KENTUCKY COAL TESTS IN A COMMERCIAL LURGI GASIFIER

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by

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OUTLINE

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KENTUCKY COAL TESTS IN A COMMERCIAL LURGI GASIFIER

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A commercial scale gasification test on Kentucky 9 coal was conducted in a Lurgi Mark IV dry-bottom gasifier at the Sasol One Plant between July and November 1981. The test was conducted to confirm the operability of the Lurgi process on Western Kentucky coal, and to confirm and modify, if necessary, the preliminary design basis for the Tri-State Synfuels Project. Other aspects of the overall program with Kentucky 9 coal included coal selection, characterization and shipping, gasification by-product characterization, wastewater treatability and long term stockpile tests.

1.0 INTRODUCTION

1.1 Tri-State Synfuels Project

Tri-State Synfuels Company, a partnership of Texas Eastern Corporation and Texas Gas Transmission Corporation affiliates, proposes to produce liquid transportation fuels and substitute natural gas from coal using the indirect liquefaction approach (Reference 1). The project is sited in Henderson County, Kentucky and will, if built, use commercially proven dry-bottom Lurgi gasification to produce the synthesis gas for subsequent liquid fuels production.

The Lurgi gasifier has been used in numerous applications on a variety of coals around the world. The Illinois Basin coals selected for the plant had swelling and caking properties in the upper range of those that had been used as Lurgi feedstocks. Therefore, it was deemed prudent to perform a full scale test on the size and type of gasifier planned for the multibillion dollar plant. The subject of this paper is the full scale test program that was undertaken at the Sasol One facility in Sasolburg, Republic of South Africa, to demonstrate the operability of the Lurgi process on the design coal and to generate the necessary design data.

The Tri-State Project, as originally conceived, would have been a very close replicate of Sasol Two which is based on Lurgi Mark IV gasification and Fischer-Tropsch synthesis. In the Tri-State project, however, methane would have been co-produced instead of reformed as in the Sasol plants for additional syngas. The plant would have produced 56,000 barrels of crude oil equivalent per day.

The configuration of the project was the logical result of a corporate strategy of pursuing a synfuels project based upon technology which was proven and operating on a large commercial scale. The only existing coal-based synthetic transportation fuel facilities operating on a world scale are located in Sasolburg and in Secunda, Republic of South Africa. Recent reviews of the status and technology of the Sasol plants are provided in References 2 and 3.

The approach of using commercial technology instead of emerging technology was pursued in order to facilitate project financing and reduce overall project risks. The economic impact associated with the somewhat lower efficiency of the so-called first generation technology was believed to be more than overcome by several factors:

1. The ability to build plants more quickly by replicating as closely as possible the Sasol Two Plant.

2. The availability of more favorable interest rates due to lower risk factors.

3. The ability to start-up sooner and achieve full production more rapidly.

4. The ability to achieve higher on-stream and production factors because of extensive operating experience and maintenance procedures.

A preliminary engineering and feasibility study had been completed by Texas Eastern in April 1980 and the philosophy of achieving early production with minimal risks appeared to be consistent with the Energy Security Act. Therefore, the project responded to the first round of U.S. Department of Energy solicitations for alternative energy projects and was awarded a Cooperative Agreement contract for a work program totaling $43.5 million.

A mid-western location had been determined to be advantageous for a Fischer-Tropsch type plant because of the quantity and diversity of chemicals produced and the need to be near existing traditional fuel markets. After an extensive site screening process, a site was selected in Henderson County, Kentucky, on the Ohio River. The site was attractive in that it was one of few available of the size required and under limited ownership, on the river, and in close proximity to coal reserves and gas and liquid pipelines.

In January 1982, the project was altered with a change of synthesis technology, product slate, and plant size. The Fischer-Tropsch synthesis was replaced with a methanol synthesis and MTG process which converts the alcohol to gasoline. The product slate was greatly simplified from a large number of chemicals, liquid fuels and substitute natural gas to gasoline and substitute natural gas. The plant size was lowered to 15,000 barrels of crude oil equivalent per calendar day which required 8,165 tons of coal.

The fundamental reason for reduction in project size was to reduce capital expenditures to a level which was more financible within the Synthetic Fuels Corporation constraints and more likely to attract additional partners. It was also found that a substitute natural gas and MTG product slate appeared more profitable than the Fischer-Tropsch product slate with its associated chemical production at least under the Tri-State product price assumption for the Kentucky area. The use of Lurgi gasification remains as the basis for for the project, thus the need for and value of the coal test were not affected by the project changes that have occurred.

1.2 Feasibility Study

Texas Eastern commissioned Sasol (Proprietary) Limited in late 1979 to conduct a six-month feasibility study on the conversion of Illinois Basin coal to liquid transportation fuels and pipeline quality gas using the commercially proven Lurgi gasification and Sasol Synthol processes. Fluor Engineers and Constructors, Inc. and Lurgi Kohle und Mineraloeltechnik GmbH participated in setting the study criteria. The study, completed in April 1980, showed that Lurgi gasification of Illinois Basin coal was technically feasible and commercially viable, and that the plant could be operated in an environmentally acceptable manner. The feasibility study formed the basis of the proposal to the U. S. Department of Energy for a cooperative agreement work program.

The coal chosen for the feasibility study was Illinois 6 which had been tested at Westfield, Scotland in the American Gas Association - Office of Coal Research Program in 1973-74. The product slate was 56,000 barrels of crude oil equivalent per calendar day from 28,600 tons of coal. The overall thermal efficiency of the plant was about 48%.

