RCRA Box 1551

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Document Number:

69) II-I-36

Docket Number:

A-95-28

Docket No. A-95-28
Item No. II-I-36

THIRD ANNUAL CLEAN COAL TECHNOLOGY CONFERENCE

September 6-8, 1994
Chicago Hilton and Towers Hotel

Technical Papers

Chicago

"The Investment Pays Off"

Co-sponsored by
The United States Department of Energy and the
Center for Energy & Economic Development

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

THE CENTER FOR ENERGY & ECONOMIC DEVELOPMENT

Third Annual
Clean Coal Technology Conference

Technical Papers

OBJECTIVE

THEME: "THE INVESTMENT PAYS OFF"

The public/private investment in Clean Coal Technology pays off. The objective of this conference is to review the status and successes of the program, the role of the program in meeting domestic and global energy and environmental needs, the opportunities for commercialization in the United States and abroad, and the challenges which are being encountered. This review will be accomplished within the context of the emerging trade agreements and global energy, economic, and environmental challenges.

ROSEBUD SYNCOAL PARTNERSHIP
SYNCOAL® DEMONSTRATION
Technology Development Update

INTRODUCTION

Rosebud SynCoal® Partnership's Advanced Coal Conversion Process (ACCP) is an advanced thermal coal upgrading process coupled with physical cleaning techniques to upgrade high-moisture, low-rank coals to produce a high-quality, low-sulfur fuel.

The coal is processed through two vibrating fluidized bed reactors where oxygen functional groups are destroyed removing chemically bound water, carboxyl and carbonyl groups, and volatile sulfur compounds. After thermal upgrading, the SynCoal® is cleaned using a deep-bed stratifier process to effectively separate the pyrite rich ash.

The SynCoal® process enhances low-rank western coals with moisture contents ranging from 25-55%, sulfur contents between 0.5 and 1.5%, and heating values between 5,500 and 9,000 Btu/lb. The upgraded stable coal product has moisture contents as low as 1%, sulfur contents as low as 0.3%, and heating values up to 12,000 Btu/lb.

Construction of the 300,000 ton per year (tpy) demonstration project adjacent to Western Energy Company's Rosebud mine unit train loadout facility near the town of Colstrip in southeastern Montana was completed in 1992. An extended startup and shakedown period lasted until August 1993. The facility has produced nearly at-design capacity since January 1994. Rosebud SynCoal's demonstration plant is sized at about one-tenth the projected throughput of a multiple processing train commercial facility. The next generation of facilities are expected to become standardized 100 TPH process trains.

Demonstration operations and testing began in April 1992 and are continuing. Initial operations discovered the normal variety of equipment problems which delayed operational and process testing. As operational testing has proceeded, the product quality issues that have emerged are dustiness and stability. The SynCoal® product has met the BTU, moisture and sulfur specifications. The project team is continuing process testing and is working toward resolution of the operational and process issues in response to market requirements.

The ACCP Demonstration Facility is a U.S. Department of Energy (DOE) Clean Coal Technology Program Project with 50% funding from the DOE and 50% from the Rosebud SynCoal Partnership through the end of the original $69 million project. DOE and Rosebud recently agreed to extend the project until November 1997 with total funding increasing to $105.7 million and DOE's contribution increased to a total of $43.125 million.

The Rosebud SynCoal Partnership is a venture involving Western SynCoal Company and Scoria Inc.. Western SynCoal is a subsidiary of Western Energy Company (WECo) which is a subsidiary of Entech Inc., Montana Power Company's non-utility group. Scoria Inc is a subsidiary of NRG Energy Inc., Northern States Power's non-utility group.

STATUS OF DEVELOPMENT

Much of the early ACCP development was performed using a small, 150 pound per hour pilot plant located at the Mineral Research Center, south of Butte, Montana. Up to 100 ton lots were produced to assess shipping and handling stability as well as chemical characteristics. A variety of coals and process conditions were tested to determine the process capabilities.

