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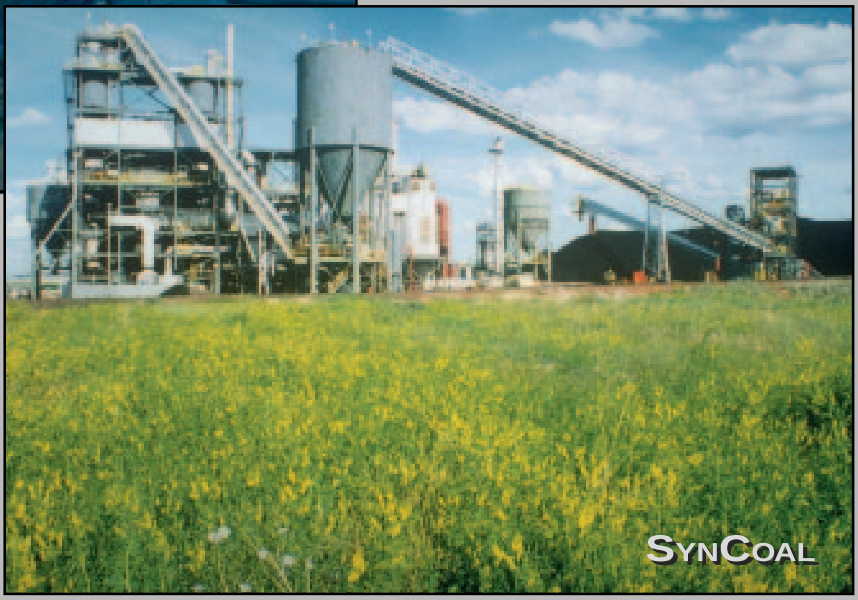
CLEAN COAL TECHNOLOGY



Upgrading of Low-Rank Coals

Upgrading of Low-Rank Coals

A report on projects conducted under separate cooperative agreements between:

The U.S. Department of Energy and
- ENCOAL Corporation
- Rosebud SynCoal Partnership

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CLEAN COAL TECHNOLOGY

Upgrading of Low-Rank Coals

Cover images: (upper left) The ENCOAL demonstration site near Gillette, Wyoming, and (lower right) the SynCoal demonstration site near Colstrip, Montana.

Introduction and Executive Summary

The Clean Coal Technology (CCT) Demonstration Program is 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/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, beginning in 1985 a multi-phased effort consisting of five separate solicitations was administered by the U.S. Department of Energy (DOE). 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.

This report discusses 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 very 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. To overcome these problems, two upgrading processes have been developed under the CCT Program: ENCOAL's Liquids From Coal (LFC®) process and Rosebud SynCoal Partnership's Advanced Coal Conversion Process (ACCP).

These projects have been administered for DOE by its Federal Energy Technology Center (FETC).

The LFC process involves mild gasification to produce a dry, solid fuel and a liquid hydrocarbon fuel. The process has been demonstrated for about five 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. A design and cost estimate have been prepared for a commercial plant processing 6,000,000 tons/yr of raw coal at Triton Coal Company's North Rochelle mine.

The ACCP involves thermal upgrading with hot combustion gas, followed by physical cleaning to separate ash. The process has been demonstrated at a test facility near Colstrip, Montana, which also has operated for about five years. Rated at 1,500 tons/day of coal feed, this plant has processed nearly 1.6 million tons of raw coal, yielding over 1 million tons of product coal. A design has been prepared for a commercial facility to produce 400,000 tons/yr of SynCoal to feed Minnkota's Milton R. Young power plant at Center, North Dakota.

Both projects have met their goals of successfully demonstrating the upgrading of low-rank coals to significantly reduce moisture and hence improve heating value. In common with other processes for removing moisture from low-rank coals, problems with product stability have been encountered. These problems include reabsorption of moisture, formation of dust, and spontaneous combustion. Solutions to these problems have been developed to meet market requirements for handling of the products.

Upgrading of Low-Rank Coals

Background

Regulatory Requirements

The Clean Coal Technology (CCT) Demonstration Program, which is sponsored by the U.S. Department of Energy (DOE), is a government and industry co-funded technology development effort conducted since 1985 to demonstrate a new generation of innovative coal utilization processes. In a parallel effort, the U.S. Environmental Protection Agency (EPA) has promulgated new regulations, authorized by the 1990 Clean Air Act Amendments (CAAA), concerning emissions from a variety of stationary sources, including coal-burning power plants.

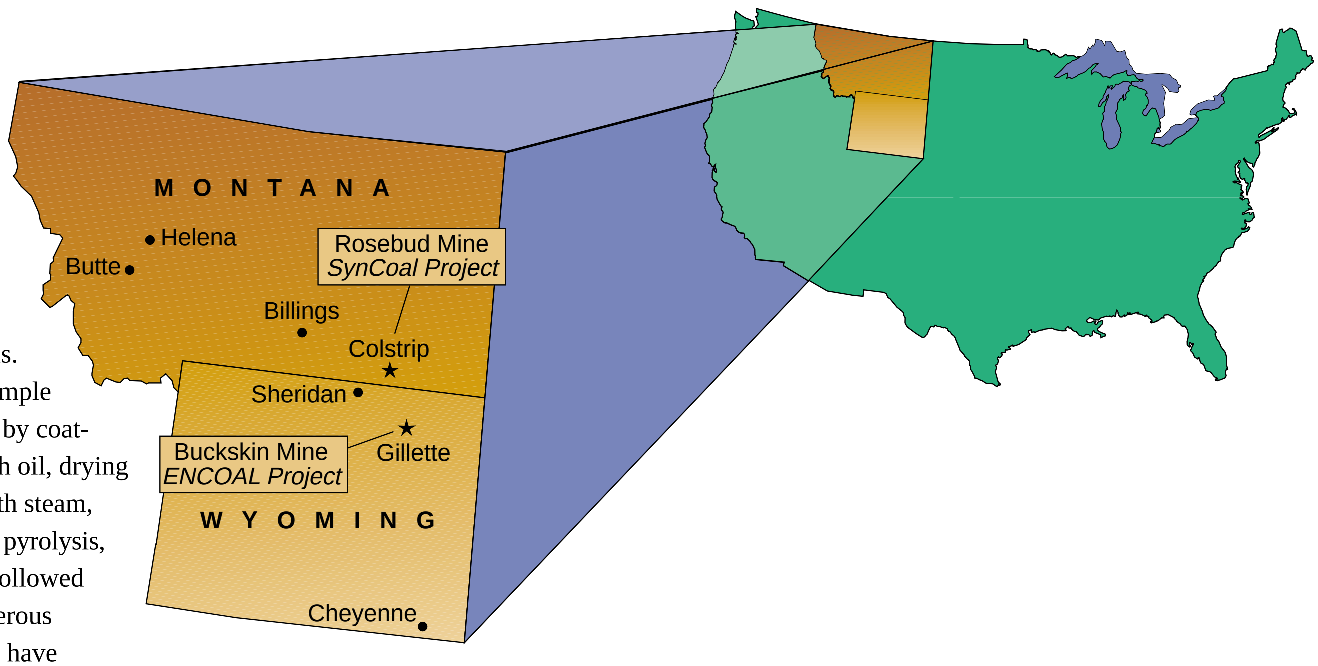
One of the major objectives of the CCT Program is to develop technologies for reducing emissions of sulfur dioxide (SO_2), which is one of the primary contributors to acid rain. SO_2 is formed through the combustion of sulfur contained in coal. Burning typical medium- and high-sulfur coals produces SO_2 emissions that exceed the allowable limits under the CAAA. The major options available to utilities to comply with the regulations consist of (1) pre-combustion removal of sulfur, (2) in-situ removal of SO_2, (3) post-combustion removal of SO_2, (4) switching to lower sulfur coals, and (5) purchasing SO_2 emissions allowances.