The transportation grade fuels and substitute natural gas would not only have been fully interchangeable with conventional fuels and compatible with fuel supply systems but could have been used in an environmentally sound manner. The gasoline, which met the projected octane requirements of the late 1980's, contained no lead and was free of sulfur and nitrogen compounds, so that no adverse impacts would have been created in end use.

1.3 Cooperative Agreement

Tri-State Synfuels Company entered into the Cooperative Agreement (No. DE-FC05-81OR20807) with the U. S. Department of Energy in February 1981. The work program, initiated on February 6, 1981, included the commercial scale coal test, complete process engineering and design, site specific cost estimates, securing all necessary environmental permits, obtaining feedstock purchase and major product sales commitments, finalization of the economic evaluation, and development and implementation of a financial plan including support from the Synthetic Fuels Corporation. The plan called for a commitment to begin construction in early 1983 with plant start-up scheduled for 1987. The change in project scope in early 1982, resulted in a schedule delay of one year.

Due to subsequent changes in the economic and political environment for synthetic fuels, Tri-State Synfuels could not justify maintaining the level of expenditures required to continue with the Cooperative Agreement work program and elected to terminate the agreement in April 1982. The work accomplished during the program has been reviewed in a series of reports issued in June 1982.

The Cooperative Agreement work program on the commercial scale coal test is reported in References 4 and 5. This paper is based on that work. A supplemental program developed to survey Illinois Basin coals as part of the supply and design effort is reported in References 6 and 7.

2.0 OVERALL TEST PROGRAM

2.1 Background and Objectives

The commercial scale coal gasification test was conducted at the Sasol One Plant in Sasolburg between July and November 1981, on Kentucky 9 coal. The test was successfully conducted on a world scale Lurgi Mark IV dry-bottom gasifier, modified with a distributor-stirrer to overcome the medium to strongly swelling and caking tendencies characteristic of Illinois Basin coals.

Previous large scale experience with this type of coal in a Lurgi dry-bottom gasifier was gained at Dorsten, Germany and at the Westfield Plant of the British Gas Corporation in 1973-74 during trials conducted for the American Gas Association and Office of Coal Research of the U.S. Department of Interior (References 8 and 9). The loads achieved during the Westfield tests were limited by the control valve supplying superheated steam to the gasifier. Nonetheless, the Illinois Basin and Pittsburgh 8 coals were processed successfully during the planned 48-hour trials.

Tri-State Synfuels is one of the very few projects in the United States that has had an opportunity to test a specific feed coal in a large scale commercial operation. Exhibit 1 summarizes the tests of U.S. coals at Lurgi coal gasification plants in Westfield and Sasolburg. A wide range of coal types representing most of the U.S. coal regions has been tested on a commercial scale. A recent Lurgi paper (Reference 10) provides an overview of coal testing in commercial and development gasifiers including tests with Kentucky 9 coal.

In 1974, ANG Coal Gasification Company tested North Dakota lignite at Sasolburg. These data were used to set the design of the Great Plains Gasification Associates Project, now under construction near Beulah, North Dakota. Other tests have been conducted by Carter Oil, Panhandle Eastern Pipeline and Phillips Coal.

The Kentucky 9 test was conducted in order to confirm the operability of the Lurgi process with Western Kentucky coal and the preliminary design basis for the Tri-State Synfuels Project used by Lurgi and Sasol in the preparation of the feasibility study. The test plan was structured to optimize design parameters of both the gasification and associated plants and their component units. Each type of coal has its own particular characteristics requiring specific adaptations to plant and equipment, and modifications and design base ranges derived from Lurgi laboratory test work can best be narrowed down by an actual gasification run on the specific coal.

The information resulting from the overall test program was used to provide a firm design basis for material and heat balances and equipment sizes and costs for the coal handling and storage, gasification, stripped gas liquor cleanup, syngas preparation, and steam generation sections. The individual gasifier load determined in this test set the number of gasifiers required to produce the desired syngas rate.

2.2 Work Scope

The overall scope of the work of Tri-State Synfuels and Kentucky Department of Energy for the coal test program was to:

- o Select an Illinois Basin coal to be used for the commercial scale gasification test and for the design and environmental criteria bases.
- o Characterize the design coal by determining:
  - Physical and chemical properties of the coarse and fine fractions.
  - Size consist since there is a likelihood of excess fines.
  - Rate at which fines are generated in handling.
  - Utilization of fines for combustion.
- o Conduct a commercial scale coal gasification test on the Lurgi Mark IV gasifier, modified with a distributor-stirrer, to:
  - Confirm the operability of Illinois Basin coal.
  - Confirm and modify, if necessary, the preliminary design basis used by Sasol and Lurgi in preparation of the April 1980 feasibility study.
  - Optimize design parameters of coal preparation, gasification and associated units.
- o Conduct a small scale cooling tower test to examine the feasibility of direct use of stripped gas liquor from the test coal as cooling water makeup. If feasible, raw water intake would be reduced, the cooling system could be used as a biotreatment facility and chemical additives might be eliminated.
- o Characterize export samples of various liquids and solids from the coal gasification test to:
  - Develop environmental design information and support permits especially in areas of wastewater treatment and ash disposal.
  - Support market development efforts, especially of crude phenols.
  - Develop engineering design data for naphtha hydrotreating and creosote/cresol upgrading, possibly leading to pilot plant tests.