Development is continuing as construction and startup has been completed and demonstration operation is continuing at the 300,000 ton per year demonstration plant at Western Energy's Rosebud Mine near Colstrip, Montana. The demonstration facility has operated nearly at full design capacity during 1994, reaching as much as 115 percent of design on an hourly basis for short periods of time. Rosebud SynCoal is developing facility designs and equipment concepts around 100 TPH process units that can be added in multiples to make facilities at virtually any production capacity desired. A listing of the most significant events in the history of the ACCP development is provided in Appendix A.

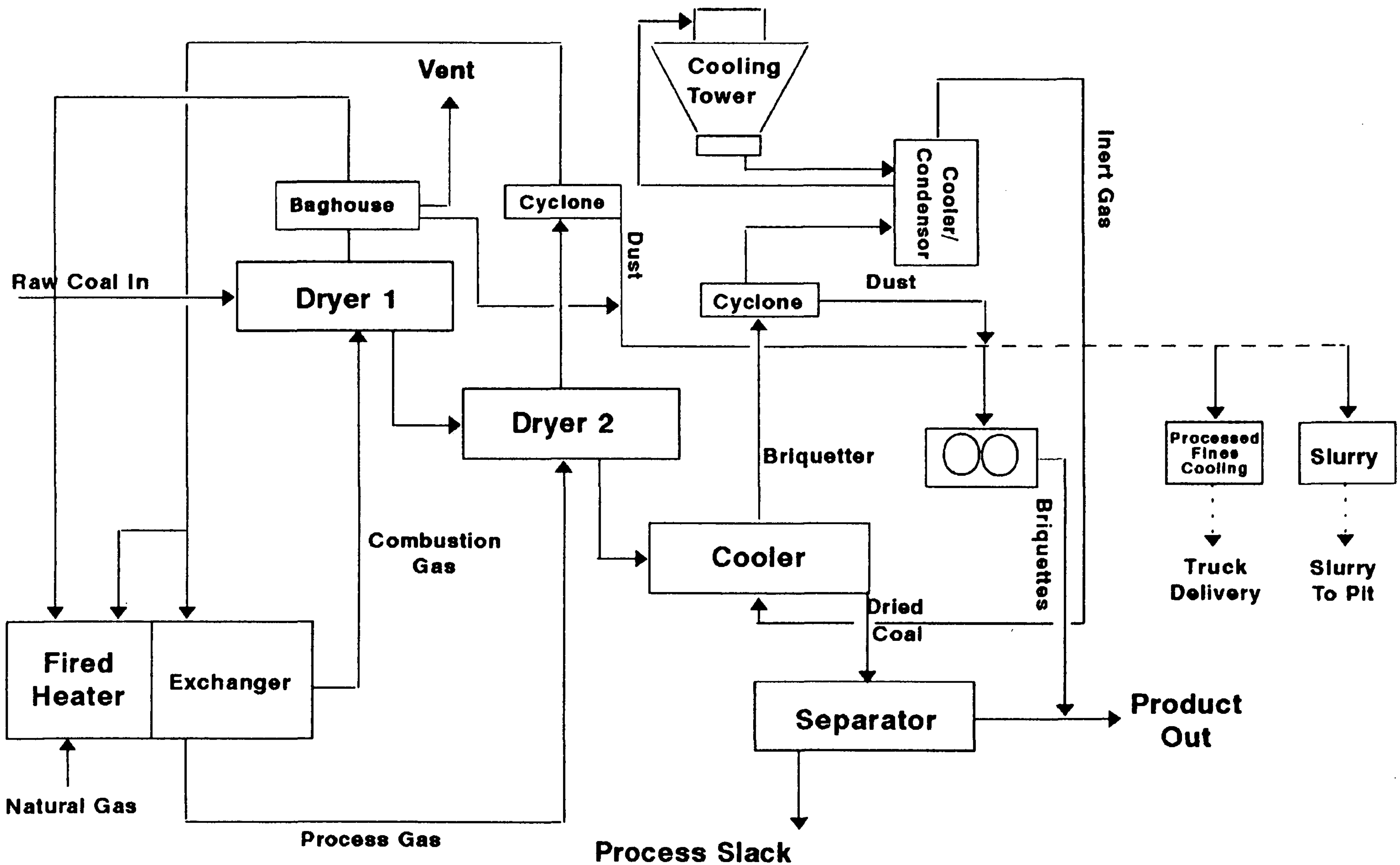
PROCESS DESIGN DESCRIPTION

In general, the ACCP is a low rank coal upgrading and conversion process using low pressure, superheated gases to process coal in vibrating fluidized beds. Two vibratory fluidized processing stages are used to heat and convert the coal followed by a water spray quench and a vibratory fluidized stage to cool the coal. The solid impurities are then removed from the dried coal using pneumatic separators. Other systems servicing and assisting the coal conversion system are:

- Product Handling
- Raw Coal Handling
- Emission Control
- Heat Plant
- Heat Rejection
- Utility and Ancillary

The nominal throughput of the demonstration plant is 450,000 tpy (1,640 tpd) of raw coal, providing 242,000 tpy (886 tpd) of coarse SynCoal® product and 66,000 tpy (240 tpd) of SynCoal® fines (minus 20 mesh). The fines are to be collected and sold, giving a combined product rate of 308,000 tpy (1,126 tpd) of high-quality, clean SynCoal® product. The central processes are depicted in Figure 1, the Process Flow Schematic.

Process Flow Diagram



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Coal Conversion

The coal conversion is performed in two parallel processing trains. Each consists of two 5-feet wide by 30-feet long vibratory fluidized bed/reactors in series, followed by a water spray quench section and a 5-feet wide by 25-feet long vibratory cooler. Each processing train is fed 1,139 pounds per minute of sized coal.

