Oil Tank Miser	The Eads Company
	2003LA	Miser for 2003F	The Eads Company
	2003U	Water Softener	York Shipley (Kisco)
ADDED	2004F	Portable MK Dust Suppressant Tank	ENCOAL
	2004FA	Portable MK Tank Heater	Appleton
ADDED	2004J	Portable MK Dust Suppressant Pump	Roper
	2004LA/LB	Portable MK Pump Strainers	Rosedale
	2005C	Glycol-Water Trim Cooler	High Country Fabrication
	2005F	Glycol-Water Storage Tank	J.W. Williams. Inc.
	2005J	Plant Air Compressor	Compression & Com.
	2005JA	Plant Air Compressor - Spare for 2005J	Compression & Com.
	2005JC	Compressor Air/Oil Cooler	Compression & Com.
	2005JCA	Spare Compressor Air/Oil Cooler	Compression & Com.
	2005JF	Air Receiver - Plant Air Compressor	Compression & Com.
CHANGED	2005JL	Air Dryer for Plant Air Compressor	Pneumatech
	2005L	Coal Liquid Rail Car/Truck Loading Arm	Progressive Product Mktg
ADDED	2006C	Oily Water Heat Exchanger	Chico
	2006F	Oily Water Storage Tank	J. W. Williams, Inc.
CHANGED	2006J	Oily Water Pump	Georgia Iron Works
ADDED	2006JA	Oily Water Pump (Spare)	Georgia Iron Works
	2006L	Nitrogen Dewar	Taylor Wharton
CHANGED	2006LC	Nitrogen Vaporizer	Cryogenic Experts

UPDATED EQUIPMENT LIST

AS OF 2/28/97

STATUS	TAG #	DESCRIPTION	VENDOR
	2007J	Glycol-Water Circulating Pump	Union Pump Company
	2007JA	Spare for 2007J	Union Pump Company
	2007L	Boiler Chemical Injection	York Shipley
	2007LJ	Injection Pump for 2007L	York Shipley
CHANGED	2008J	Process Water Booster Pump	Goulds
ADDED	2008JA	Process Water Booster Pumps	Goulds
	2008L	Ammonia Chemical Injection System	York Shipley
	2008LJ	Ammonia Injection Pump	York Shipley
	2009LA	Offspec Oil Filter	The Eads Company
	2009LB	Offspec Oil Filter	The Eads Company
ADDED	2010F	MK Car Topper Tank	J. W. Williams
ADDED	2010J	MK Car Topper Pump	Roper
ADDED	2010LA/LB	MK Car Topper Pump Strainers	Rosedale
	2012J	Offspec Chemical Injection Pump	The Eads Company
	2013J	Emergency Glycol Tracing Pump	Blackmer
ADDED	2014J	Nitrogen Vaporizer Glycol Pump	Quadna, Kenflow
TEMP/DELTD	2020F	Oily Fines Circulation Tank	Wilson Welding
TEMP/DELTD	2020J	Oily Fines Circulation Pump	Georgia Iron Works
ADDED	2021F	Filtrating Receiver	Westech
ADDED	2021L	Filter Tub Agitator	Westech
ADDED	2021v	Vacuum Drum Filter	Westech
ADDED	2022F	Clarifier Dearation Tank	Enviroclear
ADDED	20225	Clarifier Underflow Pump	Roper
ADDED	2022L	Clarifier Rake	Enviroclear
ADDED	2022V	Clarifier	Enviroclear
ADDED	2023F	Water Trap	Westech
ADDED	2023 J	Vacuum Pump	Westech
ADDED	2023L	Flocculant Blending Unit	Great-FLOC
ADDED	2024F	Oily Water Surge Tank	Kissack Water & Hot Oil Svc.
ADDED	2024J	Filtrate Pump	Westech
ADDED	2025J	Discharge Blower	Westech
ADDED	2026F	Oily Water Bulk Tank	Kissack Water & Hot Oil Svc.
ADDED	2026J	Oily Water Return Pump	Roper
ADDED	20275	Coagulant Pump	Great-FLOC
	2101A	Coal Storage Silo	Hoffman
	2101F	PDF Bin	Hoffman
	21015	Fire Water Booster Pump	Power Services
	2101L	Hyudraulic Power Supply for 2123V	Pebco
	2101LM	Motor for Hydraulic Power Supply	Pebco
	2101V	Coal Screen	Tabor Machine
	2101VM	Motor for Coal Screen	Tabor Machine
	2102A	Screening Plant Sump	
DELETED	2102F	Slurry Injection	Krebs Engineers
DELETED	2102L	Manifold W/Hydro-Cyclones(4ea)	Krebs Engineers
	2102V	Screening Plant Feed Conveyor	Robins Engrs & Constr.,Inc.
	2103A	PDF Plant Containment Sump	
CHANGED	2103F	MK Dust Suppresser	Von's Welding
	2103V	Feed Coal Crusher	R & F Coal
	2104A	PDF Cooler Area Sump	
	2104F	Screening Plant Dust Scrubber	Dust Technology
	2104J	PDF Cooler Sump Pump	Trans. Equipment & Supply
	2104V	Variable Speed Vibrating Feeder	Carmen Industries
	2104VN	Rate Control for 2104V Feeder	Carmen Industries

UPDATED EQUIPMENT LIST

AS OF 2/28/97

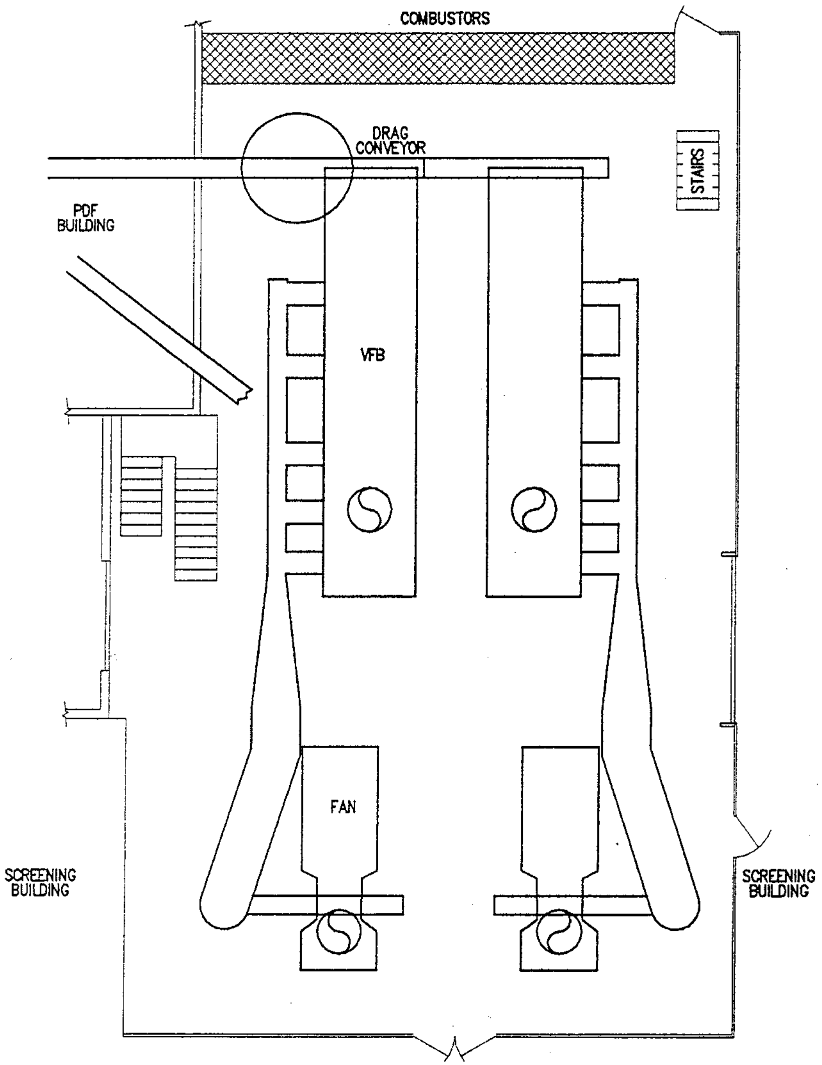
STATUS	TAG #	DESCRIPTION	VEN DOK
	2105A	PDF Silo Sump	
	2105F	Coal Feed Silo Dust Scrubber	Dust Technology
	2105J	PDF Silo Sump Pump	Trans. Equipment & Supply
	2105V	Sized Coal Surge Chute	Von's Welding
	2106A	Coal Storage Silo Sump	
ADDED	2106F	Dust Scrubber (8th Floor)	Dust Technology
	2106J	Coal Storage Silo Sump Pump	Trans. Equipment & Supply
	2106V	"S" Belt Coal Conveyor	Lakeshore, Inc.
	2107A	PDF Elevator Sump	
ADDED	2107F	Dust Scrubber (2 ½ Level)	Dust Technology
CHANGED	2 1075	PDF Elevator Sump Pump	Tram. Equipment & Supply
	2108J	Blower for SCR Plant Dust Scrubber 2104F	Cincinnati Fan & Ventilator
	2108V	"S" Belt PDF Conveyor	Lakeshore, Inc.
	2109J	Blower F/Coal Feed Silo Scrubber (2 105F)	Cincinnati Fan & Ventilator
ADDED	2110J	Blower for 8th Floor Scrubber	New York Blower
ADDED	2111J	Blower for 2 ½ Level Scrubber	New York Blower
ADDED	21125	VFB Area Sump Pump	Trans. Equipment & Supply
	2115V	Tramp Iron Magnet	Dings Magnetics
	2116V	Fines Collection Bin	Paragon Fabricators. Inc.
	2117v	Existing No. 16 Conveyor Extension & Mod	Robins Engrs & Constr.. Inc.
	2119V	Vibrating Feeder Under Fines Bin 2 116V	Carmen Industries
	2123V	Mass Flow PDF Feeder	Pebco
	2123VL	Cutoff Gate for PDF Bin (2 10 1 F)	Pebco
	2124V	Conveyor W/Motor for Coal Storage Silo	Robins Engrs & Constr.. Inc.
	2125V	Diverter Valve	Robins Engrs & Constr.. Inc.
	2126V	PDF Truck Loading Conveyor	Robins Engrs & Constr., Inc.
	2128V	Coal Analyzer Belt Conveyor	Robins Engrs & Constr.. Inc
	2129V	Coal Fines Truck Loading Conveyor	Buhler Miag. Inc.
CHANGED	2130V	Fines Truck Loading Telescopic Spout	Pebco
	2134V	Fines Bin Cutoff Gate for 2 116V	Paragon Fabricators. Inc.
	2135V	Fines Bin Cutoff Gate for 2 116V	Paragon Fabricators, Inc.
	2139V	Cutoff Gate for 504V - Vendor Package	The Datum Company
	2140V	Cutoff Gate for 2 10 1 A	Pebco
	2141V	Feed Coal Silo Heater	Powder River Heating
	2142V	PDF Bin Heater	Powder River Heating
DELETED	2143V	Dryer Fines Conveyor	Buhler Miag, Inc.
	2144V	Dust Collection Baghouse	Air-Cure Howden
ADDED	2145V	Raw Coal S-Belt Cleanup Screw Conveyor	Wolf & Associates
	2201A	Cooling Water Intake Structure	Hladky Construction
	220 1 J	Cooling Water Pump	Goulds Pumps. Inc.
	2201JA	Spare for 220 1 J	Goulds Pumps. Inc.
	2201LA	Cooling Water Filter W/Motor	Hayward Industrial Products
	220 1LB	Cooling Water Filter W/Motor	Hayward Industrial Products
ADDED	22025	Cooling Water Chemical Injection Pump	Betz Chemical
DELETED	2401 J	SCR Plant Fines Sump Pump	Goulds Pumps, Inc.
	2402J	PDF Plant Containment Pump	Trans. Equipment & Supply
DELETED	2403 J	Oil Transfer Area Sump Pump	Trans. Equipment & Supply
	2404J	Leakage Sump Pump	Tcsas Process Equipment
	2405J	SCR Plant Coarse Sump Pump	Trans. Equipment & Supply
ADDED	2410J	Drive-In Sump Pump	Flygt
ADDED	241 IJ	Pipe Trench Sump Pump	Trans. Equipment & Supply
ADDED	2412J	Oily Water Return Sump Pump	Trans. Equipment & Supply
ADDED	2413J	Boiler Room Sump Pump	Trans. Equipment & Supply

UPDATED EQUIPMENT LIST

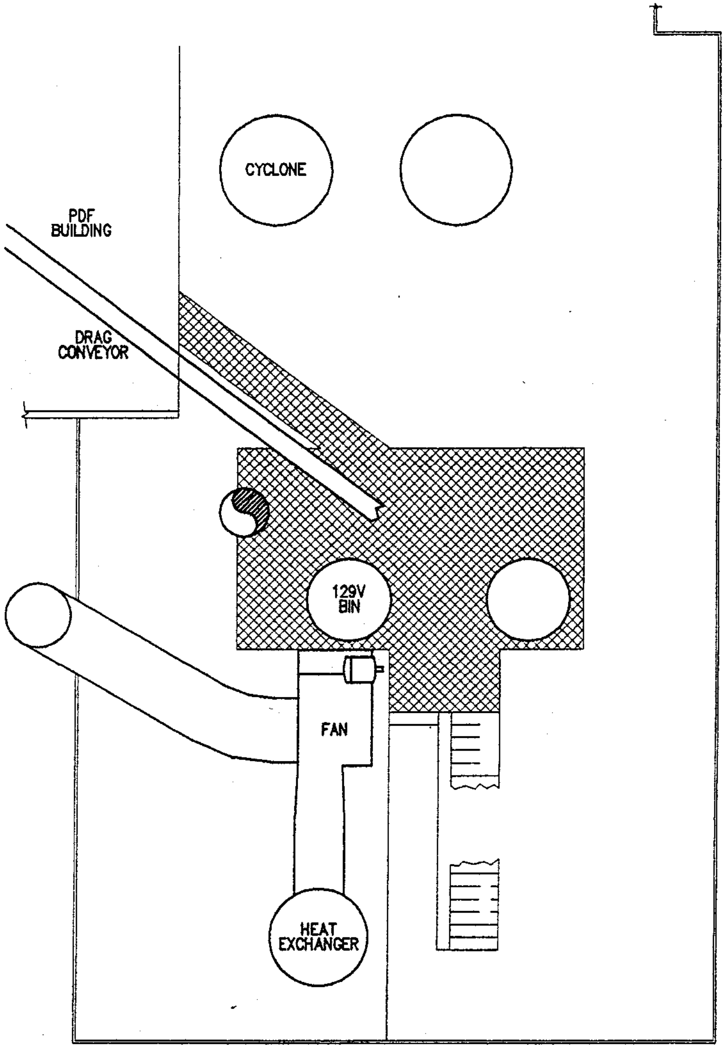
AS OF 2/28/97

STATUS	TAG #	DESCRIPTION	VENDOR
CHANGED	2501J	Lift Station Pump	Trans. Equipment & Supply
MOVED	2605K	2T Hoist - VFB Building	Trans. Equipment & Supply
	2610K	5T Hoist (Main Drop Area)	Trans. Equipment & Supply
	2621K	2T Hoist (Top of PDF Silo)	Trans. Equipment & Supply
ADDED	2622K	2T Hoist (VFB Building)	Trans. Equipment & Supply
	3406B	Emergency Generator	Caterpillar
	PV-150	48" Emergency Pressure Relief Valve	Masoneilan N. American