- Conduct a wastewater treatability study on the stripped gas liquor from the Illinois Basin coal to:

  - Optimize environmental parameters on biological treatment with emphasis on organic removal, post filtration using multimedia filters, and effluent polishing with activated carbon.

  - Obtain data to support permit applications.

- Conduct long term tests on a compacted stockpile of the test and design coal to:

  - Determine weathering effects on quality and gasification characteristics.

  - Determine leaching effects on quality and run-off compositions to establish design criteria on water collection systems.

  - Demonstrate stockpile construction that prevents spontaneous ignition.

2.3 Participants' Roles

The organizations and individuals associated with all phases of the coal test program number into the hundreds. Appreciation is expressed to those many organizations and individuals whose cooperation and expertise contributed to the execution of the program.

The commercial scale gasification test was conducted by the Technology Transfer group of Sasol Technology (Proprietary) Limited with assistance by key operating personnel from Sasol One and Sasol Three plants.

The gasification test was witnessed by Lurgi, Kentucky Department of Energy and Tri-State personnel at all times. Lurgi acted in an advisory role to Sasol and Tri-State during the test and provided the process design heat and material balances developed from the test program results.

The coal sampling and analytical testing activities during the selection, collection and shipment, fines utilization and stockpile programs were planned and supervised by Paul Weir Company, assisted by Commercial Testing & Engineering Co. and McLachlan & Lazar (Pty) Ltd.

The test coal was mined by Peabody Coal Company under contract to the Tennessee Valley Authority, owner of the mine.

Transportation services were provided by the Overland Coal Conveyor Company, American Commercial Barge Line Company, Ugland Shipping Company and South African Railways and Harbours.

Texas Gas Transmission coordinated the stockpile program including meteorological observations, sampling and testing schedule and leaching tests. Texas Gas Transmission also provided design recommendations on coal preparation.

Texas Eastern provided management, coordination and technical guidance and assistance throughout the overall program.

Major funding for the test was provided by the Kentucky Department of Energy. Under Memorandum of Agreement No. 3687 between the Tri-State Project and the Commonwealth of Kentucky, support was provided in the areas of:

1. Option for the plant site
2. Research
3. Financial assistance for the coal test at Sasol

The Kentucky Department of Energy obtained an option for $1.3 million from the American Electric Power Company for their approximately 7,000-acre site in Henderson County in August 1981. Research support has been provided by the Institute for Mining and Minerals Research, the Kentucky Department of Energy research contractor, in the areas of coal analysis, materials testing, and analysis of samples taken during the gasification test.

The Kentucky Department of Energy was authorized by its Energy Research Board to pay up to $4 million to carry out the full scale coal test at Sasol. The State was granted access to certain test data and allowed to have observers present during the coal test.

The State's primary objective in sponsoring the tests was to directly support the Tri-State project. A secondary objective was to prove more broadly the operability of the well-proven Lurgi commercial pressurized gasification process on Kentucky coal. This would expand the technology options open to industries considering synfuels project opportunities in Kentucky. The tests also provide a basis of comparison for improvements in advanced generation gasifiers, thus assisting the department in evaluating future support of gasification research and technology development.

2.4 Cost

The total cost of the overall coal test program including the expense of on-site observers and management of the program, was approximately $4.0 million as shown in Exhibit 2.

The Kentucky Department of Energy is paying approximately $3.5 million which includes all costs except Tri-State's on-site observers and management. Over half of the overall test program was the cost of producing and transporting the coal. Other costs included the gasification test, technical support, observation, management, and sampling and testing.

The sampling and testing program was conducted during the coal shipment, the Sasolburg test and Kentucky stockpile test and was far more comprehensive than those during any other test of a U. S. coal. Included in the sampling costs were supervision of collection, loading and inspection; storage; and analytical testwork.

3.0 TEST AND DESIGN COAL

3.1 Selection

In 1980, a preliminary collection of Illinois Basin coal quality data was developed to support the selection of coals for potential supply to the Tri-State Synfuels Plant and full scale commercial testing at Sasolburg. Exhibit 3 identifies the counties in the region with reserves and operating mines for which coal quality data were available. Information was provided by potential suppliers, the Kentucky Center for Energy Research and The Pennsylvania State University. Coal quality information was also developed by collecting and analyzing several run-of-mine samples. The coal quality data were used as a guide to identify representative candidate mines for the supply of the test coal. The candidate mines are located on Exhibit 4 and are mostly within 50 miles of the plant site.

In December 1980, the list of potential source mines for the 22,000 short ton sample of raw coal for the test was narrowed to three. The candidate coals were from the Kentucky 9 seam and were mined by the conventional, underground method. The mines were Camp 1, Ken and Providence.

The three candidate mines were again sampled in December 1980 and representative splits of the run-of-mine samples were flown to Lurgi and Sasol for examination.

Lurgi and Sasol indicated that both Camp 1 and Ken mine samples would qualify as suitable gasifier feed coals. Lurgi and Sasol regarded the Providence sample as a strongly swelling coal which should only be considered as a suitable feed coal for subsequent plants. Lurgi advised against using Providence coal as a feedstock for the initial plant. The Lurgi criteria included proximate analysis, carbonization assay, ash melting behavior, reactivity, free swelling and caking number tests.