In the first-stage dryer/reactors, the coal is heated using recirculated combustion gases, removing primarily surface water from the coal. The coal exits the first-stage dryer/reactors, at a temperature slightly above that required to evaporate water, and is gravity fed into the second-stage reactors. Here the coal is heated further using a superheated gas stream, removing water trapped in the pore structure of the coal, and promoting the thermal destruction of the oxygen functional groups, such as hydroxyls, carbonyls and carboxyte that are normally prevalent in lower rank coals. The superheated gases used in the second stage are actually produced from the coal. The make-gas from the second stage system is used as an additional fuel source in the process furnace, incinerating all the hydrocarbon gases produced in the process. The particle shrinkage that liberates ash minerals and imparts a unique cleaning characteristic to the SynCoal® also occurs in the second stage. As the coal exits the second-stage reactors, it falls through vertical quench coolers where process water is sprayed onto the coal to reduce the temperature. The water vaporized during this operation is drawn back into the second-stage exhaust gas. After quenching, the SynCoal® enters the vibratory coolers where the SynCoal® is contacted by cool inert gas. The SynCoal® exits the cooler at less than 150 degrees Fahrenheit (F) and is conveyed to the pneumatic cleaning system. The cooler exit gas is cooled by direct contact with water prior to returning to the vibratory fluidized coolers.

Coal Cleaning

The SynCoal® entering the cleaning system is screened into four size fractions: plus 1/2 inch, 1/2 by 1/4 inch, 1/4 inch by 6 mesh, and minus 6 mesh. These streams are fed in parallel to four deep-bed stratifiers (stoners), where a rough specific gravity separation is made using fluidizing air and a vibratory conveying action. The light (lower specific gravity) streams from the stoners are sent to the product conveyor; the heavy streams from all but the minus 6 mesh stream are sent to gravity separators. The heavy fraction of the minus 6 mesh stream goes directly to the waste conveyor. The gravity separators, again using air and vibration to effect a separation, each split the coal into light and heavy fractions. The light stream is considered product; the heavy or waste stream is sent to a 300 ton storage bin to await transport to an off site user or alternately back to a mined out pit disposal site. The dry, cool, and clean product from coal cleaning enters the product handling system.