PDF DEACTIVATION SYSTEM BUILDING

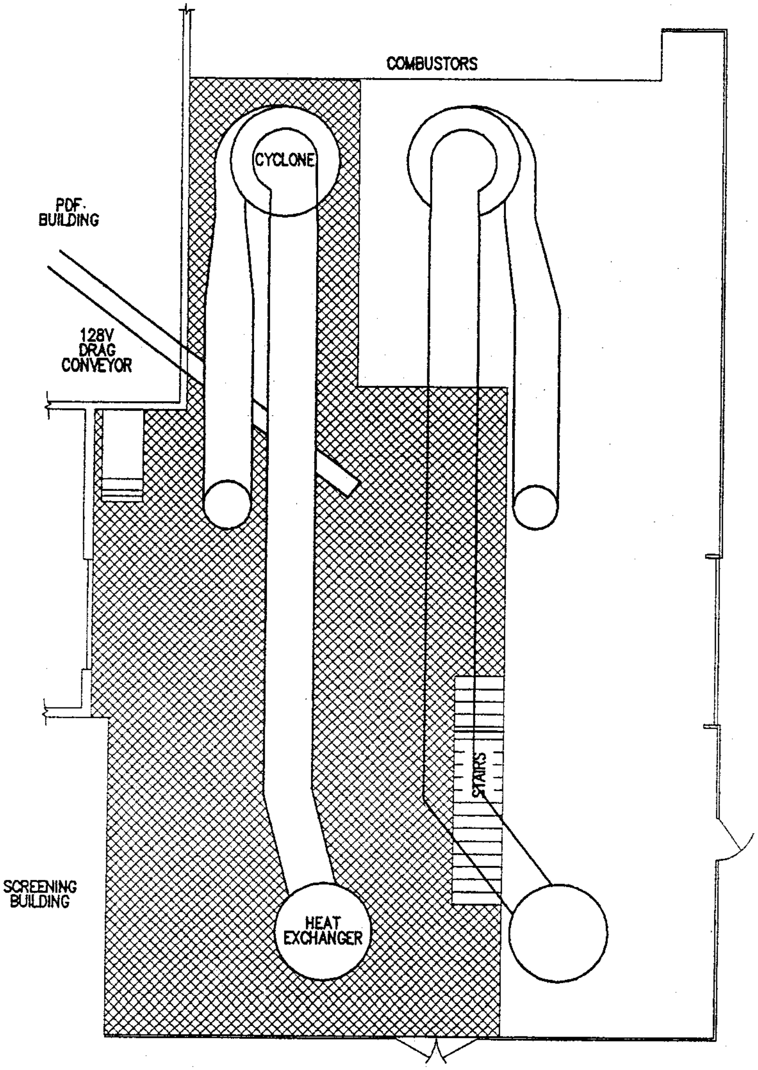


1ST FLOOR – ELEVATION 96'–6" & 106'–4"



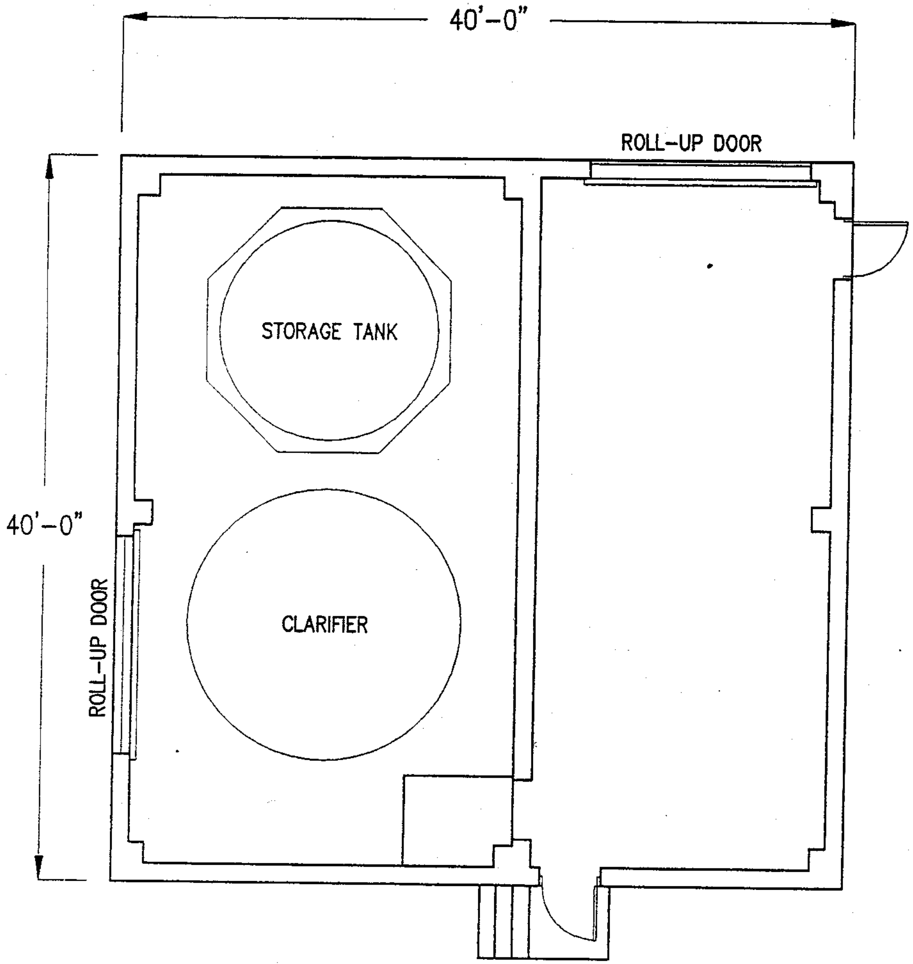
2ND FLOOR – ELEVATION 118'–4" & 129'–6"

PDF DEACTIVATION SYSTEM BUILDING

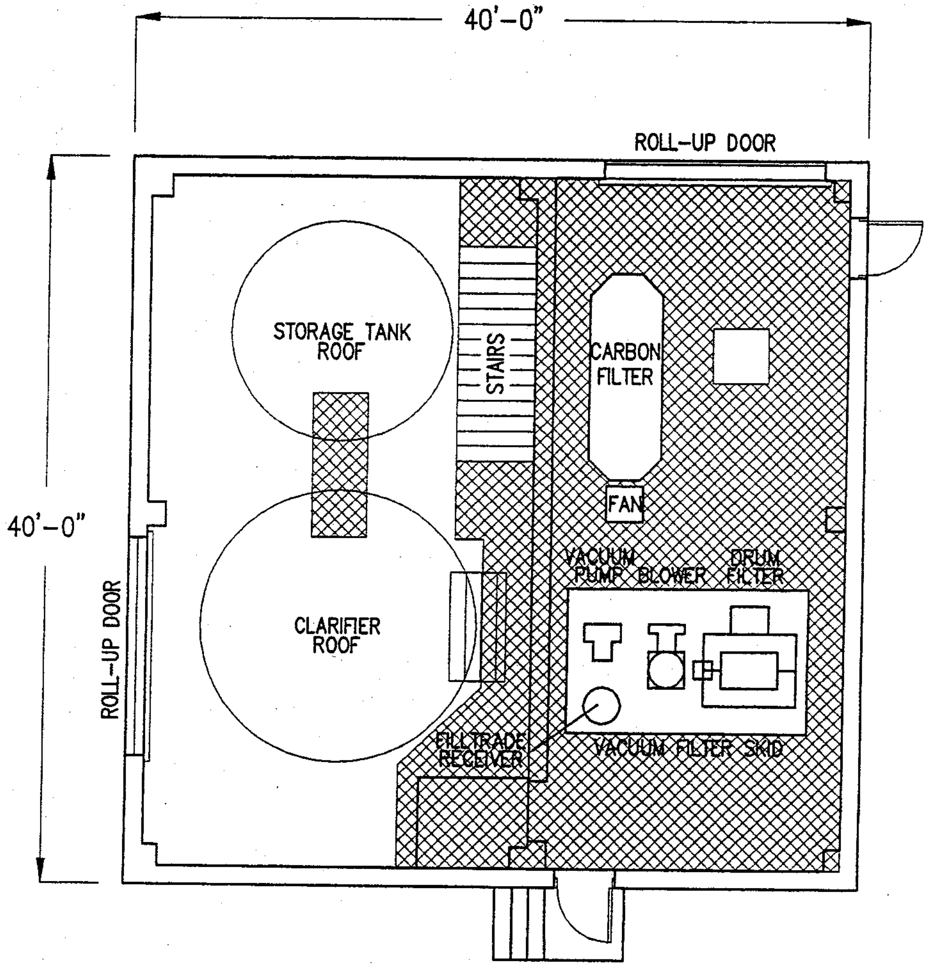


3RD FLOOR – ELEVATION 140'-0"

PROCESS WATER FINES REMOVAL BUILDING



1ST FLOOR



2ND FLOOR

Project Final Report

This report general contents page has been set up with each section linked to the page where the corresponding section begins. To use this feature, move your cursor to the section you wish to view. (Your cursor arrow will change to a pointing finger.) Click your left mouse button to jump to the correct page in the report.

To return to the primary *Contents* page or the *Cover* of the ENCOAL Project reports, click the **Go Back** button (the double left-pointing arrow) from the tool bar at the top of the screen, or choose **Go Back** from the view menu.

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ENCOAL MILD COAL GASIFICATION PROJECT:

ENCOAL Project Final Report

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PREPARED FOR:

THE UNITED STATES DEPARTMENT OF ENERGY
UNDER DOE INSTRUMENT NO. DE-FC21-90MC27339

SEPTEMBER 1997

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TRADEMARK NOTICE

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INTRODUCTION

This document is the summative report on the ENCOAL Mild Coal Gasification Project. It covers the time period from September 17, 1990, the approval date of the Cooperative Agreement between ENCOAL and the U.S. Department of Energy (DOE), to July 17, 1997, the formal end of DOE participation in the Project.

The Cooperative Agreement was the result of an application by ENCOAL to the DOE soliciting joint funding under Round III of the Clean Coal Technology Program. By June 1992, the ENCOAL Plant had been built, commissioned and started up, and in October 1994, ENCOAL was granted a two-year extension, carrying the project through to September 17, 1996. No-cost extensions have moved the Cooperative Agreement end date to July 17, 1997 to allow for completion of final reporting requirements.

At its inception, ENCOAL was a subsidiary of Shell Mining Company. In November 1992, Shell Mining Company changed ownership, becoming a subsidiary of Zeigler Coal Holding Company (Zeigler) of Fairview Heights, Illinois. Renamed successively as SMC Mining Company and then Bluegrass Coal Development Company, it remained the parent entity for ENCOAL, which has operated a 1,000-ton/day mild coal gasification demonstration plant near Gillette, Wyoming for nearly 5 years. ENCOAL operates at the Buckskin Mine owned by Triton Coal Company (Triton), another Zeigler subsidiary.

SUMMARY

The Liquids From Coal (LFC) technology employed at the ENCOAL Plant was invented by SGI International (SGI) of La Jolla, California and further developed by SMC Mining Company (SMC). The technology utilizes low-sulfur Powder River Basin coal to produce two new fuels, Process Derived Fuel (PDF) and Coal Derived Liquids (CDL).

These alternative fuel sources were intended to significantly lower current sulfur emissions at industrial and utility boiler sites and reduce pollutants causing acid rain. In support of this objective, the following goals were established:

- Provide sufficient products for full scale test burns
- Develop data for the design of future commercial plants
- Demonstrate plant and process performance
- Provide capital and operating cost data
- Support future LFC Technology licensing efforts

Each goal has not only been met, but exceeded. The ENCOAL Plant has been operated for nearly 5 years, during which the LFC process has been demonstrated and refined. Sixteen unit trains of PDF and 189 tank cars of CDL have been delivered using conventional means and have been successfully utilized on a commercial scale. PDF has successfully fueled major U.S. electric utility plants, been shipped overseas for test burns in Japan, tested as a blast furnace injectant, and combined with iron ore as a possible reductant in a direct reduced iron (DRI) process. Data have been collected over the life of the plant for use as a basis for evaluating and designing commercial plants, and the LFC licensing effort now includes several international agreements and prospects for future development.

PROJECT ORGANIZATION OVERVIEW

ENCOAL is the participant with the DOE and the signatory to the Cooperative Agreement and is the owner, manager and operator of the demonstration plant. ENCOAL is responsible for all aspects of the project, including design, permitting, construction, operation, data collection and reporting. ENCOAL managed the design and construction of the project through a project manager, who was assisted by a team of technical and managerial personnel. The engineering, procurement and construction of the plant were contracted to The M.W. Kellogg Company (Kellogg). Coal processed in the ENCOAL Plant is purchased from Triton, which also provides labor and administrative services, access to the site, associated facilities and infrastructure vital to the project. Equity funding, administrative services and product marketing are provided by service subsidiaries of Zeigler. Additional technical development support is provided by TEK-KOL, a general partnership between SGI and a subsidiary of Zeigler, that also has the primary responsibility for commercialization. All physical plant assets are assigned to ENCOAL. The LFC technology is owned by TEK-KOL and licensed to ENCOAL.

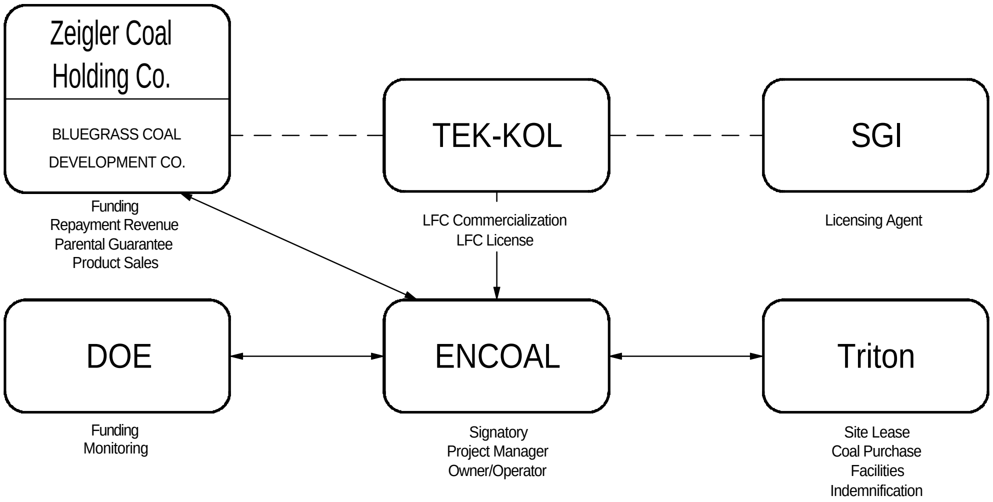


Figure 1: ENCOAL Project Organization.