Since the three coals were technically suited for gasification, the final selection of the Camp 1 mine for the test shipment resulted from the following considerations:

- Geographical proximity to the plant site, since a substantial portion of the coal feedstock would come from nearby Kentucky 9 reserves which are considered similar to the test coal.
- Ability to limit fines content to about 35% in the run-of-mine coal to compensate for attrition of coarse coal during rehandling operations in transport to Sasolburg. The conveyor belt operation at Camp 1 loadout would allow a selection period of one hour for the rejection of fine slugs before loading the barges.
- Logistics which avoided rail or small barge movement to the Ohio River to minimize rehandling and attendant fines generation.

3.2 Source

The test coal came from Tennessee Valley Authority's reserve which underlies the former Breckinridge Camp in Union County, Kentucky. The Peabody Coal Company operates, under contract, two mines on that reserve -- Camp 1 and 2 mines. The test coal was taken from the Camp 1 mine which is Peabody's third largest (1.77 million tons in 1980) mine in Kentucky. The coal is deep-mined using conventional techniques from the Number 9 seam which has a thickness in that area of approximately 60 inches and is approximately 400 feet deep. Coal is brought to the surface by both conveyors and shuttle cars. The coal was processed through a rotary breaker to a nominal 2-inch top size and transported by conveyor approximately nine miles to the barge loading facility on the Ohio River.

3.3 Characteristics

The test coal selected was from the Kentucky Number 9 seam which is the most abundant in the region surrounding the plant site and which has characteristics representative of the majority of coals within the region. Those characteristics of the test coal such as heating values, free swelling index, caking number, sulfur content, ash fusion temperatures and other key parameters insofar as gasification are concerned were generally mid-range for coals within the Illinois Basin.

Exhibit 5 lists the test coal characteristics. The classification by rank of the test coal is in the high volatile bituminous B group. The coal has a moderate free swelling index (FSI), typically 3 1/2 to 4 1/2, and a medium caking number (Damm) in the range of 12 to 23. The FSI (ASTM D 720) refers to the volume increase of a coal on free expansion during heating and may be used as an indication of the caking characteristic of the coal when burned as a fuel. The caking power refers to the wetting and binding tendency towards an added component. The nature of these characteristics required modifications to be made to the standard Mark IV gasifier and start-up procedures as discussed in Section 4.4.

Additional work on sampling and testing of run-of-mine Illinois Basin coals has been conducted (References 6 and 7) under a different program to:

- o Identify and rank other coals suitable for Lurgi gasification to supplement the data from Camp 1 being used as the design basis.
- o Establish an estimate of the size consist and quality ranges to be expected.
- o Establish a sensitivity range for the Lurgi design for Camp 1 coal to develop maximum heat and flow rates to specify equipment requirements.
- o Establish environmental design criteria in the areas of wastewater treatment and solids disposal.
- o Provide technical guidance to assess reserves potentially available for the project.

Ten mines representative of future coal production sources were examined. The mines represented a mix of underground -- both continuous and conventional mining -- and strip mining. The two predominant seams in Illinois, Indiana and Kentucky were sampled. The technical data on these run-of-mine coals were judged to be representative of the coal to be mined from potentially available reserves by the various operators.

3.4 Collection and Shipment

Once the decision was made to utilize the Camp 1 coal as the test and design coal, meetings were held to review and firm up the tentative collection and shipment schedule and responsibilities. Several key dates had to be accommodated. First, it was necessary to collect and load the coal before the mine collection belt would be shutdown to make a changeover to a newly installed wash plant. Second, it appeared that a tight schedule would be needed to avoid having the bulk carrier in the lower Mississippi incur excessive demurrage. Third, there might be severe cold weather which could have delayed barge traffic on the Ohio River system. As it turned out, cold weather was never a factor. Through the cooperation of all parties, collection and shipment were carried out in a timely fashion.

Extensive efforts were taken to ensure quality control in shipping at every step along the way since the objective was to limit the size degradation, as measured by an increase in the minus 1/4-inch fines fraction. To accomplish the desired control, Tri-State Synfuels supervised the transfer operations, sampled frequently and paid additional funds to lower the coal clamshells to the coal surface during unloading to limit breakage. Since the gasification step was believed capable of handling some fines, and the cushioning effect of fine coal would limit the attrition rate, run-of-mine (2 inch x 0) coal was shipped as opposed to sized coal (2 inch x 1/4 inch).

The collection of Camp 1 coal at the mine in Morganfield, Kentucky (Exhibit 6) and shipment of the sample to Sasolburg occurred February through April, 1981. The work involved inspection, sampling, preparation and analytical test work on coal quality and size for the mine, barge, ship and train transfer points. These locations were Morganfield and Uniontown, Kentucky; Darrow, Louisiana; and Port Elizabeth and Sasolburg, Republic of South Africa.

The samples were taken not only to ensure quality control at every step during the shipment but to obtain fines generation data during rehandling and to establish a chemical and physical characterization of the coal for testing and design purposes. These points will be discussed in Sampling and Testing, Section 5.0.

Selection and Loading at Uniontown, Kentucky - Camp 1 loading commenced February 23 at the Uniontown dock on the Ohio River and took place over a three-day period. Direct feed from the mine storage was used to enable selection from the nine-mile conveyor belt and to allow low loading rates (1300 tons per hour) to limit breakage.

Loading was completed February 25 and the barge tow left for the 900-mile trip to Darrow, Louisiana. On the 15-barge tow, 22,558 tons of 2 inch x 0 raw coal were loaded at an average fines content of 37.2% based on on-site screening.