Product Handling

Product handling conveys the clean product coal to two 6,000 ton capacity concrete silos and allows unit train loading with the mine's tipple loadout system. SynCoal® fines are collected from the process baghouses and cyclones using screw and chain conveyors. The SynCoal® fines are conveyed to an indirect cooler that uses water cooled plates to reduce the temperature of this product to safe levels. The fines are then conveyed to a 250 ton truck loadout for sale.

Raw Coal Handling

Raw sub-bituminous coal from the existing Rosebud Mine A/B stockpile is screened to provide 1-3/4 x 3/8 inch feed for the ACCP process. Coal rejected by the screening operation is conveyed back to the active stockpile. Properly sized coal is conveyed to a 1,000 ton raw coal storage bin which feeds the process facility.

Emission Control

The fugitive dust from the coal cleaning system is controlled by placing hoods over the generation sources and conveying the dust laden air to fabric filter(s). The bag filters can remove 99.99 percent of the coal dust from the air before discharge. All fines report to a fines handling system than can briquette or cool the fines for product sales or make a slurry for disposal.

Sulfur dioxide emission control philosophy was based on injecting dry sorbent (sodium bicarbonate) into the ductwork to minimize the release of sulfur dioxide to the atmosphere.

Testing has shown very low SO_2 emissions occur inherently from the process, less than one-fifth the level expected with the emission control; therefore, the dry sorbent injection is not being used.

Heat Plant

The heat required to process the coal is provided by a natural gas fired process furnace. This system is sized to provide a heat release rate of 58 MM BTU/hr. Process gas enters the furnace and is heated by radiation and convection from the burning fuel. Process make gas from coal conversion is used as fuel in the furnace. A commercial scale plant would most likely use a coal fired process furnace due to the much lower energy cost of coal.

Heat Rejection

Heat rejection from the ACCP is accomplished mainly by releasing water and flue gas to the atmosphere through the 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, maximize the dissipation of the gases. Heat removed from the coal in the coolers is rejected using an atmospheric induced-draft cooling tower.

Utility and Ancillary Systems

The coal fines that are collected in the conversion, cleaning and material handling systems are gathered and conveyed to a surge bin. The coal fines are then briquetted and returned to the product stream.

The common facilities include a plant and instrument air system, a fire protection system, and a fuel gas supply and distribution system.

The power distribution system includes a 15 KV service, a 15 KV/5 KV transformer, a 5 KV motor control center, two 5 KV/480 V transformers, two 480 V load distribution centers, and six 480 V motor control centers. An uninterruptible power supply (UPS) was added to provide minimal power for control and emergency functions in the event of power interruptions.

Control of the process is fully automated including dual control stations, dual programmable logic controllers, distributed plant control, and data acquisition hardware.

PRODUCT CHEMISTRY

Rosebud SynCoal's Advanced Coal Conversion Process yields a synthetic solid fuel that represents an evolutionary step in the coalification process. Western U.S. lignite and sub-bituminous coals are converted by the thermal environment of the ACCP to a higher rank fuel.

The ACCP changes the chemical composition and structure of the coal feedstock. The changes include:

- Increased higher heating value;
- Increased aromaticity;
- Increase fixed carbon;
- Increased carbon to hydrogen ratios;
- Increased carbon + hydrogen to oxygen ratios;
- Decreased moisture content;
- Decreased sulfur content per million Btus;
- Decreased ash content per million Btus; and
- Decreased oxygen functional groups.

The above changes are the result of the thermo-chemical reactions induced by the ACCP and the enhanced ability to remove the pyritic and ash forming minerals resulting in the upgraded synthetic coal product.

The demonstration project has allowed the SynCoal organization to test North Dakota lignite and Wyoming sub-bituminous coals as well as the regular Rosebud sub-bituminous feedstock.