LOCATION

The demonstration plant is located in Campbell County, Wyoming, approximately 10 miles north of the county seat of Gillette. The site is within Triton's Buckskin Mine boundary, near the mine's rail transportation loop. Active coal mining and reclamation operations surround the demonstration plant site. *(See Figure 2: ENCOAL Project Location)*.

The ENCOAL Plant was located at the Buckskin Mine site to take advantage of the existing mine facilities and to reduce capital and operating costs. The proximity of the ENCOAL project to the mine and subsequent expansion facilities provided optimization opportunities for ENCOAL, but also required some changes in ENCOAL's original plans. Examples were changing grade elevations, moving conveyor supports, using existing buildings and moving temporary construction facilities. The sedimentation pond and sump system also evolved over a course different from what was originally planned, but the end result was an arrangement beneficial to both Triton and ENCOAL. *(See Figure 3: ENCOAL Site Plot Plan).*

Figure 2: ENCOAL Project Location.

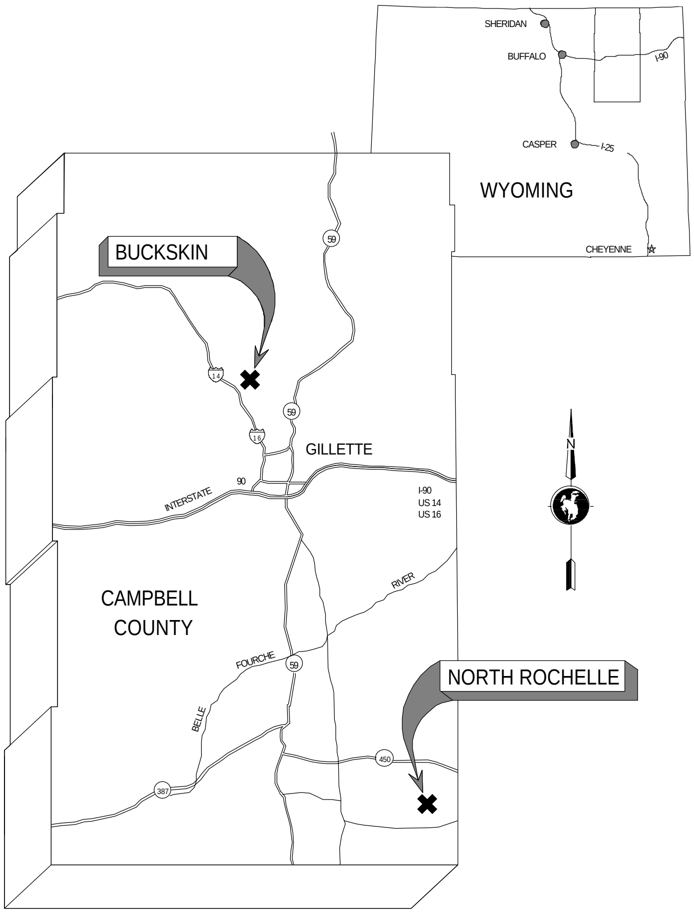
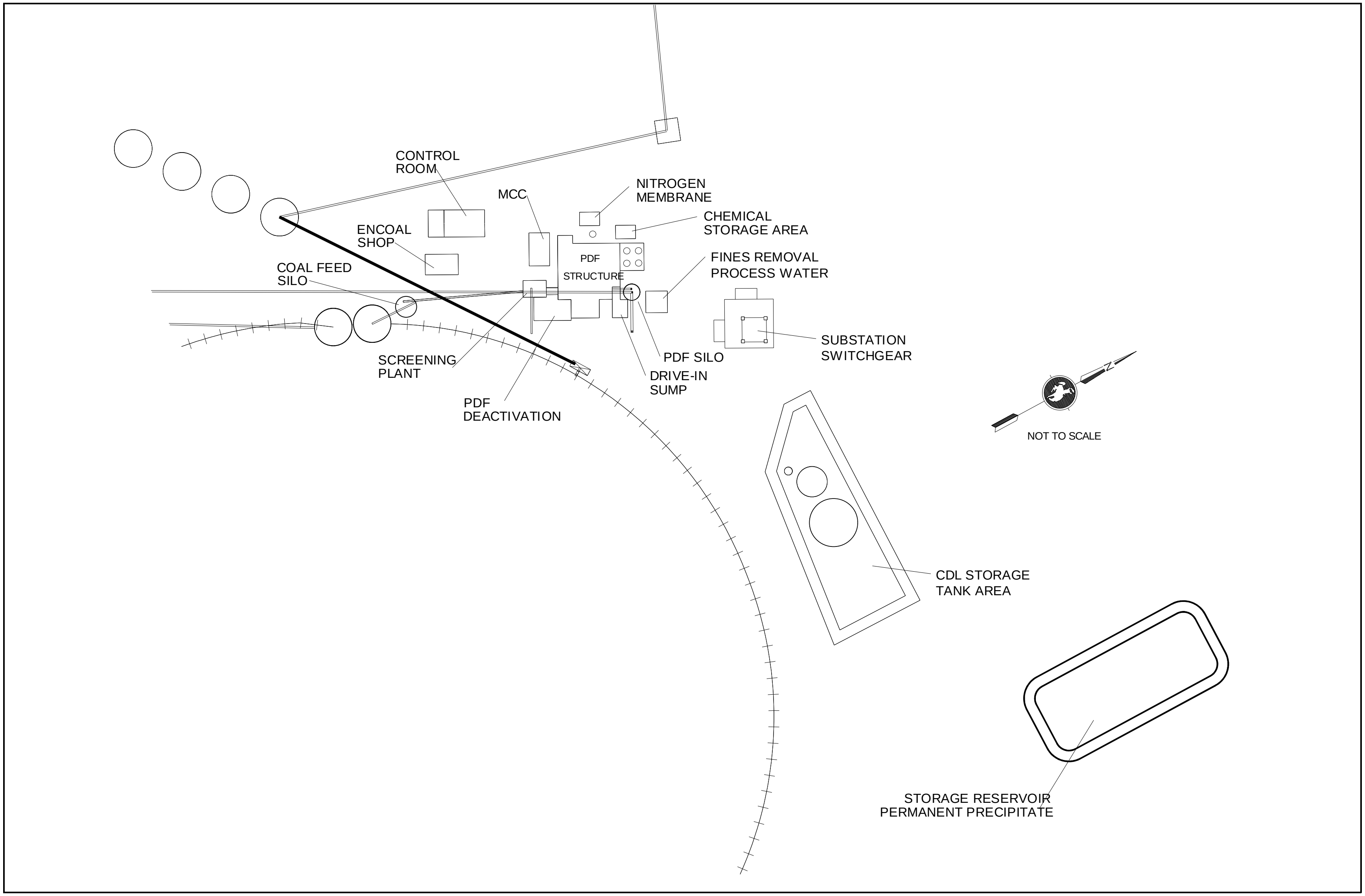


Figure 3: ENCOAL Site Plot Plan.



PROCESS CONCEPT

The LFC technology uses a mild pyrolysis or mild gasification process that involves heating the coal under carefully controlled conditions. The process causes chemical changes in the feed coal in contrast to conventional drying, which leads only to physical changes. Subbituminous coal contains considerable water, and conventional drying processes physically remove some of this moisture, causing the heating value to increase. The deeper the coal is dried, the higher the heating value and the more the pore structure permanently collapses, reducing reabsorption of moisture. However, deeply dried Powder River Basin coals exhibit significant stability problems when dried by conventional thermal processes. The LFC process overcomes these stability problems by thermally altering the solid to create PDF and CDL.

Specification PDF is a stable, low-sulfur, high-Btu fuel similar in composition and handling properties to bituminous coal. CDL is a low-sulfur industrial fuel oil that can potentially be upgraded for chemical feedstock or transportation fuels.

Figure 4 is a simplified flow diagram of the ENCOAL process, which begins when run-of-mine (ROM) coal moves from existing Buckskin Mine storage silos to ENCOAL's 3,000-ton silo. Up to 1,000 tons/day of coal from this silo are continuously fed onto a conveyor belt by a vibrating feeder, crushed and screened to 2" X 1/8", and conveyed about 195 feet to the top of the plant building.

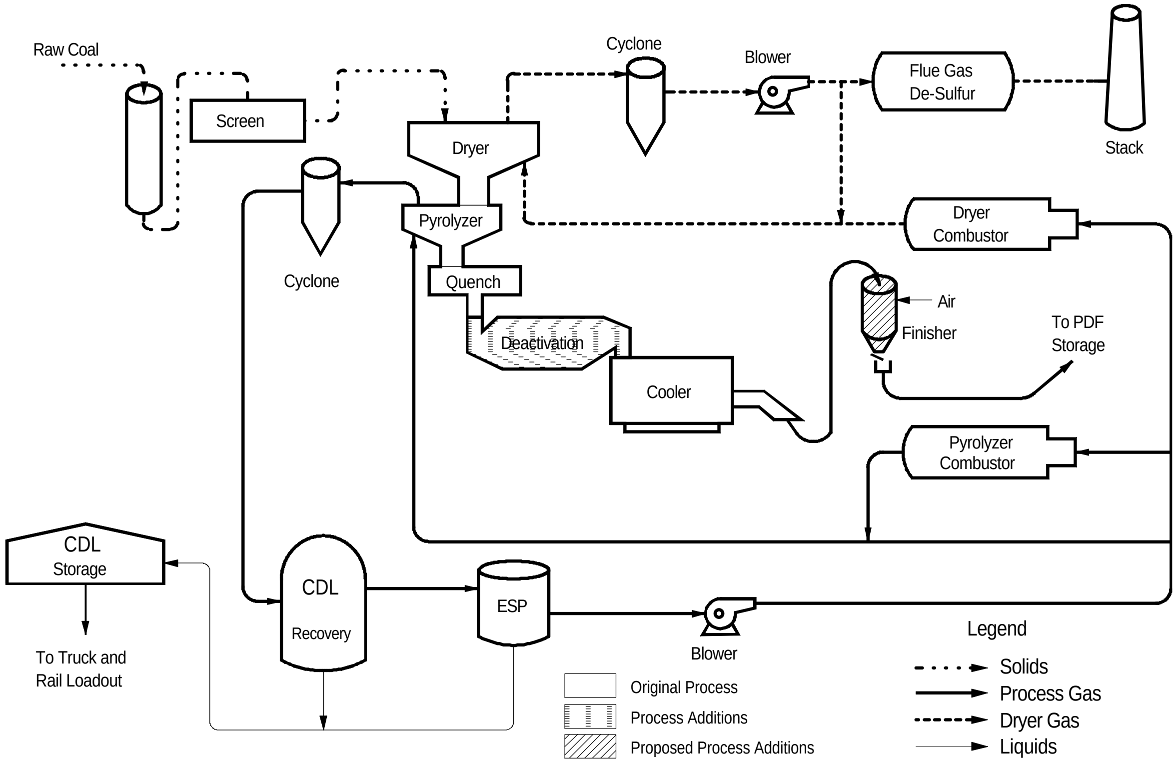


Figure 4: Simplifed Process Flow Diagram

The coal is then fed into a rotary grate dryer and heated by a hot gas stream. The solids residence time and temperature of the inlet gas have been selected to reduce the moisture content of the coal without initiating pyrolysis or chemical changes. The solid bulk temperature is controlled so that no significant amounts of methane, carbon monoxide or carbon dioxide are released from the coal.

The solids then report to the pyrolyzer rotary grate, where a hot recycled gas stream raises the temperature to about 1000°F. The rate of solids heating and the residence time are carefully controlled as these parameters affect the properties of both products. During the processing in the pyrolyzer, all remaining free water is removed, and a chemical reaction occurs in which volatile gaseous materials are released. After leaving the pyrolyzer, the solids are quickly cooled in the quench table to stop the pyrolysis reactions.

In the original process concept, the quench table solids were further cooled in a rotary cooler and transferred directly to a surge bin. A little more than halfway into the project life, extensive testing indicated the need for an addition to the process -- a separate, closed vessel for deactivating the solid product prior to final cooling and storage. The process was then altered to include a vibrating fluidized bed, or VFB, as part of a PDF deactivation loop. In the process as it currently exists, quench table solids are fed into the deactivation loop where they are partially fluidized and exposed to a gas stream in which temperature and oxygen content are carefully controlled. The deactivation gas system consists of a blower to move the gas stream, a cyclone to remove entrained solid fines, a heat exchanger to control gas temperature, and a booster blower to bleed off gas to the dryer combustor. The residence time, oxygen content and temperature of the gas stream have been selected to deactivate the coal within the VFB unit.

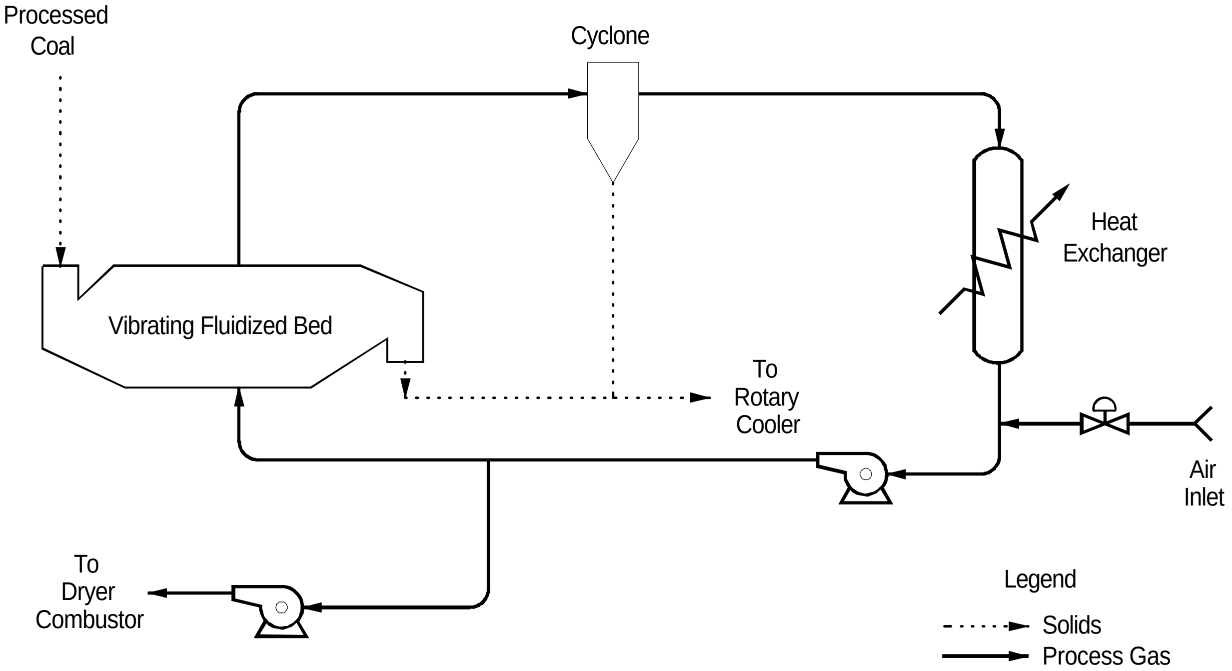


Figure 5: PDF Deactivation Loop Simplified Process Flow Diagram.