Transloading at Darrow, Louisiana - The tow arrived at Darrow milepost 175 on the Mississippi River (Exhibit 7) on March 2 where the barges were secured and inspected daily until barge-top sampling commenced March 17. Sampling took place over two days.

The M.S. Bonita's holds were inspected for cleanliness just prior to transloading which commenced on March 19 in mid stream at milepost 180. Two barge-mounted cranes with 16-cubic yard clamshells were used to transload the coal from both sides of the ship. Each clamshell was lowered to the top of the pile in the ship's holds so as to limit breakage.

The loading was completed on March 20 and the bulk carrier left Darrow early the next morning for the Gulf of Mexico and South Africa (Exhibit 8).

Offloading at Port Elizabeth, South Africa - After the 8600-mile voyage, the M.S. Bonita arrived in the Port Elizabeth harbor (Exhibit 9) on April 14 and berthed later that day. Harbor facilities at Port Elizabeth were not designed for high-rate unloading of loose bulk coal. Offloading commenced on April 15. Up to six small clamshells on shore cranes were used for loading the coal on side- dump rail cars of 35-metric ton capacity. Two or three tracks were used simultaneously. The overall unloading took 10 days including the Easter holiday. A total of 587 rail cars was inspected, loaded, sampled and weighed before dispatch in 34-car trains to Sasolburg. Seventeen trains were dispatched over the 10-day period.

Unloading at Sasolburg, South Africa - Each train arrived at Sasolburg railhead after a two-day trip covering about 800 kilometers. The side-dump rail cars were unloaded by front-end loaders into dump trucks which transported the coal about two kilometers to the Sigma mine stockpile for storage until the gasification tests started in July.

In conclusion, an extensive detailed collection and shipment program was carried out to obtain technical knowledge on the handling and chemical and physical characteristics of typical Western Kentucky coal to support supply and design criteria for the Tri-State Synfuels Project.

4.0 GASIFICATION TEST

4.1 Objectives and Plans

The specific objectives of the test on the Lurgi Mark IV gasifier, modified with a distributor-stirrer, were to:

- o Confirm gasifiability of medium swelling and medium caking Kentucky 9 coal.
- o Confirm actual consumption and production parameters.
- o Determine optimum combination and range of gasification variables.
- o Confirm maximum load conditions and identify load restrictions.
- o Determine effect of fines in coal feed on gasification process.
- o Determine physical and chemical properties of products and by-products.
- o Evaluate effect of tar injection on gasifier performance and products and by-products yield, and establish maximum tar injection rate.
- o Obtain environmental design criteria data to facilitate permit acquisition.
- o Obtain samples of process intermediates, products and by-products for export to U.S. for in-depth analysis for environmental, marketing and design purposes.

The information resulting from the test was required to provide a firm basis for the material and heat balances for all units from gasification through syngas cleanup, and to set the number of gasifiers for the project.

The original gasification test program schedule as planned is shown in Exhibit 10. The start-up was planned on Sigma -- a non-caking coal -- to be followed by mechanical checkout and optimization run on the test coal.

The optimization run is required to: (1) set the proper steam-to-oxygen ratio to avoid excessively large clinkers and (2) set the optimum gas outlet temperature in conjunction with optimum distributor-stirrer revolutions and torque measurements, as well as ash temperatures and grate revolutions required.

The mass and heat balance was planned for 2 inch x 1/4 inch (50 millimeter x 6 millimeter) dry-screened coal over a 48-hour period at reasonable loads.

The high load test was to feed 2 inch x 1/4 inch dry-screened coal with a step-wise increase in undersize material, in effect, simulating a run-of-mine coal. The final high load test was to be conducted with 2 inch x 1/8 inch (50 millimeter x 3 millimeter) wet-screened coal.

A cooling tower test was also planned to examine the feasibility of using stripped gas liquor generated from Kentucky 9 coal for cooling purposes by determining the: (1) extent of corrosion and fouling, (2) degree of passivation on carbon steel, (3) extent of biological activity and control, if needed, and (4) effect of such a cooling tower on the environment.

4.2 Test Facility Description

The Sasol One Plant has a total of 17 Lurgi gasifiers from generations built in the 1950's and 1960's up to the three prototype Lurgi Mark IV gasifiers installed in the late 1970's and a Mark V gasifier commissioned in 1980. The Lurgi Mark IV unit is the standard size gasifier now installed at Sasol Two and Three Plants. A total of 80 Mark IV's is installed at these two plants.

A simplified block flow diagram of the Sasol One Plant is shown in Exhibit 11. The plant produces transportation fuels, medium Btu gas for industry, and chemicals via Lurgi gasification and Fischer-Tropsch synthesis. The heavily outlined process blocks around the gasification section of the plant indicate the portion of the plant which was dedicated to the Tri-State test. The test unit consisted of one complete Lurgi train. The synthesis gas produced during the test was mixed with the gas produced from the normal commercial operation prior to the acid gas removal unit. This test represents the first time Kentucky coal has been converted to liquid hydrocarbon transportation fuels on a commercial basis.

Sasol removed from commercial service one of the three Mark IV gasifiers in June 1981 for installation of a distributor-stirrer of Lurgi design. This modification allows gasification of swelling and caking coals such as the Kentucky 9 coal, a representative coal from the Illinois Basin.