The average analyses of the coal feedstocks and upgraded products from the demonstration plant are shown in Table 1. The first section of the table shows standard proximate and ultimate coal

TABLE 1 - SYNCOAL QUALITY COMPARISONS - RAW FEEDSTOCKS VS. PRODUCTS

	ROSEBUD SYNCOAL FEEDSTOCK AND COAL PRODUCT ANALYSIS			CENTER SYNCOAL FEEDSTOCK AND COAL PRODUCT ANALYSIS			POWDER RIVER SYNCOAL FEEDSTOCK AND COAL PRODUCT ANALYSIS		
Proximate Analysis	Raw Coal Feedstock	Rosebud SynCoal	Rosebud SynCoal Fines	Raw Coal Feedstock	Center SynCoal	Center SynCoal Fines	Raw Coal Feedstock	Powder River SynCoal	Powder River SynCoal Fines
% Moisture	25.24	2.21	5.59	36.17	7.35	10.26	28.11	4.51	6.22
% Volatile Matter	29.16	36.98	35.32	27.13	39.39	36.33	31.78	41.4	39
% Fixed Carbon	36.69	51.19	49.65	30.16	46.74	43.92	35.25	47.48	48.48
% Ash	8.92	9.2	9.44	6.54	6.52	9.49	4.86	6.61	6.3
% Sulfur	0.74	0.56	0.87	1.07	0.77	1.06	0.34	0.45	0.48
BTU/lb	8634	11785	11194	7064	10799	9914	8727	11805	11339
lb SO2/MMBTU	1.71	0.95	1.55	3.03	1.43	2.14	0.78	0.76	0.85
lb Ash/MMBTU	10.3	7.8	8.4	9.3	6.0	9.6	5.6	5.6	5.6
% Equilibrium Moisture	24.9	14.7	20.2	34.98	20.12	21.92	28.38	14.04	20.2
Ultimate Analysis									
% Carbon	50.54	68.16	64.8	42.25	64.15	59.17	49.7	66.96	64.89
% Hydrogen	3.33	4.7	4.37	2.62	4.11	3.74	3.69	4.93	4.56
% Oxygen	10.47	13.52	13.83	10.76	16.22	15.35	12.52	15.39	16.48
% Nitrogen	0.76	1.23	1.1	0.59	0.88	0.93	0.78	1.15	1.07
C:H Ratio	15.18	14.50	14.83	16.13	15.61	15.82	13.47	13.58	14.23
(C+H):O Ratio	5.15	5.39	5.00	4.17	4.21	4.10	4.26	4.67	4.21
Petrographic Analysis									
% Huminite by volume	68.1	69.4	68.7	73.4	85.1	74.5	73.4	85.1	74.5
% Liptinite by volume	7.8	6	4.4	4.2	4.4	5.2	4.2	4.4	5.2
% Inertinite by volume	16.2	18.9	21.1	16.2	6.4	14.1	16.2	6.4	14.1
% Mineral Mater by volume	7.9	5.6	5.8	6.2	4.1	6.2	6.2	4.1	6.2
Reflectence	0.38	0.45	0.44	0.33	0.36	0.36	0.35	0.38	0.40
Carboxyl Concentration Analysis									
% COOH	0.85	0.26	0.46	0.53	0.17	0.31	1.02	0.15	0.41
Classification									
ASTM	Subbituminous C	High vol C bituminous	High vol C bituminous	Lignite A	High vol C bituminous	Subbit A	Subbit C	High vol C bituminous	High vol C bituminous

* MAF - Moisture and Ash Free

analyses of the coal feedstock and the synthetic coal product. The second section of the table shows additional analyses showing the coal upgrading by the process.

Moisture is essentially eliminated from the coal during the ACCP. This moisture removal is due to thermal dehydration of the coal particle both physical and chemical, and the chemical condensation reactions which the feedstock experiences during its residence in the high temperature environment of the second-stage reactor bed.

The moisture-free analysis of the feedstock and the upgraded product also show that, to a large extent, both the volatile matter and the fixed carbon content is retained in the SynCoal product. This phenomenon is significant and desirable, because normally raw coal, when subjected to the temperatures of the ACCP, would undergo devolatilization and substantial gasification. The ACCP products are much more desirable fuels because of their extremely good ignitability and complete combustion causing many observers to comment that it "burns like natural gas" except the opaque flame provides more radiant heat providing an additional benefit to direct fired kiln operations.