One popular choice for utilities has been to purchase low-sulfur coals. In the United States, a major source of low-sulfur fuel is western subbituminous coal, of which Powder River Basin coal from Montana and Wyoming is a prime example. Western lignites are also a source of low-sulfur fuel. However, while these coals are low in sulfur, they are also low-rank fuels having high moisture content and low heating value. Low-rank western coals often contain from 20 to 40% moisture.

Problems with Burning Low-Sulfur Coals

Power plants switching to low-rank coals frequently experience derating since they are not designed to accommodate the higher volumes of coal required to supply the same amount of heat. Another drawback is the added cost of transporting high-moisture content fuel from the mine to the point of use. Drying low-rank coals prior to shipment would be desirable but there are three attendant difficulties: (1) dried low-rank coals frequently reabsorb moisture, (2) drying leads to the formation of dust or fines, and (3) drying increases the natural spontaneous combustion tendency of low-rank coals.

Thus there has been significant interest in developing processes to upgrade low-rank coals to take advantage of their low sulfur content while avoiding problems associated with their handling, transportation, and use as boiler fuels. A number of approaches have been investigated in an effort to reduce the moisture content



of low-rank coals. These include simple drying followed by coating the solid with oil, drying in oil, drying with steam, low-temperature pyrolysis, and pelletizing followed by drying. Numerous other techniques have been proposed.

This report describes two CCT projects directed toward upgrading of low-rank coals: the ENCOAL project and the Rosebud SynCoal® project. Both projects involve conversion to higher value fuels with reduced moisture and increased heating value via the use of hot gas to dry the coal. These processes use two different approaches. ENCOAL uses a multiple-step, high-temperature process to produce two fuels, one solid and one liquid, followed by treatment to decrease particle reactivity and reduce the tendency to self heat. SynCoal uses a two-step process to heat the coal, followed by staged cooling and ash removal to produce a low-moisture, low-sulfur product.

Both of these projects have successfully demonstrated the respective technologies.

ENCOAL

Project Description

Project Participant

The ENCOAL Liquids From Coal (LFC®) process being demonstrated in Wyoming was developed by SMC Mining Company and SGI International (SGI) of La Jolla, California. The process, which incorporates mild coal gasification, upgrades low-sulfur, low-rank western coals to two new fuels, Process Derived Fuel (PDF™) and Coal Derived Liquid (CDL™).

The project was funded in part by the DOE under Round III of the CCT Program. 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 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 this CCT demonstration plant near Gillette, Wyoming for almost 5 years. The ENCOAL facility, having a coal feed capacity of 1,000 tons/day, is operated at the Buckskin mine, which is owned by Triton Coal Company, another Zeigler subsidiary, and supplies the feed coal for the project.

ENCOAL, as the owner, manager and operator of the demonstration plant, has been responsible for all aspects of the project, including design, permitting, construction, operation, data collection and reporting. The M.W. Kellogg Company was the engineering contractor for the project.

Coal processed in the ENCOAL plant

LFC Process Description

Powder River Basin coals normally have moisture contents of 25–32%, with heating value ranging from 8,200 Btu/lb to 9,200 Btu/lb. The LFC process first dries the mined coal to very nearly zero moisture. The dried coal is mildly pyrolyzed under carefully controlled conditions, and about 60% of the original volatile matter and a portion of the sulfur are removed. These two steps alter the basic coal characteristics both physically and chemically, helping to eliminate many of the problems associated with coal drying. The coal char is then treated in a multiple-step process adding moisture and oxygen, followed by cooling to produce PDF.

Volatile matter driven off during the pyrolysis is partially condensed in a multiple-step process that produces the hydrocarbon CDL. The noncondensed or collected hydrocarbon is returned to the process combustors as a heat source for the drying and pyrolysis steps. Each ton of raw North Rochelle coal produces approximately $^1/_2$ ton of PDF and $^1/_2$ barrel of CDL.

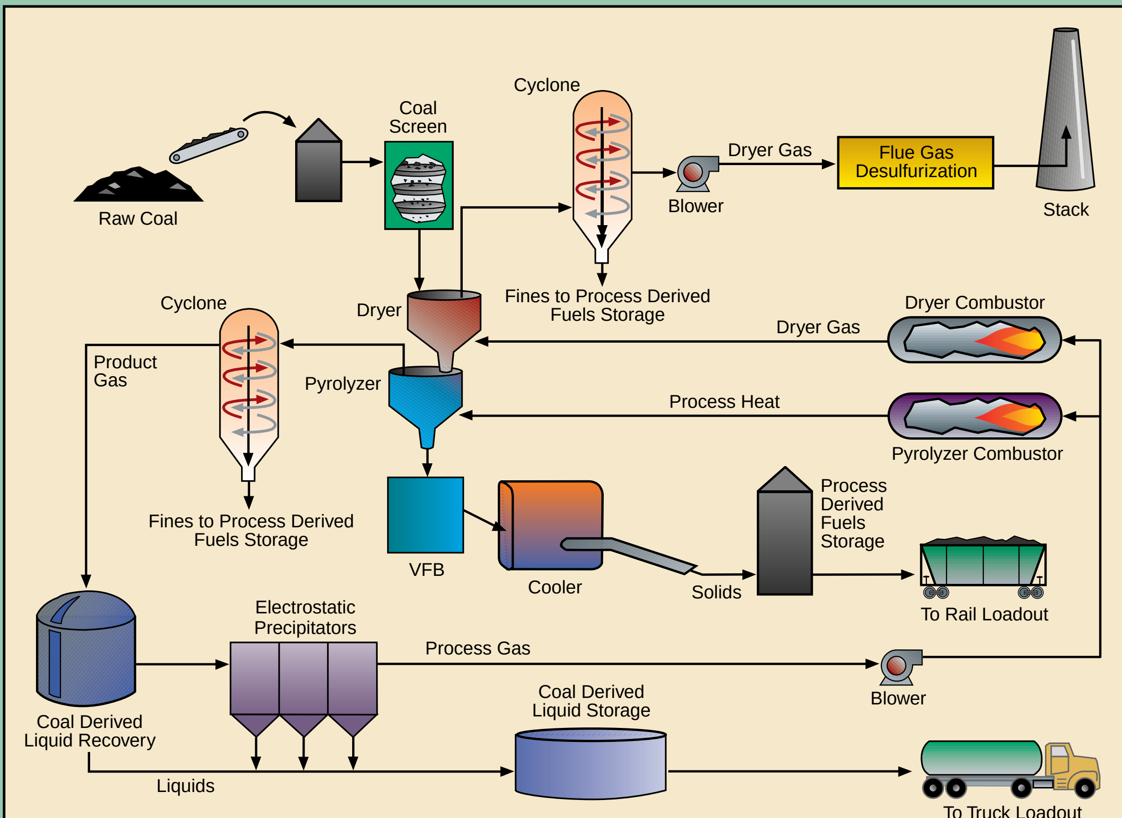
In the ENCOAL demonstration plant, run-of-mine (ROM) coal is conveyed from existing Buckskin mine storage silos to a 3,000-ton feed silo. Up to 1,000 tons/day of coal from this feed silo are continuously fed onto a conveyor belt by a vibrating feeder, crushed and screened to 2″ x $^1/_8$″, and fed into a rotary grate dryer where it is heated by hot gas. 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 are fed to the pyrolyzer rotary grate, where a hot recycle gas stream raises the temperature to about 1,000°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 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 a quench table to stop the pyrolysis reactions.