After treatment in the VFB system, the solids are cooled in an indirect rotary cooler. A controlled amount of water is added in the rotary cooler to rehydrate the PDF to near its ASTM equilibrium moisture content, an important step in the stabilization of PDF. A final or "finishing" step, the second stage of deactivation, has also been tested as an addition to the original process. In this step, PDF is oxidized at low temperatures, and then transferred to a surge bin. Since the solids have no surface moisture, they require the addition of a dust suppressant. MK, a very effective dust suppressant patented by SMC Mining Company, is added to the solid product as it leaves the surge bin. PDF, the resulting new fuel form, is transferred to storage silos where it is held for shipment by rail through existing Buckskin loadout facilities.

In the liquids recovery section of the plant, the pyrolysis gas stream is sent through a cyclone to remove entrained particles. The gas stream is then cooled in a quench tower to condense the desired hydrocarbons and to stop any additional pyrolysis reactions. The gas temperature is kept above the dew point of the water so that only CDL is condensed, preventing the formation of water in the process and the resulting separation and disposal problems. Electrostatic precipitators (ESP's) recover any remaining liquid droplets and mists from the gas leaving the condensation unit.

Most of the residual gas from the condensation unit is recycled to the pyrolyzer by a blower. Some of this gas is burned in the pyrolyzer combustor and blended with the recycled gas that provides heat for the pyrolyzer.

The remaining gas is burned in the dryer combustor, converting all sulfur compounds to sulfur oxides. Nitrogen oxides (NO_x) emissions are controlled by appropriate design of the combustor, based on evaluation of NO_x control technologies for low-Btu gases. The hot flue gas is blended with the recycle gas from the dryer to provide heat and gas flow necessary for drying. The exhaust gas from the dryer loop is treated first in a wet scrubber followed by a horizontal scrubber, both using a water-based sodium carbonate solution. The wet gas scrubber recovers fine particulates that escape the dryer cyclone, and the horizontal scrubber removes most of the sulfur oxides from the flue gas. The spent solution discharges into a clay lined pond for evaporation.

The operation of the demonstration plant for over 4 years has yielded a mass of process data that is reflected in the design of a commercial plant. In a facility approximately fifteen times the capacity of the demonstration plant, (made up of three modules of five times the demonstration plant capacity), each commercial module will represent a 5-to-1 scale up. Much research and testing have gone into selecting equipment for a commercial venture, in particular, tailoring the PDF deactivation and stabilization process equipment to fit a commercial-size plant. A number of improvements in the production of CDL will also be incorporated into the larger plant design, based on production experience and research, as well as improved knowledge of CDL marketing. Details on the commercial design are discussed in a separate report.[1]

PROJECT DESCRIPTION

Achieving the global objectives of producing, transporting, testing and marketing PDF and CDL required the design, construction and operation of the 1,000-ton/day demonstration plant and support facilities. Work scope and cost of the project were significantly reduced because the host Buckskin Mine owns and maintains coal storage and handling facilities, rail loadout, access roads, utilities, office, warehouse and shop facilities. Operations staff, supervision, administrative services and site security were also contracted with Triton, with the balance of the project requirements provided by ENCOAL and its subcontractors.

The project was divided into three phases:

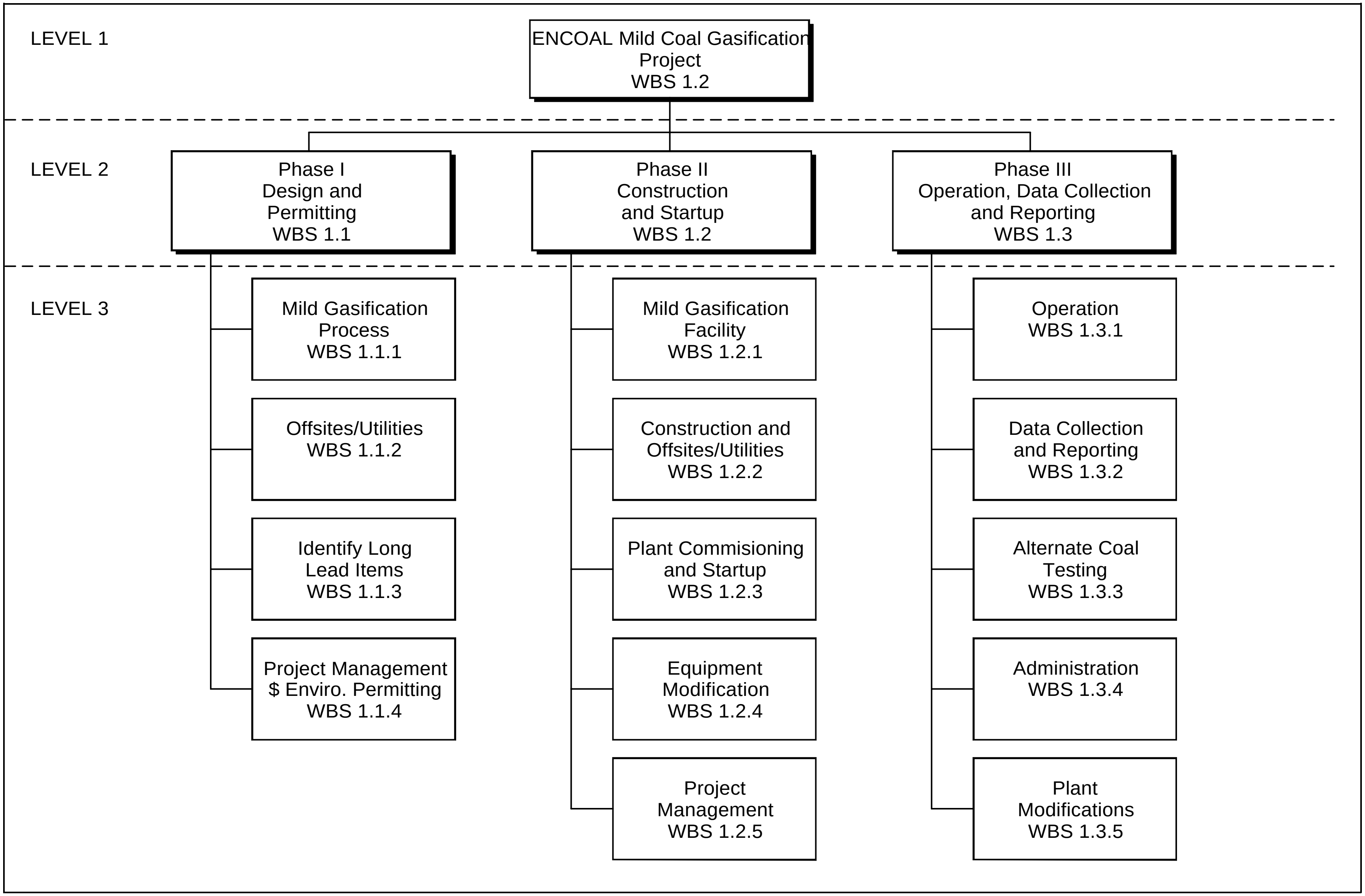
Phase I -- Design and Permitting
Phase II -- Construction and Start-up
Phase III -- Operation, Data Collection, and Reporting

Two budget periods encompassed the work, the first covering Phases I and II, and the second covering Phase III. To organize the work load during these phases, a Work Breakdown Structure was developed for the project. *(See Figure 6: ENCOAL Project Work Breakdown Structure (WBS)).*

Engineering, procurement and construction management for the project were handled by Kellogg. Kellogg's scope of work included home office design, project coordination, field construction supervision, scheduling, project controls, procurement and project management. Kellogg's engineering was considered complete by July 1991, when the project shifted to the field, and remaining engineering tasks were performed by ENCOAL. All permitting requirements were handled by ENCOAL, and field engineering and construction support were handled by ENCOAL's technical team.

Construction was performed by Kellogg Constructors, Inc., (KCI), Kellogg's construction arm, and ENCOAL handled the bulk of remaining Phase II activities: operations planning, training, maintenance planning, staffing, plant commissioning and start-up. DOE approval of the Continuation Application in July 1992 marked the beginning of ENCOAL's Phase III activities: operations, data collection and reporting. Preparation of written plans and manuals was an integral part of both Phase II and III activities.

Figure 6: ENCOAL Project Work Breakdown Structure (WBS).



EXECUTIVE SUMMARY FOR PHASES I AND II -- September 1990 through May 1992.

In September 1990, the Cooperative Agreement between ENCOAL and the DOE was signed, moving the LFC process, in development in laboratory settings since the early 1980s, into the realm of reality. Varied activities took place in the 2 years following the signing, carried out by a number of entities but focused on a single outcome -- the construction of an operable ENCOAL Plant. While there was some overlap of Phase I and II activities, almost all Phase I activities were completed well ahead of the DOE baseline schedule.

PHASE I ACCOMPLISHMENTS -- September 1990 through July 1991

1.0 Design and Permitting

1.1 Process/Plant Design

In anticipation of signing the Cooperative Agreement, the ENCOAL and Kellogg technical team and engineering task forces were mobilized in Houston, Texas, in July 1990. These two groups reviewed the 1988 LFC process release, and updated process and instrumentation diagrams, design basis documents and process flow diagrams.

During this time, SGI completed adaptation of their proprietary control system, and programming of the programmable logic controller (PLC) system moved toward completion.

When design and engineering for the plant were nearing the 60% milestone in October 1990, ground for the ENCOAL Plant was broken. Eight months later, Kellogg had completed 90% of its design and engineering efforts, leaving only some civil engineering, electrical and instrumentation work. All other disciplines were turned over to the ENCOAL field engineering team, and in July 1991, the Kellogg home office engineering task force was demobilized. All Houston engineering operations concluded as well.

In January 1991, computer stations and software were received, and by spring, initial programming of plant control systems was complete. As start-up procedures evolved the program underwent major revisions, but was considered to be about 40% complete by August 1991.

1.2 Off-Sites and Utilities

Because only expensive propane gas was available at the site, ENCOAL negotiated a contract for natural gas service. The contract included a significant reduction in the estimated price of the gas delivered, as well as installation of a major portion of line to the site at a price below the piping contractor's bid. The agreement also requires the gas supplier to maintain the line. During the 10 months of Phase I, Kellogg released all major construction design packages for bid, including off-sites underground piping, off-sites foundation concrete work and four buildings.

1.3 Identify and Design Long Lead Items

ENCOAL and Kellogg teams identified and requisitioned all long delivery items, including critical items such as the dryer, pyrolyzer, quench chamber and associated equipment, PDF cooler and ESPs.

1.4 Project Coordination and Environmental Permitting

Service agreements were finalized with Triton for administrative support and plant operation, with Shell Mining Company for technical and administrative support, and with SGI for technical services. The Project Management Plan and a draft of the Environmental Monitoring Plan were submitted to the DOE in accordance with the Cooperative Agreement.

The Wyoming Department of Environmental Quality, Air Quality Division (WDEQ-AQD) permit application was submitted in June 1988, and approval was received in June 1989. This removed a serious potential obstacle to the project as submitted to DOE. This permit to construct was required to break ground. Coinciding with the ground breaking, the federal environmental review process was completed with the issuance of an Environmental Assessment, a requirement of the National Environmental Policy Act (NEPA). As part of this process, the DOE issued the Finding of No Significant Impact Report. Fulfillment of the NEPA requirements completed Cooperative Agreement requirements and cleared the way for initiation of Phase II construction and start-up activities.

State permitting took place with the Wyoming Department of Environmental Quality (WDEQ). Most early permitting activities centered around the question of a precipitate disposal pond. Because the WDEQ questioned the location of a permanent precipitate disposal pond, ENCOAL submitted an alternative permit application to allow modification of an existing Buckskin mine sediment pond. With the addition of an 18-inch clay liner, this would serve as a temporary storage pond for ENCOAL's precipitates. Approval of the application was critical, as lack of approval would have postponed construction until 1992. The WDEQ approved the application, giving the go-ahead for construction of all facilities except the permanent disposal pond. The temporary pond served into 1997, when the permanent precipitate storage reservoir was completed.

The ENCOAL HazOp review, held to identify any potential operational safety hazards, was completed in the spring of 1991. Several action items were identified and issued to the appropriate groups for implementation. Start-up, operating, and shutdown procedures were written for use in training plant operators and technicians during this time.

PHASE II ACCOMPLISHMENTS -- October 1990 through May 1992

2.0 Construction and Start-Up

2.1 Construct Mild Coal Gasification Facilities

The demobilization of Kellogg's engineering task force in July 1991 marked ENCOAL's assumption of remaining engineering tasks and ENCOAL's and KCI's takeover of construction. Late 1991 saw the erection of the PDF structure and equipment, aboveground piping and steelwork. Considerable effort was put into winterizing the structures for interior work in cold weather: siding and natural gas heating were added to the PDF structure. By March 1992, refractory material had been installed in the combustors, dryer cyclone and large diameter duct, and structural steel for the screening building was complete. By June 1992, ENCOAL and KCI had completed the PDF structure and equipment. The CDL truck/train loadout platform was erected, and the CDL load-out was installed. Also in June, KCI construction personnel and subcontractors finished electrical and insulation work and left the site.

2.2 Construct Off-Sites and Utilities

The off-sites underground piping was almost complete by the fall of 1991. The natural gas company completed installation of the main supply pipeline, and the supply lines to the control room and PDF structure were commissioned and charged with gas during winter of 1992. Off-sites aboveground piping contract work was completed in February 1992, with the exception of the train loadout platform, which was completed in June.