The Kentucky 9 coal was stored without compacting at Sigma mine from late April until the tests started in July. The coal was continuously observed for possible ignition. The coal did not exhibit dangerous temperature levels which would indicate excessive heat build ups. After the September phase of the coal test, the remaining stockpile was relocated and compacted prior to the November tests to prevent the likelihood of spontaneous ignition.

A simplified diagram of the coal handling and preparation facility that was used for the test is shown in Exhibit 12. When the gasifier tests were ready to start, the coal was loaded onto dump trucks by front-end loader and transported to the concrete slab inside the plant and next to the loading bin at the screening plant. The screening plant is capable of dry or wet screening at several sizes. The plant was set up to prepare 2 inch x 1/4 inch (50 millimeter x 6 millimeter) coal for gasification and the fines were sent to the ash dumping area. Initial tests were done with dry screening, but, after the material balance test, all screening was done wet. During the high load tests, another screen was added to remove material greater than 2 inches (50 millimeters) in size.

The gasification test unit consisted of one complete Lurgi train from gasification through cooling and gas liquor separation. The gasifier for the Tri-State test was equipped with additional instrumentation to provide data required to do heat and material balances. Sufficient gas liquor was collected and stored and processed batchwise through the phenol recovery and ammonia removal units to provide gas liquor for feed to the test cooling tower over a three-month period.

4.3 Lurgi Process Description

The Lurgi process takes a coarse coal feed and produces a synthesis gas containing hydrogen, carbon monoxide, methane and some carbon dioxide.

In the original feasibility study for the Tri-State Synfuels Project conducted in 1980, synthesis gas was used in the Fischer-Tropsch synthesis to produce liquid hydrocarbons which were then refined to transportation fuels. In the revised version, the synthesis gas is used to produce methanol which subsequently is converted to liquid hydrocarbons in the gasoline-boiling range.

The Lurgi Mark IV gasifier is shown in Exhibit 13. For a coal with swelling and caking properties, such as the Camp 1 coal, the gasifier is equipped with a coal distributor-stirrer.

The screened coarse coal from the battery limits is transported to the bunker on top of the gasifiers and a coal level maintained to provide for shutdown and blockages at the screening plant. The coal is charged via coal lock feeding chutes to each gasifier by an automatically operated coal lock, which transfers the coal from the atmospheric bunker to the pressure reactor. The coal moves downward and is gasified by the upflowing gasification agent which is a steam and oxygen mixture. Ash formed in the gasifier accumulates at the bottom of the gasifier and is removed by a rotating grate and discharged to an ash lock and further to an ash handling system.

The typical Lurgi process flow scheme with several auxiliary processes is shown in Exhibit 14.

The hot crude gas leaving the gasifier is first washed and scrubbed with recycle gas liquor from the waste heat exchanger. Further cooling takes place in the waste heat exchanger which uses the heat to produce low pressure steam. More gas liquor and heavy tars are condensed.

Gas from the waste heat exchanger is further cooled in a series of heat exchangers. In the first cooling step, heat is recovered and normally preheats boiler feedwater. An air and a water cooler are added as second and third cooling steps.

The crude gas now enters the Rectisol unit at a temperature of about 100°F. Rectisol, a gas purification process, uses cold methanol to remove sulfur compounds and carbon dioxide as well as naphtha and hydrogen cyanide. The unit consists of absorption and regeneration steps. The gas leaving the Rectisol unit can be fed as synthesis gas to several downstream processes depending on the desired products.

Condensed gas liquor from the waste heat exchanger and from the various cooling steps is transferred to the gas liquor separation unit. This unit separates tar and oil (if produced) from the liquor streams. Separation of these components is accomplished by physical methods based on differences in their densities.

The dust-containing tar is recycled back to the gasifiers where it is gasified. Injection water to the scrubber is taken from the gas liquor surge tank.

After a final filtering, the gas liquor is routed to the Phenosolvan unit to recover phenols from the gas liquor. This is accomplished by a solvent extraction process using di-isopropylether in a series of mixer-settler type extraction units.

The tar-oil-phenol-free water is further processed to recover the ammonia. Afterwards, the effluent is finally sent to a wastewater management unit for biological treatment.

4.4 Review

The Kentucky coal tests were carried out during three different time periods at Sasol in 1981. The first phase of testing (August 1-8) was interrupted by plant production requirements. The second test phase (September 14-20) was terminated to allow for equipment modifications. The third phase (November 14-17) was carried out through completion of the test on modified equipment.

The first group of the Tri-State team arrived at Sasolburg on July 22. The test plan and operational and safety procedures were reviewed and finalized with Sasol and Lurgi. The coal handling equipment and gasification train that were used for test purposes were inspected by the project team and the separation of that system from the rest of the production system was verified. Valves and gates which were used to isolate the systems had been labeled and chained or locked in place by Sasol to prevent accidental contamination.

The distributor-stirrer, which was fabricated in South Africa to a proprietary Lurgi design, was installed just prior to the arrival of the Tri-State team. Although similarly designed distributor-stirrers had been successfully used in the Lurgi gasifiers at Westfield, Scotland and Dorsten, Germany, the device installed for the test was significantly larger than previous distributor-stirrers.

The modification to the standard Mark IV gasifier means the addition of a coal distributor in the top of the gasifier to, besides other purposes, allow room for swelling of the coal, and below this distributor, a stirrer to prevent agglomeration or caking of the coal as it is heated through the plastic range in a zone below the distributor. The distributor-stirrer, which was the first used in a Mark IV gasifier, is water cooled. The arms rotate in the zone which moves char from below upwards into the caking zone to combine leaning (reduction of caking index) with agitation (Reference 8).