The quench table solids are further deactivated in a vibrating fluidized-bed reactor, or VFB, where they are partially fluidized and exposed to a gas stream in which temperature and oxygen content are carefully controlled. A reaction, termed oxidative deactivation, occurs at active sites in the particles, reducing the tendency to spontaneously ignite. The heat generated by this reaction is absorbed by the fluidizing gas stream. 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.

After treatment in the VFB, the solids are cooled to near ambient temperature in an indirect rotary cooler. A controlled is purchased from Triton, which also provides labor and administrative services, access to the site, associated facilities, and infrastructure vital to the project. Additional technical development support is provided by TEK-KOL, a partnership between SGI and a subsidiary of Zeigler that also has the primary responsibility for marketing and licensing the technology. All assets are assigned to ENCOAL, while all technology rights are held by TEK-KOL and licensed to ENCOAL. DOE has contributed about $45 million (50%) of the $91 million demonstration project, with the remainder provided by ENCOAL.

amount of water is added in the cooler to rehydrate the PDF to near its 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 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 from which it is shipped by rail through existing Buckskin loadout facilities.



LFC process flow diagram.

The pyrolysis gas stream is sent through a cyclone to remove entrained particles and then cooled in a quench tower to condense the desired hydrocarbons and to stop any secondary reactions. Only the CDL is condensed; the condensation of water is avoided. Electrostatic precipitators (ESPs) recover any remaining liquid droplets and mists from the gas leaving the condensation unit.

About half of the residual gas from the condensation unit is recycled directly to the pyrolyzer, while some is burned in the pyrolyzer combustor before being blended with the recycled gas to provide heat for the pyrolyzer. The remaining gas is burned in the dryer combustor, converting sulfur compounds to sulfur oxides. Nitrogen oxides (NO_x) emissions are controlled by appropriate design of the combustor. The hot flue gas from the dryer combustor is blended with the recycle gas from the dryer to provide the heat and gas flow necessary for drying.

The exhaust gas from the dryer loop is treated 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 is discharged into a clay-lined pond for evaporation.

Testing of ENCOAL Coal Derived Liquid samples.

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. 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.

Product Characteristics

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. These alternative fuel sources were intended to significantly lower current sulfur emissions at industrial and utility boiler sites and reduce pollutants that are acid rain precursors.

Operating History

Design and Initial Operation

In September 1990, a Cooperative Agreement was signed between ENCOAL and DOE to initiate the project. The LFC process had been undergoing development in laboratory settings since the early 1980s. In the two years following the signing, the main focus was on the construction of an operable plant. The first 24-hour run took place in June 1992. In September, the plant achieved a continuous one-week run. A month later, the first shipment of 60,000 gallons of CDL was sent to TexPar, Inc., which experienced unloading problems. These problems were solved with heat tracing and tank heating coils.

Although improved in heating value, early batches of PDF revealed a tendency to self ignite. After attempting to stabilize PDF using in-plant equipment, it was concluded that a separate, sealed vessel was needed for product deactivation, and a vibrating fluidized-bed (VFB) reactor was installed in 1993.

ENCOAL shipped its first train containing PDF in September 1994 to Western Farmers Electric Cooperative in Hugo, Oklahoma. Three runs early in 1994 processed approximately 4,300 tons of coal, producing nearly 2,200 tons of PDF and 81,000 gallons of CDL. The second quarter of 1994 saw 54 days of continuous operation, followed by a 68-day run in the fourth quarter. However, deactivation in the VFB reactor was not complete: stabilization still involved "finishing" using outdoor pile layering or blending with ROM coal.

Environmental Health & Safety

Compliance with federal and state environmental regulations has 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, Wyoming state inspections were consistently positive. Stack and emissions testing completed in November 1995 indicated that the plant is operating within permitted limits for NO_x, sulfur oxides, carbon monoxide, volatile organic compounds, and particulates.

Although the plant's tall structures, hot gases and large rotating equipment would seem to create potential for injury, one of the project's most important accomplishments is its safety record. As of May 31, 1997, ENCOAL staff and their subcontractors had amassed over four years without a lost-time accident.

Process Improvements

As a first-of-its-kind enterprise, design and process difficulties were not unexpected, and much effort was devoted to solving those problems, especially that of PDF deactivation. As ENCOAL teams resolved obstacles, 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.

Marked improvement in operations was achieved as a result of introducing the VFB reactor. 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 reactor was being installed, several other changes paved the way for increased PDF and CDL production.

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

- Coal drying and devolatilization on a rotary grate using convective heating
- Integral solids cooling and deactivation
- Integral cooling and rehydration using internal process water streams
- Combustors operating on low-Btu gas from internal streams
- Solids stabilization for storage and shipment

Test Burns

Commercialization of PDF took a major step forward in 1994, when ENCOAL shipped six trains to two customers. Shipments to the first customer, the Western Farmers Electric Cooperative, started with a 15% blend of PDF in raw coal and ranged up to 30% PDF, the upper level being determined by boiler capacity. 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

Tank car loading facility for Coal Derived Liquid at ENCOAL demonstration plant.

Process Derived Fuel test piles at ENCOAL demonstration plant.

PDF, contained 100% PDF with a cap of ROM coal to prevent fines losses. The PDF 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 that from ROM Buckskin coal, and to ship PDF blends that were stable with respect to self heating. Furthermore, ENCOAL demonstrated 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 ($^1/_2$ unit train minimum) of PDF blends with minimal adjustment of equipment.

Test burn shipments from ENCOAL became international when Japan's Electric Power Development Company (EPDC) evaluated six 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 one-month period. Plant availability reached 89%. 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, successfully using its MK additive as a car-topper instead of ROM coal. By the end of October, two 100% PDF unit trains were delivered to two separate utilities for test burns. The first was combusted 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. Completion of this test burn achieved a primary project milestone of testing PDF at a major U.S. utility. The second 100% PDF unit train was sent to Northern Indiana Public Service Company and to Union Electric's Sioux Plant near St. Louis, Missouri.