2.3 Plant Commissioning and Start-Up

During this period, the sequencing in programming the PLCs was established, moving the plant further toward commissioning. Work teams wrote a preventive maintenance manual and an operations and training manual, and organized testing and chemical analysis plans. By the end of Phase II, all detailed individual run Test Plans were completed except for those associated with PDF deactivation, third-party stack gas testing, full-design-capacity gas loop flow testing and product test burns, which could not be completed until the onset of operations. SGI completed a preliminary data acquisition procedure for analyzing product samples. Operator training classes began February 1992, and included vital "hands-on" instruction and practice to support classroom work. Also during the winter of 1992, meetings on commissioning and testing procedures became an ongoing activity. An electrical and instrumentation contract was awarded to a small local firm during April 1992, and a mechanical maintenance contract was also awarded. These contracts helped significantly in accomplishing commissioning operations and other mechanical work, and in May 1992, commissioning activities concluded. All Phase I and II statement of work items had been completed except start-up, which began in mid-May and continued until mid-June when ENCOAL achieved its first 24-hour run.

2.4 Plant Modifications

No major modifications were made to the plant at this point, but problems with major equipment were recognized and corrected. For example, testing of the original design of the large bore piping revealed that the explosion doors released at too low a pressure. ENCOAL engineers worked in conjunction with the door manufacturer to design a new latch for the doors, and modified all five doors to hold seals under design pressure. Many platforms, handrails, and access points were added during this time to improve safety and maintenance.

2.5 Project Coordination

The coal purchase agreement with Triton was updated to reflect the method of coal measurement and to allow for the purchase of sized coal from Triton. A Pre-Manufacturing Notice for PDF was submitted to the U.S. Environmental Protection Agency (EPA) in December 1991, and granted during the winter of 1992. Drafts of Material Safety Data Sheets for PDF and CDL were also drawn up, reviewed internally and submitted to the EPA. Early in 1992, meetings were held with the WDEQ to discuss permit stipulations for continuous sulfur dioxide (SO_2) stack monitoring. These meetings resulted in agreements on quality control procedures, reporting requirements, monitoring conditions and equipment, and the WDEQ issued a letter stipulating the agreed conditions in January 1992. Midway through 1992, a formal permit for plant boiler emissions was received from the WDEQ.

EXECUTIVE SUMMARY FOR PHASE III -- Operation, Collection, and Data Reporting -- June 1992 through February 1997

In May 1992, the Continuation Application was submitted to the DOE, and 1 month later, ENCOAL accomplished the first continuous 24-hour run successfully producing PDF and CDL. These benchmarks officially moved the project into Phase III activities on July 17, 1992, 60 days after the submission of the application.

The almost 5 years comprising Phase III were a period of intense activity. As a first-of-its-kind enterprise, design and process difficulties were not unexpected, and much of Phase III was devoted to solving those problems, especially that of PDF deactivation. As ENCOAL teams resolved obstacles, and collected and analyzed operations data, the duration of plant runs lengthened, with some months exceeding 90% availability. PDF and CDL were produced and shipped using conventional equipment and successfully test burned at industrial sites. The operability of the plant and its equipment were proven, and a huge body of data was collected. The commercial plant vision reflects the amassed design, capital and operating cost data.

Although the ENCOAL Plant's tall structures, hot gases and large rotating equipment would seem to create real potential for injury, one of ENCOAL's most important accomplishments is its safety record. Since 1990, only nine reportable accidents and four lost time accidents have been reported for all personnel, including contractors and associated workers. This lost time accident rate is less than one-third the most recent available rate for petroleum and coal processing industries, while the number of reportables is less than one-fifth. As of May 31, 1997, ENCOAL workers amassed 1,600 days -- over 4 years -- without a lost time accident.

Compliance with federal and state environmental regulations has also been an important goal for the ENCOAL Project. Regular Mine Safety & Health Administration (MSHA) inspections since 1990 yielded only 10 minor noncompliance citations. With the exception of one Notice Of Violation issued by the WDEQ-Land Quality Division (LQD) for the land farm, Wyoming state inspections were consistently positive. Ongoing contractor and operations safety meetings, and comprehensive, continuing operator training contributed to these safety and compliance achievements.

3.1 Operation and Maintenance

Table 1 makes the division between early, pre-VFB operations to those after its introduction quite apparent. Because it improved PDF stability, this new equipment made it possible for the first time to ship PDF for test burns. At the same time the VFB was being installed, other major changes paved the way for increased PDF and CDL production: the sand seals in the pyrolyzer were replaced with water seals, and all three ESPs had been fitted with improved insulator design. A third modification, the installation of a process water fines handling system, also contributed to the considerable improvement in plant performance and subsequent production.

	Pre-VFB		Post-VFB				
	1992	1993	1994	1995	1996	*1997	SUM
Raw Coal Feed (Tons)	5,200	12,400	67,500	65,800	68,000	28,000	246,900
PDF Produced (Tons)	2,200	4,900	31,700	28,600	33,300	14,200	114,900
PDF Sold (Tons)	0	0	23,700	19,100	32,700	7,400	82,900
CDL Produced (Bbl)	2,600	6,600	28,000	31,700	32,500	14,700	116,100
Hours on Line	314	980	4,300	3,400	3,600	1,944	14,538
Average Length of Runs (Days)	2	8	26	38	44	81	

* *Through May 31, 1997*

Table 1: ENCOAL Plant Performance

Before VFB Installation (1992-1994)

Production/Operations

ENCOAL's first 24-hour run took place in June 1992. After that landmark event, mechanical problems, system debugging and equipment modifications were the primary focus until September 1992, when the ENCOAL Plant achieved a continuous 1-week run. A month later, the first shipment of 60,000 gallons of CDL was sent to TexPar, Inc., which experienced unloading problems. These experiences prepared ENCOAL to work with other customers, such as Dakota Gas, to handle CDL with heat tracing and tank heating coils. Customers reported no further CDL handling problems.

The months following the first production milestone included equipment problems that frequently shut down production. While some delays in the new facility had been expected, numerous runs were stopped while equipment was modified and repaired. To minimize the impact of these delays, tests were performed during each run, and data were aggregated to provide information for ongoing and future changes. Problem areas such as ESP failures, combustor controls and coal slurry handling were gradually resolved, although some difficulties with the sand seals, PLCs, material handling and process blowers remained. April 1993 saw an extremely successful 16-day run, which was continuous except for a 24-hour stoppage when the dryer sand seal failed. All planned tests were completed within the first 7 days; more were drawn up, and over 5,000 tons of raw coal were ultimately processed. A June run processed over 4,000 tons of coal and produced 2,500 barrels of CDL before ending in a planned shutdown.

Although improved in heating value, early batches of PDF revealed a tendency to self ignite. In an attempt to stabilize PDF using in-plant equipment, ENCOAL engineers first tried manipulating the process: speeds on the rotary cooler were varied; and solids flow, temperature and PDF oxidative deactivation were controlled in three separate stages within the rotary cooler. Mechanical equipment failures shortened the runs, but considerable data were collected for further study. Modifications were made to control solids flow and product cooling, but deactivation remained elusive. Early in 1993, it was concluded that a separate, sealed vessel was needed for product deactivation, and a search for a suitable design began immediately. In June 1993, the first of two planned VFBs was installed in series with the original plant equipment. Installation was completed in December 1993, and the entire system was commissioned in mid-January of the next year. See Section 3.5 Equipment Modification for more detail.

The first shipment of ENCOAL's liquid product to TexPar contained more solids and water than had been hoped for, but was considered usable as a lower grade oil. To reduce water content, ductwork and major equipment such as ESPs and the pyrolyzer cyclone were insulated, allowing temperatures throughout the process to remain above the dew point of water. As insulation was completed, CDL contained less water than previous batches, but still had a slightly higher solids content than desired.

After VFB installation (1994-1997)

Production/Operations

The VFB was designed to handle only half the ENCOAL plant's designed capacity; when proven, a second VFB was to be installed. During the test runs, the plant achieved operation at 50% of the design rate, as predicted.

Operations became notably smoother and more productive. This was attributable not only to the VFB's improved stabilization of the PDF and the subsequent increased ease of handling, but also to the replacement of the pyrolyzer sand seal with a water seal and the installation of the process water fines handling system.

All these improvements combined to produce a major landmark when ENCOAL shipped its first train containing PDF on September 17, 1994 to Western Farmers Electric Cooperative in Hugo, Oklahoma. Three runs in the winter of 1994 processed approximately 4,300 tons of coal, producing nearly 2,200 tons of PDF and 81,000 gallons of CDL.

May 1994 saw the best run to date -- 54 days of continuous operation, followed by a 68-day run in the fourth quarter of the year. However, VFB deactivation was not complete: stabilization still involved "finishing" using pile layering as well as blending with run-of-mine (ROM) coal, increased silo retention time and higher rehydration.

Test Burns

Commercialization of PDF from the ENCOAL Plant took a major step forward in 1994. In the fall of that year, ENCOAL shipped six trains to two customers. Shipments made to the first customer, the Western Farmers Electric Cooperative in Hugo, Oklahoma, started at a 15% blend level and ranged up to 30% PDF, the upper level being determined by the heat content limit of the boilers. Shipments to the second customer, Muscatine Power & Water in Muscatine, Iowa, started at 40% PDF and ranged up to 91%. The rail cars in this shipment, the first full unit train of PDF, contained near-100% PDF with a cap of ROM coal to prevent fines losses. The PDF shipped exhibited no handling, dustiness or self-heating problems.

ENCOAL met all its goals for these first shipments: to demonstrate its ability to coordinate with the Buckskin Mine in loading and shipping consistent blends, to ship PDF with dust generation comparable to or less than ROM Buckskin coal, and to ship PDF blends that were stable with respect to self heating. Furthermore, ENCOAL intended to demonstrate that PDF could be transported and delivered to customers using regular commercial equipment. With respect to utilization, the goal was for customers to burn trial amounts (½ unit train minimum) of PDF blends with minimal adjustment of equipment.

ENCOAL's test burn shipments became international when Japan's Electric Power Development Company (EPDC) evaluated 6 metric tons of PDF in 1994. The EPDC, which must approve all fuels being considered for electric power generation in Japan, found PDF acceptable for use in Japanese utility boilers.

Early 1995 saw much increased plant volume when 13,700 tons of raw coal were processed in a 1-month period. Plant availability reached 89%, with downtime attributable to the replacement of the original quench table heat exchanger with a new, high capacity unit. ENCOAL shipped two additional trains to Muscatine and three trains to its third customer, Omaha Public Power District in Omaha, Nebraska. This customer had been burning Powder River Basin coal in a boiler designed for bituminous coal for some time, and the increased heat content of the PDF blends helped increase plant output.

ENCOAL began shipping unit trains of 100% PDF for the first time in 1996. By the end of October, two 100% PDF unit trains were delivered to two separate utilities for test burns. The first was burned in Indiana-Kentucky Electric Cooperative's Clifty Creek Station, which is jointly owned by American Electric Power. The PDF was blended with Ohio high-sulfur coal at the utility and burned in the Babcock & Wilcox open-path, slag-tap boiler with full instrumentation. Blends tested ranged between 70 and 90% PDF, and burn results indicated that even with one pulverizer out of service, the unit capacity was increased significantly relative to the base blend. More importantly, there was at least a 20% NO_x reduction due to a more stable flame.[2] Completion of this test burn achieved a primary project milestone of testing PDF at a major U.S. utility. The remaining 100% PDF unit train was sent to Northern Indiana Power Services Company and to Union Electric's Sioux Plant near St. Louis, Missouri.

Figure 7: PDF Train

By the end of May 31, 1997, 246,900 tons of coal had been processed into 114,900 tons of PDF and 4,875,000 gallons of CDL. Over 83,500 tons of PDF had been shipped to seven customers in six states, as well as 203 tank cars of CDL to eight customers in seven states. Tables 2 and 3 summarize the PDF and CDL shipments for the life of the project. Further detail on PDF and CDL test burns and shipments can be found in early evaluative reports.[3]

DATE LOADED	CUSTOMER	BLEND (%PDF)	TONS SHIPPED			HEAT CONTENT (Btu/lb)
			PDF	COAL	BLEND	
09/17/94	W. Farmers	14.4	922	5,448	6,370	8,760
09/24/94	W. Farmers	21.2	1,080	4,020	5,100	8,910
10/01/94	W. Farmers	25.1	1,508	4,493	6,001	8,940
10/10/94	W. Farmers	31.9	1,603	3,241	5,024	9,310
10/24/94	W. Farmers	24.0	2,665	8,426	11,091	9,060
11/23/94	Muscatine	39.0	1,957	3,122	5,079	9,630
11/29/94	Muscatine	66.6	3,423	1,713	5,136	9,670
12/13/94	Muscatine	90.7	10,576	1,082	11,658	10,000
04/23/95	Muscatine	33.0	3,979	8,094	12,073	9,127
05/05/95	Omaha PPD	24.4	2,711	8,412	11,123	8,940
05/11/95	Omaha PPD	24.0	2,669	8,464	11,133	8,939
05/13/95	Omaha PPD	26.0	2,952	8,398	11,350	8,854
08/16/95	Muscatine	94.0	6,750	434	7,184	9,873
04/25/96	IKEC (AEP)	100.0	9,739	0	9,739	10,682
07/22/96	Union Electric	100.0	11,260	0	11,260	10,450
11/06/96	NIPSCO & Union Electric	100.0	11,700	0	11,700	11,100
12/10/96	Black Hills Corp.	46.7	700	800	1,500	9,158
3/21/97	IKEC (AEP)	53.0	7,356	6,523	13,879	9,486

Table 2: Summary of Trains Shipped Containing PDF *(Through 5/31/97).*

CUSTOMER	# OF CARS	DESTINATION	USE
Dakota Gas	101	Beulah, ND	Industrial Boiler
Texpar	3	Milwaukee, WI	Small Boilers
3 M Company	14	Hutchinson, MN	Industrial Boiler
Kiesel	2	St. Louis, MO	Blend W/ #6 Oil
US Steel	2	Chicago, IL	Steel Mill Blast Furnace
Michigan Marine	18	Detroit, MI	Blend W/ #6 Oil
M&S Petroleum	40	Lake Charles, LA	Fuel Oil Blend
Baka Energy INC.	23	Houston, TX	Fuel Oil Blend

Table 3: Summary Of CDL Tank Car Shipments *(Through 5/31/97)*.

3.2 Data Collection and Reporting

Monthly and Quarterly Technical Progress Reports and Quarterly Environmental Monitoring Reports have been submitted on a regular basis, while other reports were delivered as scheduled. A draft Design Report was submitted in December 1992, and in July 1994, a draft of the updated Project Management Plan for Phase III activities was submitted, along with an Environmental Information Volume Update. A revised Public Design and Construction Report was drafted to include civil design and construction of the project, and was submitted to the DOE in December 1994, along with the final ENCOAL Evaluation Report.

The organizational changes resulting from the move into Phase III and Zeigler's purchase of ENCOAL were reflected in the updated Project Management Plan, which was submitted in final form to the DOE in September of 1996.

Data collection also included compilation of information from all production runs. ENCOAL developed test plans prior to each start-up, and organized the data collected into "run books." These books contained the data sheets, test results and computer trending information for each plant test to be used as reference for future plant project designs or records. The books were also used to create reports on overall plant performance and to create a summary of significant plant operation run data. This proprietary information is kept at the ENCOAL plant site and is available for review on an as-needed basis for those covered by confidentiality agreements.