The distributor-stirrer was first tested in a cold pressurized mode before the initial operation on Sigma coal. A few days operation on Sigma coal were required to workout minor mechanical and electrical problems, develop operational procedures, and line out the operation. For all subsequent cold start-ups during the test, Sigma coal was used initially followed by introduction of the Kentucky coal.

Commercial operation would require similar procedures using either a coke or non-caking coal for start-up of an empty gasifier. The start-up procedure requires a gasifier full of coal at ambient temperature to be heated to operating temperatures, i.e., through the plastic range. If this procedure is done on a gasifier filled with caking coal, it will result in caking of all coal in the gasifier.

Phase 1 - Kentucky coal, dry-screened at 6 millimeters as measured at the screening plant, was first introduced into the test gasifier on August 1. The operating parameters including steam and oxygen rates, gas outlet temperatures, distributor-stirrer speeds, ash temperature and grate speeds were determined during an optimization run. The steam-to-oxygen ratio was optimized at the lowest value such that the ash did not contain excessively large clinkers and the gasifier operated with stability.

After 13 hours of the optimization run, the gasifer tripped out due to high gas outlet temperature. It was shutdown for inspection, emptied and the contents placed on the ground in the order removed, thereby giving an easily examinable profile of the gasifier bed from top (coal) to bottom (ash). No large agglomerated coal lumps were present, which indicated that the distributor-stirrer was operating as expected and preventing coal particles from caking together. It was also realized that the gas outlet temperature and ash bed could be lowered because there was no danger of the caking zone extending below the reach of the stirrer. Sasol reported that these factors made operation of the gasifier on the test coal much simpler than anticipated.

The unit was restarted on Sigma coal, followed by introduction of Kentucky coal. After 13 hours steady run on the Kentucky test coal, the mass balance test began on August 5 and continued over a 50-hour period. The crude gas production during the mass balance was maintained at approximately 34,200 normal cubic meters per hour with a coal throughput of 19.1 metric tons per hour (dry basis). At those rates, the high pressure steam consumption was 34.6 metric tons per hour, and the oxygen consumption was 5,793 normal cubic meters per hour on a 100% purity basis. The total steam consumption rate, which includes jacket water and desuperheater water, was the same as projected in the feasibility study. The oxygen rate was about 8% lower than the feasibility study value. The ash was described by Sasol as being medium coarse and easy to handle.

The other mass balance operating and flow parameters are presented in Exhibit 15. The crude gas composition and tar and gas liquor characteristics are given in Exhibits 16 and 17, respectively. The hydrogen content of the gas was higher and the carbon monoxide was lower than projected thus the hydrogen-to-carbon monoxide ratio was higher than the feasibility study ratio (which was based on data for Illinois 6 coal) and no shift unit is required. The methane content was essentially the same as projected for the feasibility study.

The simplified corrected mass and energy balances determined by Sasol are given in Exhibit 18. The source of these technical data is "Coal Gasification Test for Tri-State Synfuels Company: Summary," 1981, prepared by Sasol Technology (Proprietary) Limited. The energy balance around the gasifer indicates that approximately 81% of the coal energy input appears in the raw gas and by-products.

Tar injection was planned for the mass balance test but all attempts during the pre-mass balance period to draw fairly dust-free tar from the primary tar separator bottom failed. All tar was completely mixed with dust (coal and char fines). The lower-than-anticipated tar production observed and higher-than-normal dust carryover rates made tar injection impossible. It was agreed that the mass balance would be run without tar injection.

During the mass balance run, dust carryover was still high. It was determined that it would be impossible to increase the load above that used during the mass balance test for the high load test and also perform tar injection without reducing the fines in the feedstock coal. The dry-screened coal contained an average 5.6% fines of less than 6 millimeters in size. It was also realized that the maximum gasifier load would probably be limited by the amount of dust that the system would handle. In a commercial operation, all dust would be carried over and end up in the dusty tar and would have to be reinjected into the gasifier.

The required reduction in fines was achieved by wet screening the coal and reducing the undersize (minus 6 millimeters) coal to less than 3%. The effects of wet-screened coal were immediately noticeable and 10 hours following that change clear tar was obtained, tar injection was started, and the gasifier load was increased stepwise while monitoring dust carryover. In this run and all subsequent runs, successful tar injection was achieved.

After 18 hours of operation, a commercially acceptable gas rate had been reached but then the unit started showing signs of bad clinkering and was shut down and inspected. The clinkering was primarily due to a low steam-to-oxygen ratio. In addition, lumps of heavy, hard material, consisting of both pyritic coal and rock were found in the gasifier and were suspected to have contributed to the clinkering since they require a somewhat higher steam-to-oxygen ratio compared with the ratio determined so far. The test team agreed to control that material, which occurred in large pieces, by top screening at 50 millimeters to reject the oversize. The clinkers were removed from the gasifier, but, before high load testing could be resumed, the gasifier had to be placed back into normal operation with Sigma coal due to production priorities.

During the test period between August 1 and August 8, 4,500 metric tons of Kentucky coal were processed, of which 2,160 metric tons were rejected as undersize at the screen house and 2,340 metric tons were fed to the gasifier.