By the conclusion of DOE involvement in the ENCOAL project in July 1997, 247,000 tons of coal had been processed into PDF and CDL. Over 83,000 tons of specification PDF had been shipped to seven customers in six states, as well as 203 tank cars of CDL to eight customers in seven states.

Alternative Coal Testing

In addition to Buckskin coal, ENCOAL tested two other coals. Beginning in November 1995, 3,280 tons of North Rochelle mine subbituminous coal was processed at the same plant parameters as those used for Buckskin coal. The plant performed well, but high ash content in the feed coal limited increases in heating value, the fines rate was doubled, and the CDL yield was lower than predicted. The coal processed did not appear to be representative of the overall mine quality.

A second alternative 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.

Alaskan subbituminous coal, North Dakota lignite and Texas lignites have also been laboratory tested. For North Dakota lignite, laboratory testing was carried out in two stages over a four-year span. In 1992, a blend of two seams of Knife River lignites was tested at the TEK-KOL Development Center, where an analysis procedure has been developed to predict applicability of the LFC process to different coals. In 1996, Freedom mine and Knife River lignite samples were 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

The Clean Coal Technology Program

The Clean Coal Technology (CCT) Program is a unique partnership between the federal government and industry that has as its primary goal the successful introduction of new clean coal utilization technologies into the energy marketplace. With its roots in the acid rain debate of the 1980s, the program is on the verge of meeting its early objective of broadening the range of technological solutions available to eliminate acid rain concerns associated with coal use. Moreover, the program has evolved and has been expanded to address the need for new, high-efficiency power-generating technologies that will allow coal to continue to be a fuel option well into the 21st century.

Begun in 1985 and expanded in 1987 consistent with the recommendation of the U.S. and Canadian Special Envoys on Acid Rain, the program has been implemented through a series of five nationwide competitive solicitations. Each solicitation has been associated with specific government funding and program objectives. After five solicitations, the CCT Program comprises a total of 40 projects located in 18 states with a capital investment value of nearly $6.0 billion. DOE’s share of the total project costs is about $2.0 billion, or approximately 34 percent of the total. The projects’ industrial participants (i.e., the non-DOE participants) are providing the remainder—nearly $4.0 billion.

Clean coal technologies being demonstrated under the CCT Program are establishing a technology base that will enable the nation to meet more stringent energy and environmental goals. Most of the demonstrations are being conducted at commercial scale, in actual user environments, and under circumstances typical of commercial operations. These features allow the potential of the technologies to be evaluated in their intended commercial applications. Each application addresses one of the following four market sectors:

- Advanced electric power generation
- Environmental control devices
- Coal processing for clean fuels
- Industrial applications

Given its programmatic success, the CCT Program serves as a model for other cooperative government/industry programs aimed at introducing new technologies into the commercial marketplace.

solicited joint funding from the North Dakota Lignite Research Council for an alternative coal study. This application was turned down in November 1996, and the test was abandoned. Based upon the successful laboratory screening test, however, ENCOAL believes that lignite is an acceptable candidate for LFC processing.

Commercial Plant Design

Using the process concepts developed at the demonstration plant, ENCOAL has prepared a plant design and economic evaluation of a commercial plant, located at the North Rochelle mine site near Gillette. This work involved the participation of Mitsubishi Heavy Industries (MHI). The commercial plant concept consists of three 5,000 metric ton/day parallel modules with a total capacity of 15,000 metric tons/day of raw coal feed. For this plant, the total capital requirement is estimated to be $475 million. PDF product prices are based on the competitive Btu value of equivalent bituminous coal in the midwest market. CDL product prices are based on the average netback for a mixture of transportation fuels, chemical feedstocks, and industrial fuel oil. Based on these assumptions and an operating cost of $10.00/ton of feedstock, the internal rate of return is in the 15–17% range.

International Interest

Similar studies have been prepared for two proposed international projects involving Indonesian coal mines operated by P.T. Tambang Batubara Bukit Asam (PTBA) and P.T. Berau. 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.

China, the world's largest producer and consumer of coal, offers 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 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 study which indicated that the coals tested were suitable for LFC upgrading. Work on a follow-up study has been approved by the Russian government and private participants.

Domestic Applications

In the United States, potential applications exist in Alaska, North Dakota, and Texas. 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 low 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, 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.

Ongoing Work

Demonstrating the LFC technology required the resolution of a number of challenging problems: lighting burners in combustors with inert atmospheres, removing particulates from process streams, and suppressing dust during the handling and transport of 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, a twin-fluidized-bed atomized dust collection system, and low-Btu combustion technology; other patents have been applied for.

As discussed previously, a VFB reactor has been incorporated in the LFC process to achieve product stability. A variety of finishing techniques also have been studied, including 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.

A Pilot Air Stabilization System (PASS) was completed in November 1995, and the unit operated through January 1996. PASS testing was successful: the PASS unit processed $^1/_2$ to 1 ton of solids per hour, 24 hours a day, for $2^1/_2$ months. Even more important, PDF was formed for the first time into stable, uncompacted piles without ground stabilization techniques.

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 data were scaled up for application to a larger plant. Financial restrictions delayed the fabrication and installation of the full-scale unit, but this project is now proceeding. Work on the finishing step is now outside the scope of DOE involvement and is being jointly addressed by several companies with common interests.

Unit train shipment of Process Derived Fuel from ENCOAL plant.

Product Utilization

Markets for PDF

The U.S. electric utility market is clearly the largest market for PDF, but a growing market for noncoking metallurgical coals offers an opportunity for higher product prices. A market study of the utility industry by Resource Data International identified a large number of power plants whose fuel needs are most nearly met by PDF. These plants represent a significant market.

As high costs and environmental problems continue to cause shutdown of coke ovens, the steel industry is replacing coke in blast furnaces with pulverized coal. PDF may prove to be a viable fuel for this purpose. In addition, PDF could be an ideal source of carbon in the direct reduction of iron to produce steel.

Markets for CDL

The physical characteristics of CDL such as pour point, heating value, flash point, viscosity, and gravity are within the range of acceptability for many residual oil markets, and the product has been tested successfully as an injectant fuel in a blast furnace. However, a market evaluation has indicated the need to upgrade CDL for increased profitability. The commercial plant design includes an upgrading process to produce petroleum refinery feedstock, oxygenated distillates, and residual fuels. Hydrogenation testing was started in 1997 as part of this study.

Technical and economic feasibility and market acceptability are important factors that will determine which CDL upgrading scheme is most applicable. In-plant finishing and CDL upgrading are the last of the major technical issues.

Summary

The goals set for the ENCOAL project have not only been met, but exceeded. Seventeen unit trains containing PDF have been shipped and successfully burned at seven utilities. PDF has been tested for use in the direct reduction of iron, and holds promise as a blast furnace injectant. The LFC process has been demonstrated and improved, both through operational refinements and equipment modifications. Almost five years of operating data have been collected for use 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 remain for resolution before a commercial plant project can be completed. Contracts for the sale of products are needed and financial partners must be obtained. An in-plant finisher that will substantiate the large-scale testing of PDF finishing, the second stage of stabilization, needs to be installed at the ENCOAL plant. CDL upgrading efforts will continue.