Plant operation and test data have been collected since the beginning of the operations phase, and Table 1, p.15 summarizes significant run data for Phase III.

3.3 Alternate Coal Testing

Two major goals of the ENCOAL Project involved demonstrating the LFC technology and collecting data applicable to a commercial plant. In support of those goals, ENCOAL demonstrated the processing of Buckskin coal and sought to test a variety of other coals and lignites. Alternate coal testing first took place in November 1995, when 3,280 tons of North Rochelle mine subbituminous coal were processed at the same plant parameters as those for Buckskin coal. The Plant performed well, but non-typical high ash content in the feed coal limited increases in heating value, the fines rate was doubled, and CDL yield was lower than predicted. *(Ash content of the feed coal during the test was approximately 5.6% compared to an expected 4.6% typical of the mine-wide reserve average)*.

A second alternate coal test took place in December 1996, when the ENCOAL Plant processed approximately 3,000 tons of Wyodak coal, and the Black Hills Corporation reciprocated with a test burn of a mixture of PDF fines and ROM coal. Results from the tests will be analyzed and used to determine the viability of a commercial plant sited at the Wyodak Mine. Initial results by both ENCOAL and Black Hills indicated no operability or handling problems.

Alaskan subbituminous coal, North Dakota lignite and Texas lignites were also considered for alternate coal testing. For North Dakota lignite, laboratory testing was carried out in two stages over a 4-year span. In 1992, a blend of two seams of Knife River lignites was tested at the TEK-KOL Development Center, where a three-step evaluation process has been found to be a reliable predictor for the applicability of the LFC process to different coals.

In the first step, the lignite's physical and chemical properties were compared to technical screening criteria -- good agreement suggested success in the next phase of testing.

The second step comprised small-sample testing using a thermogravimetric analyzer, and analysis of the resulting gases with Fourier Transform Infrared (FTIR) spectroscopy. Combining these results with proximate and ultimate analysis data for the as-received coal and the residual char generated a mass balance suitable for preliminary LFC plant design. Successful completion of this step demonstrated the technical feasibility of using the LFC process to upgrade the North Dakota lignite.

The third step employed large-scale sample testing in the Development Center's sample preparation unit, which is equipped with a CDL recovery system and FTIR analytical capability for gas analysis. The unit provided enough CDL and PDF for the detailed product analysis needed to obtain an accurate mass balance, and for product marketing assessments.

In 1996, Freedom Mine and Knife River lignite samples were also strength tested to determine which coals were more suitable for processing. The 1992 tests verified the applicability of the LFC process, while the 1996 strength tests indicated that the lignite would not break down excessively during processing.

Because the laboratory tests of these lignites appeared promising, ENCOAL solicited joint funding from the North Dakota Lignite Research Council for a North Dakota lignite alternate coal test at the ENCOAL Plant. This application was turned down in November 1996, and the test was abandoned. Based upon the successful laboratory screening test, however, ENCOAL believes that North Dakota lignite is an acceptable candidate for LFC processing.

Tables 4 and 5 summarize the PDF and CDL qualities of the alternate coal tests conducted to date, including laboratory data from North Dakota lignite.

PROXIMATE ANALYSIS	**ENCOAL** **Plant Run PDF** *Subbituminous* **(Buckskin Mine)** (1995 Average)	**ENCOAL** **Plant Run PDF** *Subbituminous* **(N. Rochelle Mine)** (11/21/95 - 11/26/95)	**ENCOAL** **Plant Run PDF** *Subbituminous* **(Wyodak Mine)** (12/14/96 - 12/16/96)	*** Laboratory** **Produced PDF** ***N. Dakota*** *Lignite* **(Knife River Mine)** *(Corrected to 8% Moisture)*
Heat Content (Btu/lb)	11,100	11,300	10,900	11,200
Moisture (%)	8.9	8.1	9.3	8.0
Ash (%)	8.9	7.5	9.7	11.3
Volatile Matter	24.5	22.3	25.5	22.5
Fixed Carbon (%)	57.3	61.8	55.0	56.9
Sulfur (%)	0.36	0.30	0.46	1.29
OTHER				
Hardgrove Grindability	47	46	42	51
[#]Sulfur/MMBtu	0.32	0.27	0.42	1.15
[#]SO_2/MMBtu	0.65	0.53	0.84	2.30
Ash Mineral Analysis	Same as Coal	Same as Coal	Same as Coal	Same as Coal
Ash Fusion Temperature	2220°F (1216ºC)	2250°F (1232ºC)	2220°F (1216ºC)	Not Measured

* North Dakota lignite information is based on laboratory data only and should not be directly compared to ENCOAL plant run material data.

Table 4: Average Representative Properties of PDF, Including Alternate Coal Tests

	ENCOAL Plant CDL *Subbituminous* **(Buckskin Mine)** (1995 Average)	**ENCOAL Plant CDL** *Subbituminous* **(N. Rochelle Mine)** (11/21/95 - 11/26/95)	**ENCOAL Plant CDL** *Subbituminous* **(Wyodak Mine)** (12/14/96 - 12/16/96)	*** Laboratory CDL** *N. Dakota Lignite* **(Knife River Mine)**
API Gravity (°)	2.3	3	0	-0.6
Sulfur (%)	0.6	0.3	0.5	0.7
Nitrogen (%)	0.7	1.6	1.1	1.0
Oxygen (%)	10.8	8.0	9.0	13.2
Viscosity @ 122°F (50ºC) cSt	240	350	330	326
Pour Point °F (ºC)	80 (27)	77 (25)	85 (29)	65 (18)
Flash Point °F (ºC)	218 (103)	220 (104)	215 (102)	150 (66)
MBtu/gal	140	138	140	126
Water (wt %)	0.6	0.5	0.7	6.8
Solids (wt %)	2 - 4	3.8	4.2	0.57
Ash (wt %)	0.2 - 0.4	0.6	0.7	0.04
* North Dakota lignite information is based on laboratory data only and should not be directly compared to ENCOAL plant run material data.				

Table 5. Average CDL Quality, Including Alternate Coal Tests

3.4 Administration

ENCOAL's move into Phase III operations was followed by the transition from Shell Mining Company ownership and administration to that of Zeigler Coal. Zeigler became the source of legal and administrative services, as well as providing funding and Project guarantees through Bluegrass and Triton. Other services once furnished by Shell became the province of ENCOAL's sister subsidiaries. Franklin Coal Sales supplies marketing, Americoal provides accounting and purchasing support, and Triton leases the site, provides utilities and services, sells coal to ENCOAL, and handles accounts payable/receivable, purchasing, payroll and general accounting. These organizational changes were reflected in the updated Project Management Plan. See Section 3.2.

One of ENCOAL's primary administrative tasks was tracking progress toward completing milestones. Late in 1994, it became apparent that the project's primary objectives would not be attainable in the time remaining because of delays caused by construction of the PDF deactivation facilities and other plant modifications. An extension request for 2 years' additional operation with joint funding was submitted to the DOE by ENCOAL in

July 1994, together with an Evaluation Report and Extension Plan. The key objectives of the extension period were those necessary to achieve commercialization of the LFC technology: the collection of cost and design data for commercial plants, testing of alternate coals and test burns to support commercial contracts. The DOE granted a 30-day, no-cost extension to October 17, 1994, while the request was being evaluated, and approved the extension in October 1994, expanding their participation to September 17, 1996. After that time, the DOE granted no-cost extensions to complete alternate coal testing and final reporting by July 17, 1997.

Environmental Compliance

An integral component of demonstrating the LFC technology was to operate the plant while complying with environmental regulations, and considerable amounts of administrative time and effort went toward that goal during Phase III.

Air Quality Issues

Late in 1992, ENCOAL staff members met with the WDEQ to discuss the status of plant operation, notification requirements and the status of stack gas monitoring. As a result of this meeting, a letter was sent to the WDEQ confirming the stack gas monitoring schedule and explaining ENCOAL's temporary noncondensable gas venting arrangements installed for the pyrolyzer quench table. The letter, which also discussed the quench table steam condenser tests scheduled for January, was approved in December 1992.

In mid-1993, ENCOAL submitted a permit application for a vapor collection system exhaust on the process water system. The vapor collection system uses a small blower and an activated carbon filter to collect and filter nuisance odors from the existing process water containment areas prior to exhausting the filtered air outside the building. Although a permit was not required by current regulations, it was agreed that a permit would be prudent, and data were collected from plant runs to support a permit application.

Stack Gas Emissions

In October 1995, a third-party testing firm mobilized to perform emission testing necessary to obtain ENCOAL's permit to operate from the WDEQ. The stack and emissions testing using DEQ-approved protocol was successfully completed in November 1995, and indicated that the plant is operating within permitted limits for NO_x, sulfur oxides, carbon monoxide, volatile organic compounds, and particulates. The SO_2 Continuous Emission Rate Monitoring System for the ENCOAL plant stack gas was certified as a result of the testing.

Air Quality Permit

Revisions to the AQ permit, delayed since the beginning of Phase III by interruptions in plant operation, were reviewed by the WDEQ in March 1996, and ENCOAL responded to the Department's questions. In mid-1996, ENCOAL received a notice of completeness for its application for Section 21 AQ permit from the WDEQ. The permit included a 5½-acre laydown area that was not anticipated in the original application. The application proceeded smoothly through the technical review and was formally approved in November 1996.

Land Quality Issues

Permanent Precipitate Storage Reservoir

A permanent storage reservoir was part of ENCOAL's original plan, but because the WDEQ questioned the location of the permanent precipitate disposal pond, an alternative permit application was submitted, modifying an existing mine sediment pond (see Section 1.0 Design and Permitting). Because the temporary pond proved adequate far longer than originally believed, ENCOAL was allowed to defer permitting and construction of the permanent disposal pond until 1995, when geotechnical survey holes were drilled on the preferred site for the permanent precipitate storage reservoir. After core sample testing indicated that soils were acceptable at the construction site, the design for the pond was completed in cooperation with the WDEQ, and the permit application was finalized in June 1995. When the WDEQ determined that public notice would be required, construction was deferred, this time until 1996, and options to extend the life of the temporary pond were again evaluated. After weighing several options, a system designed to improve the evaporation rate was installed. The system included a portable diesel powered pump, floating platform and a nozzle bank to spray the effluent into the air. It was approved by the WDEQ and started up in September 1995.

The WDEQ reviewed the application for revisions to the permanent pond, and ENCOAL responded to WDEQ questions in March 1996. At that time, a bid package for construction of the permanent reservoir was sent to potential contractors. The permit for construction cleared public comment and was sent to WDEQ's head office; final approval for the reservoir was received in June. Reservoir construction began the first week in July and continued through 1996. This reservoir is scheduled to be commissioned for use in July 1997.

Land Farm

Early in 1993, ENCOAL initiated discussions for construction and permitting of an onsite land farm. The land farm, conceived in response to the collection of greater amounts of process water fines than originally anticipated, would biologically eliminate hydrocarbons from process fines prior to onsite disposal. It was intended as a temporary facility, since the ultimate plan is to transfer fines back into the PDF product.

The first step in the development of the land farm was the collection and testing of fines samples and the gathering of information from plant runs. In the fall of 1993, ENCOAL reviewed a preliminary design for the land farm before submission to the WDEQ, and construction began when preliminary approval from the WDEQ was received. Workers completed earthwork and underground piping installations in November 1993, and final piping and commissioning were scheduled for mid-January of the following year. Final approval was received in August 1994.

In the fall of 1995, the LQD of the WDEQ approved a permit for revisions that included a new concrete holding area for wet fines, a higher retaining dike to improve capacity, and provisions for continuous operation with pit disposal of treated fines. Specifications to complete the modifications were developed, and a bid package was issued. Modifications began in July 1996 and were completed 2 months later, and the facility was commissioned in October of the same year.

Intellectual Property Development

Demonstrating and proving the LFC technology required the resolution of a number of challenging problems: lighting burners in combustors with inert atmospheres, removing particulates and gases from process streams and suppressing dust on PDF, among others. Not only were the problems solved, but many of the innovative solutions qualified as patentable technologies. TEK-KOL currently holds patents on flue gas desulfurization, MK dust suppressant, twin-fluid dust collection system, and low-Btu combustion technology, and other patents have been applied for. The DOE has been informed of these inventions as required by the Cooperative Agreement, and Table 6 lists these technologies and their status.

Table 6: TEK-KOL INTELLECTUAL PROPERTY STATUS 3/12/97
DOE PATENT WAIVER ISSUED FOR ALL

No.	Subject of Invention	Inventors	Responsible Person	Filing Date	Estimated Bar Date	Patent Atty. Location	Status
1	U.S. Patent #5,401,364 a process for treating noncaking, noncoking coal to form char with process derived gaseous fuel having a variably controllable calorific heating value.	F. Rinker	F. Rinker	Filed 3/11/93 Name Change CIP 7/94	April 1994	Larry Meenan Toledo, OH	Issue Date: March 28, 1995
2	U.S. Patent #5,372,497 Process and Apparatus for igniting a burner in an Inert atmosphere. Issue Date: December 13, 1994	F. Rinker D. Coolidge	F. Rinker	Filed in Japan 11/29/95	May 1994	Larry Meenan Toledo, OH	Amended 9 Apr 96 Formal examination by Japanese patent office requested. Patent "Pending."
3	Process for passivation of reactive coal char. Russian Patent #96105953/Feb 97	D. Coolidge F. Rinker E. Esztergar D. Horne	F. Rinker	Filed 9/8/95 U.S. Patent office.	May 1995	Larry Meenan Toledo, OH	U.S. awaiting examiner's response to latest amendment filed 5 Dec 96. Filed 8 Apr 96 in Japan Filed 27 March 96 in Russia. Filed 8 May 96 in Uzbekistan. Filed 15 Apr 96 in Kazakhstan. Filed 25 July 96 in Indonesia. Patent "Pending" in U.S., Japan, Uzbekistan, Kazakhstan & Indonesia.
4	U.S. Patent #5,547,548 Pyrolysis Process Water Disposition.	M. Siddoway F. Rinker E. Esztergar	F. Rinker	Filed 7/18/94	May 1995	Ned Randle St. Louis, MO	Issue Date: 20 Aug 96
5	U.S. Patent #5,582,807 Method and apparatus for removing particulate and gaseous pollutants from a gas stream.	M. Siddoway C.F. Liao	F. Rinker	Filed 11/11/94	November 1994	Ned Randle St. Louis, MO	Issue date: Dec 10, 96.
6	Method for creating a hydrocarbon liquid from coal pyrolysis by condensation of the hydrocarbon liquid from the gas phase.	M. Siddoway A. Cover J. O'Donnell C. Chang R. Londrigan J. Frederick E. Manning S. Anderson	F. Rinker	Filed 11/4/94	November 9, 1994	Ned Randle St. Louis, MO	Final rejection received decision made not to pursue with U.S. Patent Office.
7	U.S. Patent #4,582,511 Spray system for MK dust suppression additive. (Issued Apr 15, 1986)	M. Siddoway C.F. Liao	F. Rinker	Filed 7/18/94	May 1995	Ned Randle St. Louis, MO	Original Patent Expires 2003 Decision made to not pursue with US Patent Office.
8	U.S. Patent #5,601,692 Process for treating non-caking coal to form passivated char. Russian Patent #96105954/Feb 97	F. Rinker E. Esztergar D. Coolidge D. Horne	F. Rinker	Filed 12/1/95 U.S. patent office.	April 1996	Larry Meenan Toledo, OH	Issue Date: 11 Feb 97 Filed 12 April 96 in Japan Filed 27 March 96 in Russia. Filed 8 May 96 in Uzbekistan. Filed 15 Apr 96 in Kazakhstan. Filed 25 July 96 in Indonesia. Patent "Pending" in Japan, Uzbekistan, Kazakhstan & Indonesia.
9	Lean Fuel combustion control method.	D. Coolidge T. Kuhn J. Powers F. Rinker	F. Rinker	Filed 10/30/95 U.S. patent office.	September 1995	Ned Randle St. Louis, MO	Formal Examination Requested. Patent "Pending." Status inquiry to examiner has been sent in Nov 96. Second Letter sent Feb 97.