The reduction in total sulfur is due primarily to the mechanical removal of pyrites during the cleaning step. However, the ability to remove these pyrites is a result of the chemical repolymerization and consequent shrinkage of the organic components of the coal, which causes fracture release of the ash or mineral components. A small amount of organic sulfur is volatilized from the coal in the form of hydrogen sulfide (H_2S) during the upgrading process.

PROJECT STATUS

Construction of Rosebud SynCoal's ACCP Demonstration Facility was completed during the first quarter of 1992 at a total cost of approximately $35 million. Initial equipment startup was conducted from December 1991 through March 1992. Initial operations discovered the normal variety of equipment problems. The project's startup and operations groups worked together to overcome the initial equipment problems and achieve an operating system. The fines handling equipment was undersized originally and required a significant modification to expand the capability of this system. This modification was completed in August 1993. The lack of fines handling capacity prevented the facility from achieving full production rate and limited operating hours due to frequent fines handling equipment failures. The new fines handling system has expected to allow full production and more reliable operations. Table 2 shows the improved operations since September 1993.

TABLE 2 - SYNCOAL DEMONSTRATION OPERATING STATISTICS

Month	Production Availability	Forced Outage Rate	Tons Processed	Capacity Factor	Shipments
Sept 1993	73%	18%	14,371	65%	3,545
Oct 1993	76%	11%	23,528	63%	12,753
Nov 1993	85%	14%	27,930	74%	14,349
Dec 1993	74%	9%	26,009	69%	16,951
Jan 1994	73%	17%	34,979	93%	18,754
Feb 1994	67%	25%	29,280	85%	7,369
March 1994	82%	13%	41,891	112%	24,351
April 1994	72%	26%	34,438	92%	15,022
May 1994	76%	17%	39,440	105%	26,355
June 1994	77%	23%	36,657	98%	18,772

The SynCoal® product has displayed a tendency towards self heating that was not expected. The project's technical and operating team has conducted an extensive process testing program in order to determine the cause of the product's lack of stability. A number of approaches have been partially successful; however, to date, the demonstration product has not met the level of resistance to spontaneous combustion that was apparent in the earlier pilot plant work. This has reduced the storage life and as a result delayed the full-scale test burn program. An initial test burn program has been conducted at Montana Power's Corette station. A significant amount of handling and storage testing was conducted in preparation for the anticipated full-scale test burn program.

A test program was initiated March 1, 1994 at the J.E. Corette power plant using a 50/50 blend of raw sub-bituminous and DSE Conditioned SynCoal®. Testing has continued into the summer with some variations in plant loads and blend ratios. The results are still being evaluated, but the immediate indications include significantly improved boiler cleanliness, efficiency and operations capacity while the SO_2 emissions decreased with no noticeable effect on NO_x. With the higher SynCoal® blends SO_2 emissions decrease by as much as 43% and the plant could hold a 170 MWe load which is well above the normal 160 MWe load. The boiler efficiency increased from 84.9% to 85.7% with the 50/50 blend and to 86.2% with a 75/25 blend. The corresponding decreases in net unit heat rate were 130 Btu/kWh and 181 Btu/kWh respectively.

Additional testburning is anticipated later this year in a variety of facilities. The primary marketing focus this year has been expanding the industrial market applications of SynCoal®. This market niche is the most lucrative for SynCoal since it can take better advantage of the specific benefits of SynCoal®, adapts quickly and will pay for the additional benefits.

PROJECTIONS FOR THE FUTURE

The Rosebud Syncoal Partnership intends to commercialize the process by both preparing coal in their own plants and by licensing to other firms. The target markets are primarily the U.S. utilities, the industrial sector and Pacific Rim export market. Current projections suggest the utility market for this quality coal is approximately 60 million tons per year with potential industrial markets of 38 million tons per year. The Partnership is currently working on three potential semi commercial projects tentatively located in Wyoming, North Dakota and Montana. Each project represents significant enhancements toward the ultimate goal of a standardized process train and modular commercial design that will allow development of future facilities sized to match the needs of the specific markets anywhere from 500,000 to 5 million tons per year.