A large-scale commercial plant, the long-term goal of the project, should move toward implementation at the North Rochelle mine site. The demonstration plant will continue to test the viability of alternative 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 proposed commercial plant.

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

Rosebud SynCoal

Project Description

Project Participant

The SynCoal Advanced Coal Conversion Process (ACCP) being demonstrated in Montana consists of thermal treatment coupled with physical cleaning to upgrade high-moisture, low-rank coals, giving a fuel with improved heating value and low sulfur content.

The process has been developed by the Rosebud SynCoal Partnership (RSCP) as part of Round I of the U.S. Department of Energy's CCT Program. RSCP is a general partnership formed in December 1990 for the purpose of conducting the demonstration and commercializing the ACCP technology. Western SynCoal Company, a subsidiary of Montana Power Company's Energy Supply Division, is the managing general partner of RSCP. The other general partner is Scoria Inc., a subsidiary of NRG Energy, the nonutility entity of Northern States Power Company.

Montana Power Company's subsidiary, Western Energy Company, initially developed the ACCP technology. RSCP's partners own the technology in undivided interests and have exclusively licensed it to the partnership. The partnership manages the demonstration project and all activities related to commercialization. DOE has contributed about $43 million (41%) to the $105 million demonstration project, with the remainder provided by RSCP.

Rosebud SynCoal demonstration unit.

ACCP Process Description

The SynCoal ACCP enhances low-rank subbituminous and lignite coals by a combination of thermal processing and cleaning. The results are a reduction in moisture content from 25–40% in the feed to as low as 1% in the product, concurrently increasing heating value from 5,500–9,000 Btu/lb to as high as 12,000 Btu/lb, and reducing sulfur content from a range of 0.5–1.5% to as low as 0.3%. The process consists of three major steps: thermal treatment in an inert atmosphere, inert gas cooling of the hot coal, and cleaning. The thermal upgrading removes chemically bound water, carboxyl groups, and volatile sulfur compounds. The cleaning step separates the pyrite-rich ash, thereby reducing the sulfur content of the product. Each ton of raw Rosebud subbituminous coal produces about $^{2}/_{3}$ ton of SynCoal.

Raw coal from the Rosebud mine unit train stockpile is screened and fed to a vibrating fluidized-bed reactor, where surface water is removed by heating with hot combustion gas. Coal exits this reactor at a temperature slightly higher than that required to evaporate water and is further heated to nearly 600°F in a second vibrating reactor. This temperature is sufficient to remove pore water and cause decarboxylation. In addition, a small amount of tar is released, sealing the dried product from reaction with oxygen. Particle shrinkage causes fracturing, destroys moisture reaction sites, and liberates the ash-creating mineral matter.

The coal then is cooled to less than 150°F by contact with an inert gas (carbon dioxide and nitrogen at less than 100°F) in a vibrating fluidized-bed cooler. Finally, the cooled coal is fed to deep bed stratifiers where flowing air and vibration separate mineral matter from the coal by rough density-based separation. The low-specific-gravity fractions are sent to a product conveyor while heavier fractions go to fluidized-bed separators for additional ash removal. Different procedures for product stabilization are used, depending on feed coal and market application. Fines from various parts of the cleaning process are collected in baghouses and cyclones, cooled, and made available as an additional product line.

Most of the heat rejection from the ACCP is accomplished by discharging water and flue gas to the atmosphere through an exhaust stack. The stack design allows for vapor release at an elevation great enough that, when coupled with the vertical velocity resulting from a forced draft fan, dissipation of the gases is maximized. Heat removed from the coal in the coolers is rejected using an atmospheric induced draft cooling tower.

The fines handling system consolidates the coal fines that are produced in the conversion, cleaning, and material handling systems. The fines are gathered by screw conveyors and transported by drag conveyors to a bulk cooling system.

Location

The demonstration plant is located adjacent to the unit train loadout facility within Western Energy's Rosebud mine boundary near Colstrip, Montana. The production unit, having a capacity of 1,000 tons/day of upgraded coal, is one-tenth the size of a commercial facility and benefits from the existing mine and community infrastructure.