Commercial Plant

As part of its mission to develop data for a commercial plant, ENCOAL began work in March 1995 on a commercial plant cost and economics study. Teams developed a project definition and timeline schedule, and prepared to review plant design, capital costs, operating costs, CDL and PDF marketing, and overall costs and economics of a commercial venture. By April, the heat and material balance for the commercial plant design was completed, and work on material handling, cogeneration concepts, equipment selection and site infrastructure began. CDL upgrading was also studied to determine its feasibility in a commercial plant design, and upgrading studies continued through contracts with Dakota Gas and Kellogg. Mitsubishi Heavy Industries (MHI) became actively involved in August 1995, when ENCOAL delivered an updated heat and material balance, and MHI assisted by performing preliminary engineering and cost estimating for the LFC commercial plant modules. Preliminary subsystem design, equipment data specifications, motor list and flow sheets for dryer/pyrolyzer system were completed in October 1995. One month later, an initial commercial plant design was assembled for a scoping estimate, and an economics model incorporating the capital and operating costs was completed in December.

This body of information was compiled in three detailed Phase II studies completed by the TEK-KOL/MHI team: the Powder River Basin study that focuses on the North Rochelle mine site near Gillette, and two international studies on Indonesian coal mines operated by P.T. Tambang Batubara Bukit Asam (PTBA) and P.T. Berau.

The Powder River Basin Phase II Study, the cumulation of work by ENCOAL, MHI and TEK-KOL, provided the foundation for the decision to commence permitting for a commercial-size plant at the North Rochelle mine site. To that end, schedules for permit applications for air quality, industrial siting, land quality and Forest Service use have been developed and are being followed, and a hearing with the Industrial Siting Division resulted in issuance of an industrial siting permit in February 1997. Stormwater, surface water discharge and groundwater permits must also be obtained from the State of Wyoming, and federal permits, especially a large water storage reservoir permit, must be obtained.[1]

The Indonesian studies were the culmination of over 5 years work promoting the advantages of the LFC process in meeting many of Indonesia's needs. The PTBA study revealed promising economics, and while the P.T. Berau coal was determined to be an excellent LFC process candidate, local issues, including the price of feed coal, will have to be resolved before a commercial LFC plant can be considered for the area. MHI and Mitsui SRC of Japan are working with TEK-KOL on continuing commercialization efforts in Indonesia and other Pacific Rim countries.

To date, three Phase II studies have been completed, and enormous opportunities await in other areas. China, the world's largest producer and consumer of coal, offers particular potential for commercialization of the LFC technology. Regions of China are experiencing rapid economic growth, with the concurrent appetite for electrical power, and the country possesses huge reserves of subbituminous coal and lignites that are promising candidates for LFC processing. These factors, combined with the potential for environmental problems resulting from burning large quantities of coal, especially high-sulfur coal, make China an ideal candidate for the commercial application of the LFC technology. China's Ministry of Coal Industry has expressed keen interest in the LFC technology, and TEK-KOL's representatives continue to cultivate market potential in that country.

Developments in Russia have included the completion of a Phase I study in late 1995, which indicated that the coals tested were suitable for LFC upgrading. Work on a Phase II study is expected to begin this year, pending Russian agreement to proceed. If successful, this Russian endeavor could be the first of many projects in this country with huge potential reserves.

Other international opportunities await in the Pacific Rim, Southeast Asia, India, Pakistan, Eastern Europe and Australia. Mixed results from coal testing and less favorable economics, however, make these areas less promising than Indonesia, China and Russia, but background work will continue in all areas.

Domestically, Alaska, North Dakota, and Texas hold significant potential. The Beluga fields and Healy deposits in Alaska are considered promising locations for commercial LFC plants. Both have extensive reserves that are largely subbituminous and have low ash and sulfur, but both also involve high transportation costs. Laboratory tests of North Dakota coals from the Williston Basin have indicated that LFC processing would yield good quality PDF and CDL (see Section 3.3), and economics appear attractive. Texas lignites have been tested at the TEK-KOL Development Center as well, and some indicate acceptable PDF quality and CDL recoveries. Existing Texas lignite mines are located close to plants designed to burn ROM material, making the export of upgraded lignites into other markets the most likely possibility.

3.5 Equipment Modifications

Because the ENCOAL Plant is a first-of-its-kind operation, some equipment problems were anticipated; unexpected problems like stabilization were deeper and took much more time and effort than expected.

Equipment Shakedown - June 1992 - September 1992

In June 1992, ENCOAL accomplished its first 24-hour run, producing solid and liquid coproducts. Actual production highlighted needed changes in combustor control, conveyors, pump sizes, piping changes and sumps, and many modifications were made in the first 4 to 6 months of production.

Equipment Design Modifications - September 1992 - June 1993

As production runs lengthened, different problems emerged. Insulators on the ESPs proved to be unreliable, and 1 year after production began, all three had been redesigned with new insulator materials. Pyrolyzer and dryer sand seal problems surfaced late in 1992 as run intervals expanded. Seal design and materials were adjusted many times, but by August 1993, the sand seal in the pyrolyzer had been replaced with a water seal, and eventually, a water seal had replaced the sand seal in the dryer as well. A number of variations on the rotary cooler were tried in attempts to deactivate PDF using existing equipment. When this proved ineffective, the plant was shut down for the installation of the VFB system.

Process Modifications and Optimization - June 1993 - February 1997

A number of plant runs and extensive testing in 1992 and 1993 indicated that a separate, sealed vessel would be needed to deactivate PDF. After considerable study involving ENCOAL, SGI and the Development Center, a vibrating fluidized bed was selected, and the ENCOAL Plant was shut down in June for a 6-month installation period.

Between June and December 1993, the first of two planned 6' x 30' VFBs and support equipment were installed in series with the original plant equipment. The unit was designed to handle half the plant throughput; when it had proven itself, a second VFB could be installed. A process water fines handling system was also installed in 1993 to remove solids and cool the process water stream prior to recirculation. VFB construction and start-up were completed in January 1994, and the unit is still in operation.

By spring of 1994, production runs were considerably smoother and longer, achieving continuous runs of 54 and 68 days by mid-year. Although more than 20 different operating conditions were varied and evaluated during these runs, deactivation still required "finishing" using pile layering before being shipped. Blending with ROM coal, increased silo retention time and higher rehydration also contributed to stabilization.

Extensive study of run data and bench model tests indicated that more oxygen was needed to achieve deactivation. Better oxygen control and subsequent increased concentration of oxygen in the deactivation loop were planned for future test runs, along with stringent control on solids temperatures in the VFB. The decision also was made to "finish" the oxidative deactivation of the solids by laying the PDF on the ground outside the plant. This process, which came to be known as "pile layering," involved spreading the PDF in 12-inch thick layers, allowing PDF particles to react with oxygen in the air and become stable. As each thickness was stabilized, more PDF could be layered.

In-plant stabilization of PDF, however, still eluded the ENCOAL and SGI team. A "cascade oxidative deactivation" (COD) approach was studied extensively at the Development Center and tested in MHI's pot test unit in Hiroshima, Japan. The system involved exposing reactive PDF to a series of controlled temperature and oxygen gas streams, with each successive step being lower in temperature and higher in oxygen content.

In April 1995, a "stability task force" composed of ENCOAL and SGI representatives and selected consultants joined to develop an acceptable in-plant stabilization method and test it in the ENCOAL Plant. The chosen method would be developed in parallel with the ongoing COD work. The task force met with engineers and scientists from the Pittsburgh Energy Technology Center (PETC) and the Morgantown Energy Technology Center (METC) to identify areas where assistance was needed in solving stability problems. As a result of the meeting, a Cooperative Research and Development Agreement (CRADA), a separate, research-oriented accord with PETC, was developed, and a project combining the applied research efforts of ENCOAL, Western Syncoal, PETC and METC was formed. These entities would develop measurement methods, define reaction kinetics and mechanics, and evaluate new stabilization techniques. A Bureau of Mines test, nicknamed "Jar-O-R," was modified to measure product reactivity and is still used to measure the oxygen appetite of upgraded Powder River Basin coal.

By July 1995, the stabilization task force, working with the resources represented by the CRADA, performed successful bench scale tests for oxidizing PDF at low temperatures, and work began in fabricating a pilot-scale stabilization unit. At the same time, the COD unit was dismissed as a possible solution to stabilization problems, and investigations into using spray-on additives were concluded. At this time, the CRADA completed its contributions to stabilization research.

Design and installation of the Pilot Air Stabilization System (PASS) was completed in November 1995, and the unit operated from late November through January of the next year. PASS testing was successful: the PASS unit processed ½ to 1 ton of solids per hour, 24 hours a day, for 2½ months. Even more important, PDF was formed for the first time into stable, uncompacted piles without ground stabilization techniques. *(See Figure 7: Uncompacted PDF piles)*. The data obtained were used to develop specifications and design requirements for a full-scale, in-plant PDF finishing unit. As part of the commercialization effort, these same data were then scaled up for application to a larger plant. Financial restrictions have delayed the fabrication and installation of the full-scale unit, but ENCOAL will continue to seek funding for this project. Work on stabilization continues although it is now outside the scope of DOE involvement.

Figure 8: Uncompacted PDF Piles.

CDL Upgrading

The high point of the runs following the VFB installation was the production of better quality CDL. The pour point ranged from 75° to 95°F, and the flash point averaged 230°F, both within the proper range. Water content was down to 1 - 2%, and solids content was 2 - 4% -- improvements attributable to lower pyrolysis temperatures and higher pyrolysis gas flow rates -- both achievable because of a new pyrolyzer water seal. During the first 3 months of 1994, six tank cars were shipped to Dakota Gasification where CDL was blended with their fuel and burned for process heat. During the last quarter of the same year, ENCOAL started compatibility and CDL characterization studies to expand future markets.

Figure 9: Loading CDL Rail Cars

In June 1995, Dakota Gas completed a thorough characterization of CDL, and a kickoff meeting was held with Kellogg to initiate technical feasibility studies for various upgrading processes. A market evaluation indicated the need to upgrade CDL to reach markets other than heavy fuel oil, and Kellogg moved into developing a design and cost estimate for an in-plant CDL upgrading process to produce cresylic acids, petroleum refinery feed stock, oxygenated liquid and pitch. A pilot-size quench tower was acquired in early 1996, and testing was initiated to test the two-stage condensation step of the upgrading process. ENCOAL staff members held discussions with potential consumers of the fractions to learn more about CDL characteristics that would improve quality and marketability.

By the third quarter of 1996, the two-stage quench column pilot was installed and started up. The pilot unit was designed to produce small amounts of CDL separated roughly into two cuts: one with an initial boiling point below 500°F, and another with a boiling point above 500°F. By November 1996, it was decided that the desired product separation could not be proven utilizing the Kellogg design. Communications with potential cresylic acid and pitch customers continued, with customers specifying desired improvements in CDL quality, particularly sediment removal.

After the two-stage quench column project was concluded, ENCOAL engineers tested the effectiveness of a small centrifuge in removing sediment. The centrifuge successfully removed 90% of the solids in the parent CDL. Because ENCOAL believes solids removal to be a key factor in the success of any CDL sales plan, a larger second centrifuge will be extensively tested in March 1997, along with efforts to recover and agglomerate the CDL solids with dryer or pyrolyzer cyclone fines.

Work on CDL upgrading continues: an energy industry consulting firm was contracted to review literature on coal liquids upgrading, perform economic evaluations and make recommendations, and a number of laboratories are currently evaluating raw CDL, as well as pitch and cresylic acid samples. The TEK-KOL Development Center will be performing hydrogenation testing in 1997 as part of continuing investigations into upgrading CDL.

In early 1997, ENCOAL began evaluating laboratories to test the applicability of conventional petroleum processing techniques to CDL. A contract for petroleum testing was awarded to one laboratory, which will attempt to prove that CDL can be refined to produce competitively priced transportation fuels.

Significant modifications are summarized in the table below and are discussed in the ENCOAL Mild Coal Gasification Project Final Design Report.[4]

AREA OF PLANT	DEFINITION OF PROBLEM	SOLUTION
Electrostatic Precipitators	Insulator Failures	Modified Insulators, Improved Temperature Control
Material Handling	Plugging and Spillage	Modified S-belts & Chutes
PDF Quenching and Steam Condenser	Oil and Coal Dust, Too Small	Added Scrubber, Added 2 Larger Exchangers
Dryer and Pyrolyzer	Sand Seal Failures	Replaced With Water Seals
Combustors	Unstable Operation	Revised Control System
Pumps and Blowers	Sizing Problems, Mostly Too Small	Replaced With Larger Equipment
Changing Process Variables	Initial Plant Design Parameters Were Off	Adjusted Operating Set Points
PDF Dust Collection	Dusty Conditions On Product Side of Plant - No Scrubbers	Added Two Wet Scrubbers
PDF Deactivation	Could Not Produce Stable PDF In Original Equipment	Added VFB Deactivation Loop Equipment; Utilized Layered Laydown Techniques; Pilot Tested PDF Finishing
Process Water System	Accumulation Of Oily Fines In Process Equipment	Installed Clarifier, Floc & Vacuum Filter
Cyclone Fines Handling	Loss Of Excessive Amounts Of PDF In Cyclone Fines, Labor Intensive Clean-up	Recovered VFB Deactivation Fines Into PDF Product, Reduced Handling System
VFB Drag Conveyors	Excessive Wear and Maintenance Intensive	Redesigned High Wear Points, Modified Discharges To Reduce Plugging
Plant Operability And Maintenance	Difficult Access, Labor Intensive Clean-up, Inflexible To Operate	Piping Revisions, Access Platforms And Doors, Relocate Valves

Table 7. Summary Of Plant Modifications

TECHNICAL IMPACTS ON SCHEDULE AND MILESTONES

A great number of refinements to the process design and to the function of some process equipment have been effected to produce the highest quality products and improve plant operability. These, especially efforts to stabilize PDF, strongly influenced scheduling and milestones. Numerous attempts were made to stabilize the solid product using in-plant equipment, and when these did not accomplish the task, the VFB was installed during a 6-month hiatus in production. Other delays were incurred when sand seals were replaced with water seals. Construction and testing of the PASS unit was also not in the original plant design and impacted ENCOAL's production schedule.