The Wyoming project is a stand alone mine mouth design. The North Dakota project is integrated into a mine mount power plant with the product sales offsite to regional markets. The Montana project is designed either as an integration into a power plant and fuel user or an expansion of the existing demonstration facility.

CONCLUSION

The ACCP is a relatively simple, low pressure, medium temperature coal upgrading and conversion process. The synthetic upgraded coal product exhibits the characteristics of reduced equilibrium moisture level, reduced sulfur content and increased heating value. The SynCoal product retains a majority of its volatile matter and demonstrates favorable combustion characteristics.

Although some difficulties have been encountered, SynCoal's technical and operating team are resolving the issues and SynCoal marketing is starting to expand rapidly. The ACCP Demonstration program is continuing with a complete team effort involving all three of the major participants. It is expected that the ACCP demonstration will continue to produce test results and technology development through the extended demonstration resulting from DOE's expanded funding and time schedule and the continued efforts of the Rosebud SynCoal Partnership.

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SynCoal® is a registered trademark of the Rosebud SynCoal Partnership.

APPENDIX A

ADVANCED COAL CONVERSION PROCESS SIGNIFICANT EVENTS

September	1981	Western Energy contracts Mountain States Energy to review LRC upgrading concept called the Greene process.
November	1984	Initial operation of a 150 lb/hr continuous pilot plant modeling the Greene drying process at Montana Tech's Mineral Research Center in Butte, Montana.
December	1984	Initial patent application filed for the Greene process, December 1984.
January	1986	Initiated process engineering for a demonstration-size Advanced Coal Conversion Process (ACCP) facility.
October	1986	Completed six month continuous operating test at the pilot plant with over 3,000 operating hours producing approximately 200 tons of SynCoal*.
October	1986	Western Energy submitted a Clean Coal I proposal to DOE for the ACCP Demonstration Project in Colstrip, Montana, October 18, 1986.
November	1987	Internal Revenue Service issued a private letter ruling designating the ACCP product as a "qualified fuel" under Section 29 of the IRS code, November 6, 1987.
February	1988	First U.S. patent issued February 16, 1988, No. 4, 725,337.
May	1988	Western Energy submitted an updated proposal to DOE in response to the Clean Coal II solicitation, May 23, 1988.
December	1988	Western Energy was selected by DOE to negotiate a Cooperative Agreement under the Clean Coal I program.
March	1989	Second U.S. patent issued March 7, 1989, No. 4, 810,258.
September	1990	Signed Cooperative Agreement, after Congressional approval, September 13, 1990.
September	1990	Contracted project engineering with Stone & Webster Engineering Corporation, September 17, 1990.
December	1990	Formed Rosebud SynCoal Partnership, December 5, 1990.

December	1990	Started construction on the Colstrip site.
March	1991	Novated the Cooperative Agreement to the Rosebud SynCoal Partnership, March 25, 1991.
March	1991	Formal ground breaking ceremony in Colstrip, Montana, March 28, 1991.
December	1991	Initiated commissioning of the ACCP Demonstration Facility.
April	1992	Completed construction of the ACCP Demonstration Facility and entered Phase III, Demonstration Operation.
June	1992	Formal dedication ceremony for the ACCP Demonstration Project in Colstrip, Montana, June 25, 1992
July	1992	Identified a variety of mechanical and process issues.
June	1993	Initiated deliveries of SynCoal® under a contract with industrial customer.
August	1993	State evaluated emissions, and the ACCP process is in compliance with air quality permit. ACCP Demonstration Facility went commercial on August 10, 1993, having resolved major mechanical issues.
October	1993	Tested North Dakota lignite as a potential process feedstock, achieving nearly 11,000 Btu/lb heating value and substantially reducing the sulfur content in the resultant period.
December	1993	Signed a Letter of Intent with Minnkota Power Cooperative to attempt development of a SynCoal® facility at M.R. Young plant site near Center, ND.
May	1994	Tested Wyoming Powder River sub-bituminous coal as a potential process feedstock, achieving 11,800 Btu/lb heating value in the resultant product.

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