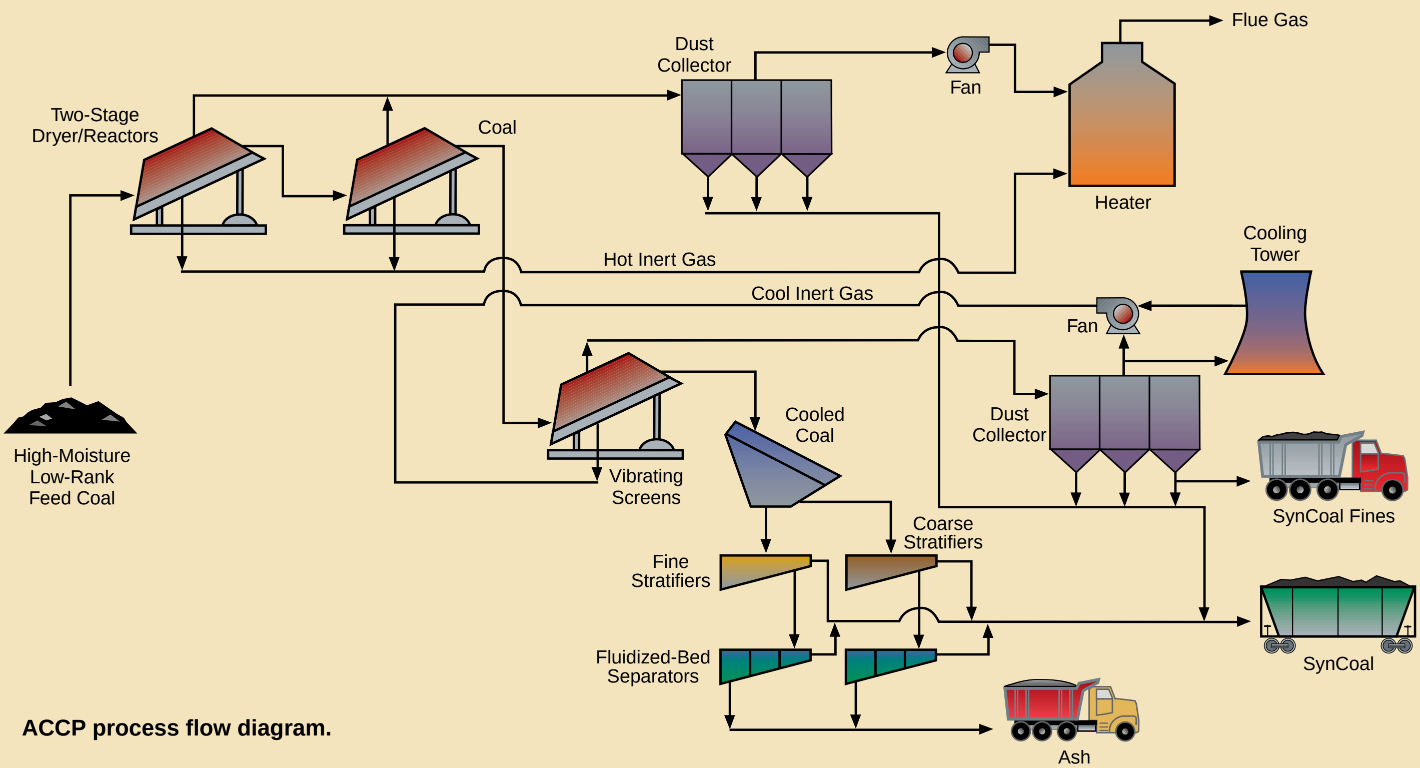
Product Characteristics

SynCoal is a high quality product with less than 5% moisture, sulfur content of about 0.6%, ash content of about 9%, and a heating value of about 11,800 Btu/lb. The enhanced properties of the product provide evidence that the molecular structure of low-rank coals can be altered successfully to produce a unique fuel for a variety of utility and industrial applications.

Operating History

Design and Initial Operation

The Cooperative Agreement with DOE for the ACCP demonstration facility was signed in September 1990. Initial operations began in April 1992, with the first 24-hour run occurring in May 1992 and the first significant shipments in June. Several material handling problems were encountered during



ACCP process flow diagram.

The cooled fines are stored in a 250-ton capacity bin until loaded into pneumatic trucks for off-site sales.

When sales lag production, the fines are slurried with water in a specially designed tank and returned to the mine pit.

initial operations that required extensive modifications and hampered the efforts to address the product issues of dustiness and spontaneous heating. Parallel efforts to correct the material handling shortfalls and investigate treatments to mitigate the product issues were pursued until August 1993, when the demonstration facility reached full production capability. Efforts continued to establish test customers and address the product handling issues to allow safe and reliable transportation and handling. Three different feedstocks were trucked to and tested at the facility in 1993 and early 1994. In 1994, several test burn programs were conducted in both utility and industrial applications and three regular customers were established. The demonstration facility started focusing increasing amounts of attention on process improvements and operating cost reductions. Since 1995, an additional focus has been the development of commercial markets.

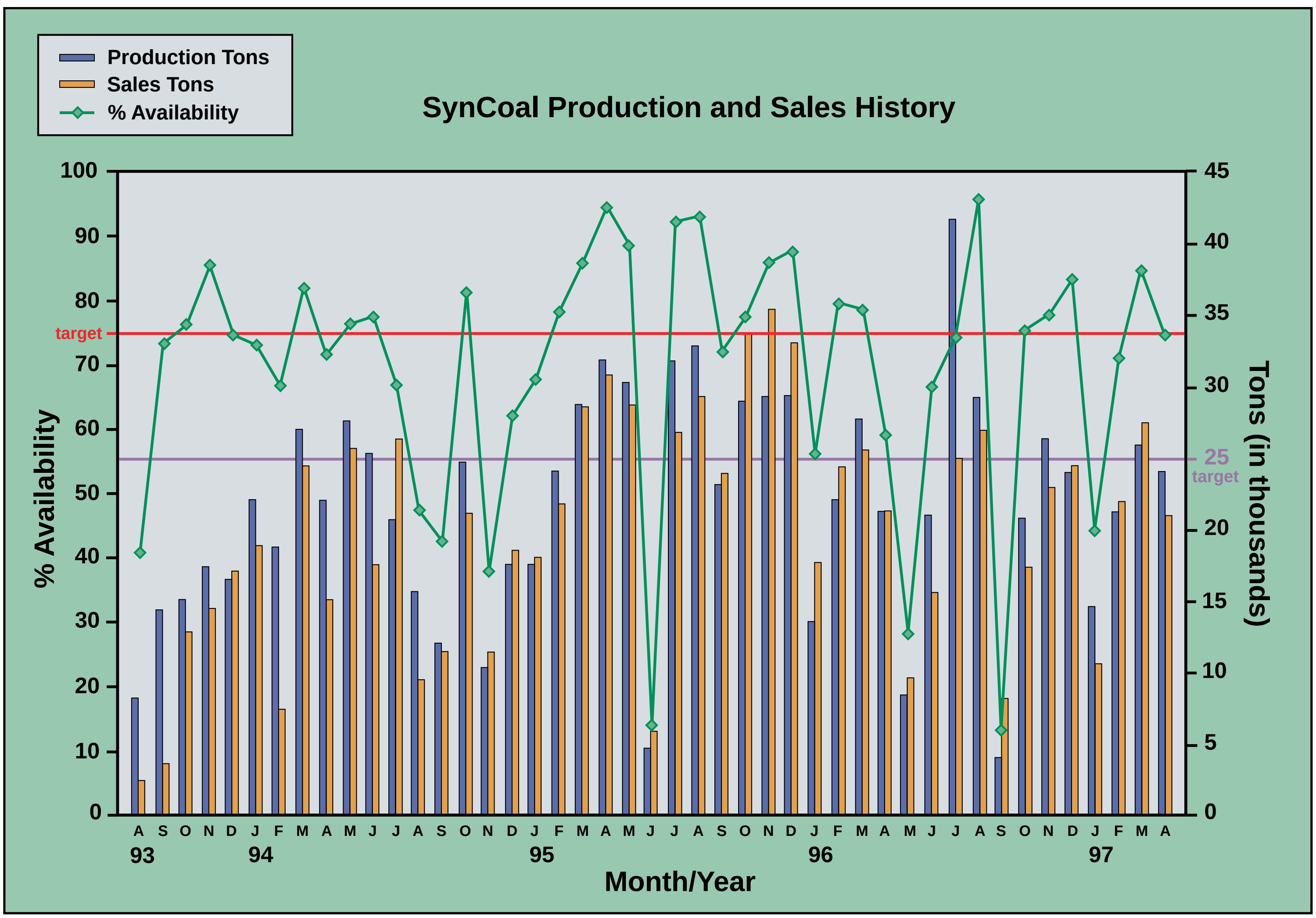
Through June 1997, 1.6 million tons of raw coal have been processed and over 1 million tons of SynCoal have been produced. Total shipments of SynCoal products have exceeded 950,000 tons. The plant has consistently operated at over 100% of its design capacity and at its target 75% availability. The demonstration facility is expected to operate through June 1998 under the Cooperative Agreement.

Environmental Health & Safety

It was originally assumed that SO_2 emissions would have to be controlled by injecting chemical sorbents into the ductwork. However, it has been discovered during performance testing that the process configuration inherently limits the gaseous sulfur production, eliminating the need for chemical sorbent injection. A mass spectrometer was installed to monitor emissions for performance testing, but the sorbent injection system remains in place should a higher sulfur coal be processed.