Because of careful planning, however, much was accomplished during these shutdowns, including training, normal maintenance, and repair activities. Comprehensive operator education in such topics as respirator training, ambient gas monitoring, boiler operations and pyrolyzer dynamics contributed to operators' knowledge and safety.

As the project has neared its close, budget restrictions have affected the schedule as well. The in-plant PDF finishing unit has been placed on indefinite hold and remains subject to available funding. Work on CDL upgrading has continued, and alternative processes for upgrading are being evaluated. Technical and economic feasibility, and market acceptability are important factors that will determine which CDL upgrading scheme is most applicable. The in-plant finishing, deactivation unit testing and CDL upgrading complete the last of the major technical issues.

CONCLUSIONS AND LOOK AHEAD

The goals set for the ENCOAL Project have not only been met, but exceeded. Seventeen unit trains and one truck shipment of PDF have been shipped and successfully burned at seven utilities. PDF has been tested as a reductant (combined with iron ore) in the DRI process, and holds promise as a blast furnace injectant. The LFC process has been demonstrated and improved, both through operational refinements and equipment modifications. Almost 5 years of operating data have been collected for use as a basis for the evaluation and design of a commercial plant. The ENCOAL Project has demonstrated for the first time the integrated operation of several unique process steps:

- Coal drying on a rotary grate using convective heating
- Coal devolatization on a rotary grate using convective heating
- Hot particulate removal with cyclones
- Integral solids cooling and deactivation/passivation
- Combustors operating on low Btu gas from internal streams
- Solids stabilization for storage and shipment
- Computer control and optimization of mild coal gasification process
- Dust suppressant on PDF Solids

The product fuels have been used economically in commercial boilers and furnaces and have reduced sulfur and NO_x emissions significantly at utility and industrial facilities currently burning high sulfur bituminous coal or fuel oils.

Although major DOE objectives have been reached, some issues remain for resolution before a commercial plant project can be completed. As work proceeded in applying the technology from the ENCOAL Plant to a commercial plant, it was determined that a replacement for the VFB, the first stage in PDF deactivation, would have to be found. The VFB operating in the ENCOAL Plant is the largest such unit that is commercially available; scaling up to a plant approximately five times larger would require much larger equipment, or the installation of multiple VFBs. A possible alternative is a Salem grate, a concept which was tested using a slipstream deactivation unit. Further testing will need to be completed before optimal commercial plant design for PDF deactivation can be decided. Additional funding will also enable ENCOAL to install an in-plant finisher that will substantiate the large-scale testing of PDF finishing, the second stage of stabilization. CDL upgrading efforts will continue.

A large-scale commercial plant, the long-term goal of the ENCOAL Project, should move toward implementation at the North Rochelle Mine site. An Industrial Siting Permit has already been issued, and the WDEQ-AQD is expected to issue an Air Quality Construction Permit in July 1997. Other regulatory approvals must be received before construction and start-up of the commercial plant: a groundwater well permit, a WDEQ-LQD mining permit, WDEQ-WQD's stormwater permit, a National Pollutant Discharge Elimination System permit, approval from the U.S. Forest Service for use of the proposed plant site land, and MSHA's permit for large water impoundments. As investment participants commit to the project, permitting will continue, and detailed design, procurement and construction will commence.

The ENCOAL Demonstration Plant will continue to test the viability of alternate commercial-scale equipment, deliver additional test burn quantities of products, train operators for the commercial plant and provide additional design and economic data for the commercial plant.

Efforts to license the technology will proceed under the auspices of TEK-KOL, both domestically and internationally.

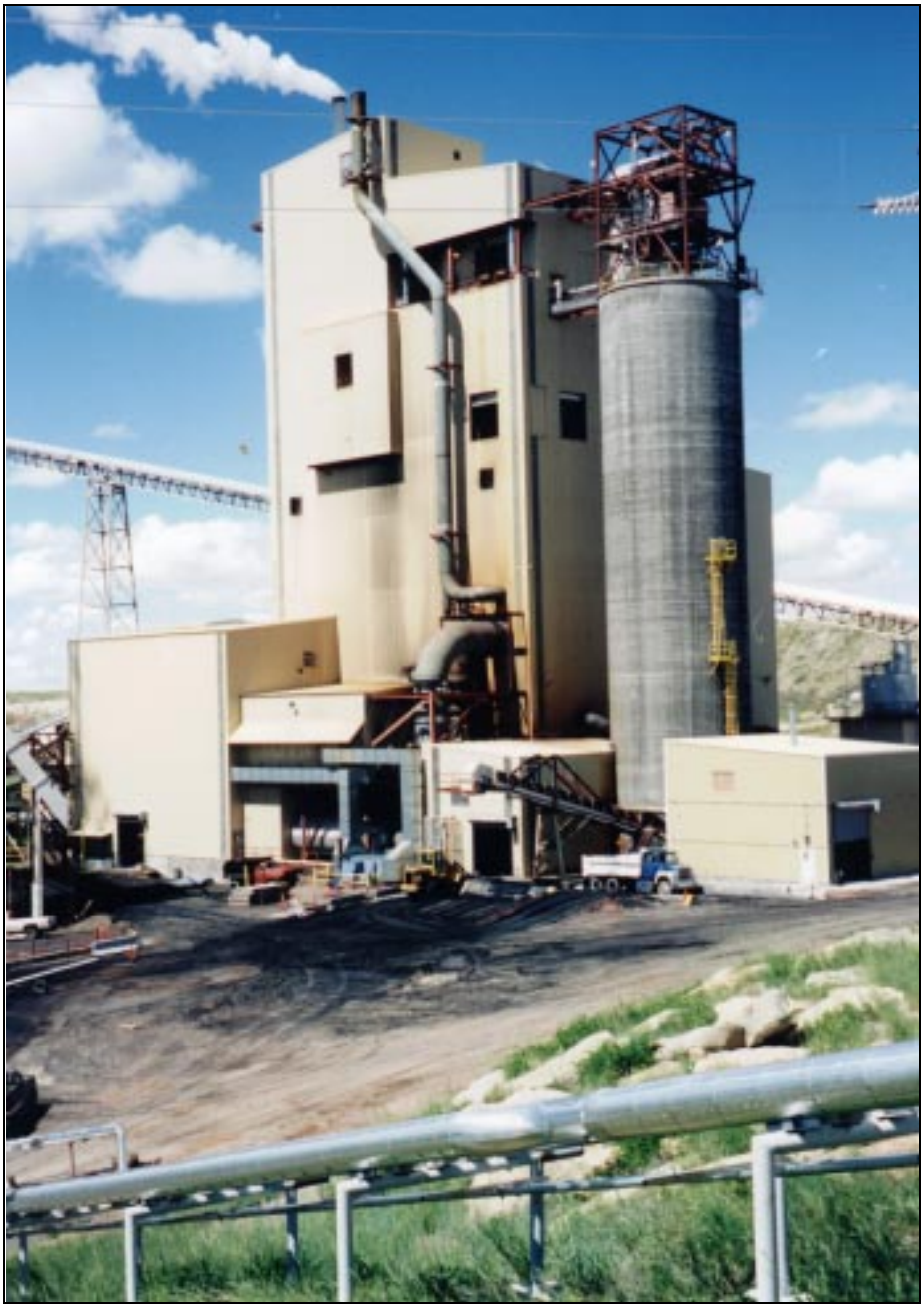


Figure 10: ENCOAL Mild Coal Gasification Plant

REFERENCES

1. "ENCOAL Mild Coal Gasification Plant: Commercial Plant Feasibility Study," U.S. Department of Energy Report, July 1997.

2. S.A. Johnson, B.A. Knottnerus, "Results of the PDF Test Burn at Clifty Creek Station," U.S. Department of Energy Topical Report No. DOE/MC/27339-5310, October 1996.

3. "The ENCOAL Project: Initial Commercial Shipment and Utilization of Both Solid and Liquid Products; Topical Report, Report No. DOE/MC/27339-4088. ENCOAL Corporation, March 1995.

4. "ENCOAL Mild Coal Gasification Project Final Design Report, June 1992 - February 1997," U.S. Department of Energy Report, July 1997.

BIBLIOGRAPHY

"Role of the Liquids From Coal Process in the World Energy Picture." J.P. Frederick and B.A. Knottnerus. Fifth Annual Clean Coal Technology Conference. January 7-10, 1997. Tampa, FL.

S.A. Johnson, B.A. Knottnerus, "Results of the PDF TEST Burn at Clifty Creek Station," U.S. Department of Energy Topical Report. October 1996.

"PRB Technology Developments - The ENCOAL Project." J.P. Frederick. Western Coal Council 1996 Spring Meeting. May 14-16. Gillette, WY.

"The ENCOAL Project - A Progress Report." J.P. Frederick. The Rocky Mountain Coal Mining Institute. May 3-4, 1996. Gillette, WY.

"Clean Coal Reference Plants: Pulverized ENCOAL PDF Fired Boiler." Gilbert Commonwealth, Inc. G/C Report No. 3010. December 1995. U.S. Department of Energy, Morgantown, WV.

Keynote Address. Chand B. Vyas. Pacific Rim Coal Conference. June 14, 1995.

"Upgraded Low Rank Coal - Technology and Fuel Utilization - The ENCOAL Project." J.P. Frederick and T.G. McCord, Upgraded Coal Interest Group. May 2-3, 1995 Meeting. Cleveland, OH.

"The ENCOAL Project: Initial Commercial Shipment and Utilization of Both Solid and Liquid Products; Topical Report, Report No. DOE/MC/27339-4088. ENCOAL Corporation. March 1995.

"The ENCOAL Project - Progress Report." J.P. Frederick. Western Coal Transportation Association. Twentieth Annual Meeting & Conference. September 12-14, 1994.

ENCOAL Mild Coal Gasification Demonstration Project; Annual Report. October 1993-September 1994. Report No. DOE/MC/27339-4064. ENCOAL Corporation. March 1995.

ENCOAL Mild Coal Gasification Demonstration Project Public Design and Construction Report. Report No. DOE/MC/27339-4065. ENCOAL Corporation. December 1994.

"The Liquids from Coal Process." J.C. Castro, D.A. Horne, R.E. Nickell, and J. Russ.
Proceedings: Production and Utilization of Ecological Fuels from East Central European Coals Workshop, pp. 97-113. October 31-November 1, 1994. Prague, Czech Republic.

ENCOAL Mild Coal Gasification Project; Annual Report. Report No. DOE/MC/273390-3842. ENCOAL Corporation. October 1993.

BIBLIOGRAPHY Continued

"Upgrading Low-Rank Coals Using the Liquids from Coal (LFC) Process." R.E. Nickell. Presented by S.A. van Hoften, Clean Coal Technology Technical Seminar, Asia Pacific Economic Corporation. September 8-9, 1993. Chiang Mai, Thailand.

"Low Grade Coal Upgrading: Application of Liquids from Coal (LFC) Technology to Low Grade Coals in the Pacific Rim." J.C. Castro, D.A. Horne, R.E. Nickell, S.A. van Hoften. IEA Second International Conference on the Clean and Efficient Use of Coal and Lignite: Its Role in Energy Environment and Life. November 30-December 3, 1993. Hong Kong.

"The Added Value of Upgrading Coal." R.E. Nickell. The World Coal Trade Conference COALTRANS 93. October 18-20, 1993. Amsterdam, The Netherlands.

"Refining the Art of Coal Upgrading." R.E. Nickell. World Coal, pp. 28-35. October 1993.
.
ENCOAL Mild Coal Gasification Project; Annual Report. October 1990 - September 1991. Report No. DOE/MC/27339-3087. ENCOAL Corporation. February 1992.

“Clean Coal Technology Program." J.P.Frederick. Wyoming Mining Association Teacher Workshop. June 2, 1992. Casper, WY.

"Start-Up of the ENCOAL Plant." J.P. Frederick. Western Coal Workshop sponsored by The University of Wyoming. May 1992. Gillette, WY.

"Current Status of Design and Construction of ENCOAL Mild Gasification Plant." J.P. Frederick, M.A. Siddoway, D.W. Coolidge. Eleventh Annual METC Gasification and Gas Stream Cleanup Systems Contractors Review Meeting. September 1991. Morgantown, WV.

"The ENCOAL Project." J.P. Frederick. Western Coal Workshop sponsored by The University of Wyoming. May 30, 1991. Gillette, WY.

"ENCOAL Mild Gasification Demonstration Project: Preliminary Plans." J.P. Frederick, M.A. Siddoway. Tenth Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting. August 1990. Morgantown, WV.

Comprehensive Report to Congress on the Clean Coal Technology Program: ENCOAL Mild Coal Gasification Project. ENCOAL Corporation. Report No. DOE/FE-0194P. U.S. Department of Energy. June 1990.

GLOSSARY

ASME	American Society of Mechanical Engineers
BS&W	Basic Sediment & Water
Btu	British Thermal Units
CDL	Coal Derived Liquid
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
ENCOAL	ENCOAL Corporation, wholly-owned subsidiary of Bluegrass Coal Development Company
ESP	Electrostatic Precipitators
^0F	Degrees Fahrenheit
ft.	Feet
ft.^{2}	Square Feet
HP	Horsepower
H_2O	Water
H_2S	Hydrogen Sulfide
in.	Inches
Kellogg	The M. W. Kellogg Company
lb/hr	Pounds per Hour
LFC Technology	Liquid From Coal Technology
MM Btu/hr	Million British Thermal Units per Hour
Max	Maximum
MSHA	Mine Safety and Health Administration
NO_X	Nitrogen Oxides
O_2	Oxygen
PDF	Process Derived Fuel
PLC	Programmable Logic Controller
%	Percent
pH	Measure of alkalinity and acidity on a scale of 0 to 14
psia	Pounds per Square Inch Absolute
psig	Pounds per Square Inch Gauge
RPM	Rotations per Minute
SMC	SMC Mining Company, renamed Bluegrass Coal Development Company, wholly owned subsidiary of Zeigler Coal Holding Company
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
turnkey	Subcontracting method that includes design, furnishing and installation responsibility
vol	Volume