Fugitive dust from material handling and coal cleaning operations throughout the plant is controlled by negative pressure dust collection hoods located at all transfer points and other dust emission sources. High-efficiency baghouses are connected to the dust collection hoods. These baghouses have been effective, as demonstrated by stack tests on the east and west baghouse outlet ducts and the first-stage drying gas baghouse stack in 1993. Emission rates were well within the limits specified in the air quality permit, at 0.0013 grains/dry standard cubic foot (gr/dscf) for the baghouse outlet ducts and 0.0027 gr/dscf for the drying gas baghouse stack. Another stack survey conducted in May 1994 verified that emissions of particulates, SO_2, oxides of nitrogen (NO_x), carbon monoxide (CO), total hydrocarbons, and hydrogen sulfide (H_2S) from the process stack are within permitted levels.

Through June 1997, the demonstration operations have been cited for only five minor violations as a result of MSHA's



regular inspections. It was noted at the celebration of 1 million tons of production that the operating work force had completed over 300,000 manhours without a lost-time accident.

Process Improvements

The project team has worked continuously to improve the process and product since the initial startup identified the dustiness and spontaneous combustion issues. Additionally, as with any first-of-a-kind plant, significant efforts have been directed toward improving process efficiencies and reducing overall costs. A CO_2 inerting system was added to prevent self heating in the storage areas and enhance the product stability in transit to customers. After verifying the effectiveness of this system, an additional inert gas process was added to reduce the gas expenses and further test the impact on product stability.

A wide variety of additives and application techniques were tested in an effort to reduce dustiness and spontaneous combustion. A commercial anionic polymer applied in a dilute concentration with water was found to provide effective dust control and is environmentally acceptable. A companion product was identified that can be used as a rail car topping agent to reduce wind losses. The application of the dilute water-based suppressant, which is known as dust stabilization enhancement (DSE), also provided a temporary heat sink, helping control spontaneous combustion for short duration shipments and stockpile storage. This work led to extensive investigation into stockpile management and blending techniques.

After adapting these lessons, safe and effective techniques for blending SynCoal with raw coal, petroleum coke, and SynCoal fines and handling the resultant products have evolved. This work further led to the development of stabilization process concepts (patents pending) which were successfully piloted at a 1,000 lb/hr scale. A plant modification was designed, but has not been installed due to the high retrofit costs. The next generation plant is expected to incorporate the stabilization process technology.

Demonstration facility at Rosebud mine with reclamation area in background.

Test Burns — Utility Applications

A SynCoal test-burn was conducted at the 160 MW J.E. Corette plant in Billings, Montana. A total of 204,000 tons of SynCoal was burned between mid 1992 and April 1996. The testing involved both handling and combustion of DSE-treated SynCoal in a variety of blends. These blends ranged from approximately 15% to 85% SynCoal with raw coal. Overall, the results indicate that a 50% SynCoal/raw-coal blend provides improved performance, with SO_2 emissions reduced by 21% at normal operating loads, and no noticeable impact on NO_x emissions.

In addition, the use of SynCoal permitted deslagging the boiler at full load, thereby eliminating costly ash shedding operations. This also provided reduced gas flow resistance in the boiler and convection passage, thereby reducing fan horsepower and improving heat transfer in the boiler area, resulting in an increase in net power generation of about 3 MW.

Montana Power Company's Colstrip Units 1–4.

Deliveries of SynCoal are now being sent to Colstrip Units 1 & 2 in Colstrip, Montana. Testing has begun on the use of SynCoal in these twin 320-MW pulverized coal fired plants. The results of these tests will provide information on boiler efficiency, power output, and air emissions. A total of 158,000 tons have been consumed to date. A new SynCoal delivery system is being designed which, if installed, would provide selectively controlled pneumatic delivery of fuel to individual pulverizers in the two units. This system would allow controlled tests, providing valuable comparative data on emissions, performance and slagging.

Alternative Coal Testing

In May 1993, 190 tons of Center, North Dakota, lignite was processed at the ACCP demonstration facility, producing a 10,740 Btu/lb product, with 47% reduction in sulfur and 7% reduction in ash. In September 1993, a second test was performed processing 532 tons of lignite, producing a 10,567 Btu/lb product with 48% sulfur reduction and 27% ash reduction. The Center lignite before beneficiation had 36% moisture, about 6,800 Btu/lb, and about 3.0 lb of SO_2/million Btu.

Approximately 190 tons of these upgraded products was burned in the Milton R. Young Power Station Unit #1, located near Center. This initial test showed dramatic improvement in cyclone combustion, improved slag tapping, and a 13% reduction in boiler air flow, reducing the auxiliary power loads on the forced draft and induced draft fans. In addition, the boiler efficiency increased from 82% to over 86% and the total gross heat rate improved by 123 Btu/kWh.

Similar test programs were also conducted on 290 tons of Knife River lignite from North Dakota and 681 tons of AMAX subbituminous coal from Wyoming, producing 10,670 Btu/lb and 11,700 Btu/lb products, respectively.

Test Burns — Industry Applications

Several industrial cement and lime plants have been customers of SynCoal for an extended period of time. A total of about 190,000 tons have been delivered to these customers since 1993. They have found that SynCoal improves both capacity and product quality in their direct-fired kiln applications, because the steady flame produced by SynCoal appears to allow tighter process control and improved process optimization.

A bentonite producer has been using SynCoal as an additive in greensand molding product for use in the foundry industry, having purchased about 37,500 tons. They have found SynCoal to be a very consistent product, allowing their greensand binder customers to reduce the quantity of additives used and improving the quality of the metal castings produced.

Commercial Plant Design

Western SynCoal Company has aggressively pursued construction of a $37.5 million lignite-based commercial plant at Minnkota's Milton R. Young Power Station. However, in April 1997 the project was suspended due to a lack of equity investors. Minnkota is a generation and transmission cooperative supplying wholesale electricity to 12 rural electric cooperatives in eastern North Dakota and northwestern Minnesota.

Minnkota owns and operates the 250-MW Unit 1 at the Young Station, and operates the 438-MW Unit 2 which is owned by Square Butte Electric Cooperative of Grand Forks. This power station is already one of the lowest cost electric generating plants in the nation; however, with the use of SynCoal the operations of the plant could further improve.

The cyclone units at the Young facility are plagued by cyclone barrel slagging, which is typically removed by burning additional No. 2 fuel oil. These units also slag and foul in the boiler and convective passes, requiring complete shutdown and cold boiler washing three or four times a year. In an effort to reduce these detrimental effects, Minnkota Power has tested the use of SynCoal as a substitute for fuel oil when removing cyclone slag and also as a steady additive.

The fuel oil substitute, nicknamed "Klinker Killer," has been shown to be at least as effective in removing cyclone barrel clinkers on a Btu for Btu basis as fuel oil. Burning SynCoal produces a much higher temperature in the cyclone barrel than lignite, increasing the cyclone barrel front wall temperature as much as 900°F and more closely matching the design temperature profile, which improves the cyclone combustion operation dramatically.

ACCP facility during construction.

The commercial plant is designed to produce 400,000 tons/yr of SynCoal, which would be fed to the boilers. The reduced slagging and fouling would improve generating plant maintenance and allow potentially longer runs between downtimes, as well as boosting the lignite heating value by 60%.

RSCP has been actively marketing and promoting the SynCoal technology worldwide, working closely with a Japanese equipment and technology company to expand into Asian markets. Prospects are also being pursued in Europe.

Ongoing Work

Additional development is required to improve two major product characteristics: spontaneous combustion and dusting. In addition, further market development and customer education are needed to position SynCoal in the proper market niches and overcome natural resistance to a new product.

Spontaneous Combustion and Dusting

The upgraded, cooled, and cleaned coal produced to date has exhibited spontaneous heating and combustion. When a mass of coal (more than 1 to 2 tons) is exposed to any significant air flow for periods ranging from 18 to 72 hours, the coal reaches temperatures at which spontaneous combustion or autoignition occurs. Spontaneous heating of ROM, low-rank coals has been a common problem but usually occurs after open-air exposure periods of days or weeks, not hours. However, dried low-rank coals have universally displayed spontaneous heating tendencies to a greater degree than raw low-rank coals.

The product is basically dust free when it exits the processing facility because of numerous steps where the coal is fluidized in process gas or air, which removes the dust-size particles. The gas and air entrain any dust that has been produced since the last process step. However, typical of coal handling systems, each activity performed on the product coal after it leaves the process degrades the coal size and produces some dust. Because the SynCoal product is dry, it does not have any inherent ability to hold small particles to the coal surfaces. This allows dust-size particles that are generated by handling to be released and become fugitive.

In January 1995, a cooperative research project was initiated to determine the effects of different processing environments and treatments on low-rank coal composition and structure. Specific objectives are (1) to elucidate the causes of spontaneous heating of upgraded coals and to develop preventive measures, and (2) to study the explosibility and flammability limits of dust from the process. Other participants in this study are the AMAX Coal Company and ENCOAL, who have also experienced the same effects on their upgraded products.

Market Development and Customer Education

Due to the handling issues, RSCP has taken a three-pronged approach to satisfying customer needs for a safe, effective way to handle SynCoal. The first method is to employ DSE treatment, which allows conventional bulk handling for a short period (about one week) but does degrade the product heat content. The product eventually becomes dusty and susceptible to spontaneous heating again.

The second technique uses contained storage and transportation systems with pneumatic or minimal-exposure transfer devices. This technique provides maximum product quality and actually enhances the material handling performance for many industrial customers; however, transportation requires equipment not conventionally used in coal delivery systems and is impractical for large utility customers.

The third approach is to develop a stabilization process step. SynCoal's previous work has been of great benefit in the collaborative research with ENCOAL. SynCoal hopes to incorporate its stabilization process in the next generation facility or develop a smaller pilot operation in direct response to a specific customer requirement.

These approaches should allow SynCoal to be tested in some more novel applications such as blast furnace injection systems and electric arc furnace reducing agents.

Product Utilization

Utility Markets

The utility segment is the largest and most established market for all domestic coal sales. Since the ACCP is by its nature a value added process and the product has been determined to require special handling, unique situations must be identified where the addition of SynCoal to the firing mix provides sufficient benefit to more than offset the increased delivered cost compared to raw western coal. These requirements have led RSCP to focus on marketing the product as a supplemental fuel in utility applications and then only to units that have specific problems with slagging or flame stability.

Since SynCoal can not be handled in conventional unit trains without DSE treatment, the higher transportation costs to deliver SynCoal are an additional barrier to the bulk utility market at this time. DSE is effective for short haul distances and storage times, but does decrease the energy density (Btu/lb) compared to the untreated SynCoal. The low sulfur content is important but does not provide any market advantage since Wyoming Powder River Basin coals are low in sulfur and currently very inexpensive.

Industrial Markets

The industrial market segment is much more amenable to special handling since these customers normally receive much smaller quantities and are much more sensitive to fuel quality issues. RSCP has developed a technique of shipments in covered hopper rail cars and/or pneumatic trucks that allows long haul distances and, when combined with inerted bin storage, provides safe and efficient handling.

SynCoal has been found to provide superior performance in direct-fired applications particularly as a blend with petroleum coke. SynCoal provides good ignition and stable flame characteristics while the petroleum coke is a low-cost product which gives a longer burning time, expanding the processing zone. This blend of characteristics has provided a significant advantage to SynCoal's cement and quicklime customers. Additionally, recent tests of SynCoal/petroleum coke blends have shown improved handling characteristics with regard to dustiness and self heating.

SynCoal produces a gas-like flame when burned alone. In some direct-fired applications (such as road paving asphalt plants), it can be a much lower cost option than propane, providing a small but valuable market.

Metallurgical Markets

SynCoal's consistent characteristics and high volatile matter and carbon contents make it a good reducing agent for some metallurgical processing applications. Since low moisture content is a key characteristic for this segment, the covered hopper rail car and/or pneumatic truck delivery system is readily accepted. SynCoal has been used successfully in ductile iron metal casting applications as a greensand binder additive because of these characteristics. RSCP has been working with a metallurgical silica producer to determine if SynCoal is viable in their application. RSCP is continuing to pursue alternative markets in various metallurgical reduction applications, and SynCoal may even be a viable substitute for natural gas used to reduce consumption of metallurgical coke in blast furnaces.

Summary

Rosebud SynCoal has developed an advanced coal conversion process that has the potential to enhance the utility and industrial use of low-rank western subbituminous and lignite coals. Many of the power plants located through the upper Midwest have cyclone boilers, which burn low ash fusion temperature coals. Currently, most of these plants burn Illinois Basin high-sulfur coal. SynCoal is an ideal supplemental fuel for these and other plants because it allows a wider range of low-sulfur raw coals to be used to meet more restrictive emissions guidelines without derating of the units or the addition of costly flue gas desulfurization systems.

The ACCP has potential to convert inexpensive low-sulfur, low-rank coals into valuable carbon-based reducing agents for many metallurgical applications, further helping to reduce worldwide emissions and decrease our national dependence on foreign energy sources.

The ACCP produces a fuel that has a consistently low moisture content, low sulfur content, high heating value, and high volatile content. Because of these characteristics, SynCoal could have significant impact on SO_2 reduction and provide a clean, economical alternative fuel to many regional industrial facilities and small utility plants, allowing them to remain competitively in operation.

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List of Acronyms and Abbreviations

ACCP .... Advanced Coal Conversion Process

Btu .... British thermal unit

CCT .... Clean Coal Technology

CDL .... coal derived liquid

DOE .... United States Department of Energy

DSE .... dust stabilization enhancement

EPDC .... Electric Power Development Company (Japan)

ESP .... electrostatic precipitator

LFC .... liquids from coal

MHI .... Mitsubishi Heavy Industries

MSHA .... Mine Safety & Health Administration

MW .... Megawatts of power

NO_x .... nitrogen oxides

PASS .... pilot air stabilization system

PDF .... process derived fuel

PTBA .... P.T. Tambang Batubara Bukit Asam

ROM .... run-of-mine

RSCP .... Rosebud SynCoal Partnership

SGI .... SGI International

SO_2 .... sulfur dioxide

VFB .... vibrating fluidized bed

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