The following objectives had been achieved in the first phase:

1. The operability of the dry-bottom Lurgi gasification process on medium swelling and medium caking coal was confirmed and demonstrated.

2. A steady-state operation and the predetermined throughput condition was maintained as planned over a 50-hour period at set load allowing material and energy balances to be developed.

3. The percentage of fines in the feed coal that could be handled by the system was determined.

4. Samples of process and product streams were taken for environmental and market studies.

Phase 2 - The second phase of the test began on September 14 with the primary objective of determining the maximum gasifier load and the secondary objective of demonstrating closed-loop tar reinjection. The feed coal was wet screened to a 50-millimeter x 6-millimeter size and tar injection was employed during the test. A variety of changes in operating parameters was attempted to determine the maximum load. When the previously established maximum gas production rates were increased very rapidly, however, blockages in the gas liquor and tar handling system occurred due to excessive dust carryover consisting predominately of coal particles typically about 6-millimeter size.

It proved impossible to sustain loads significantly greater than those achieved during Phase 1 of the test. Although loads up to 60,000 normal cubic meters per hour were achieved, the maximum load sustainable was determined to be 47,000 normal cubic meters per hour. At this gas load, recycled tar injection was maintained for a 15-hour period proving that dust carryover was controllable with a wet-screened coal containing an average of less than 3% fines. Further, it was determined that the tar was gasified almost entirely.

During the approximately 100 hours of operation over the six-day period ending September 20, 4,900 metric tons of coal were processed through the screening operation, of which 2,558 metric tons were fed to the gasifier. The September test confirmed the major operating parameters observed during the first test and further demonstrated that the gasifier and distributor-stirrer can be operated smoothly and reliably.

During this series of runs, other feed size options were considered in an attempt to gasify a wider size consist. The wet-screened 50-millimeter x 3-millimeter size consist planned as part of the test was not attempted because the dust carried over contained particles of 3-millimeter size and slightly larger. This was on coal screened at 6 millimeters with very little material of 3-millimeter size, indicating that particles as large as 3 millimeters would be carried over. Screening at 3 millimeters would therefore have been impractical.

At the conclusion of the second test phase, several modifications were proposed which were believed to offer the potential for operation at higher loads. These included modification to the distributor-stirrer and increases in the tar injection rate capability. In October and early November, these modifications were completed.

Phase 3 - The third phase tests were begun on November 14 using the same procedures as in previous runs. It was established that dust carryover was not significantly reduced by the modified distributor-stirrer. During 37 hours of testing, it was determined that the maximum practical load, in the range of 45,000 to 48,000 normal cubic meters per hour, was limited by dust carryover verifying the findings of the previous test phase. The upper limit for dusty tar injection was reconfirmed.

During the final test phase, 3,100 metric tons of coal were processed through the screening plant, of which only 1,025 metric tons were suitable for gasifier feed. This is indicative of the attrition of the coal that resulted from moving and compacting the test coal stockpile following the second test period to prevent spontaneous ignition.

The team agreed that within the constraints of the test program all possible attempts had been made to achieve higher loads. It was therefore agreed that the test program had been completed and the test series was terminated.

5.0 SAMPLING AND TESTING

5.1 Shipping and Storage

The sampling and testing plan was set up to ensure quality control of the sample during collection and shipment, obtain data to predict fines generation with rehandling, and thoroughly characterize the properties of the coal for the Tri-State design basis -- not only the coarse coal for gasification but the fine coal for steam and power generation.

The program (Exhibit 19) utilized the following five methods to sample the coal:

- o Conveyor belt - mechanical
- o Barge top - manual
- o Stratified railcar - manual
- o Front-end loader - manual
- o Stockpile - manual posthole digger or power auger

Sampling at the Mine - The immediate objective was to limit the fines in the run-of-mine coal being loaded to 35% so as to maximize the coarse content of the coal for test purposes at Sasolburg. It was decided to ship run-of-mine coal rather than screened coal because the gasification plan required some fine coal and the cushioning effect of fines would limit further attrition of coarse coal during handling.

The transport of the coal over the length of the nine-mile overland belt afforded opportunity for identifing an excessively fines-rich portion and rejecting it to the dock stockpile. The appearance of a periodic fines-rich portion of the coal resulted from the cyclic behavior of the doughnut (storage) discharge at the mine since it was filled and emptied on three different occasions. Overall, a coal with a fines content of 37.2% was loaded based on on-site screening.

The gross sample, representative of the 22,500 short tons, was taken at the mine mechanical sampling system by collecting, in the 69 minutes of loading time per barge, eleven primary increments of 350 pounds for each of 15 barges.

Three of these eleven increments were taken for the gross size analysis sample. One of these increments was manually screened over a 1/4-inch round hole screen to obtain a preliminary estimate for quality control of the fines being loaded, then recombined for use as part of the gross sample for size analysis. The increments from rejected sampling units were analyzed separately and not as part of the gross samples.

After the size analysis, the recombined three increments from all barge samples were further prepared to provide coal samples for laboratory analysis by Lurgi, Sasol, Commercial Testing & Engineering, University of Kentucky - Institute for Mining and Minerals Research, and The Pennsylvania State University - College of Earth and Mineral Sciences, Coal Research Section. The analytical scope of work included the items shown in Exhibit 20. The analytical program involved complete sieve and physical/chemical characterization of the total sample and coarse and fine fractions, including ASTM and RCRA leaching tests. The coal was dry-screened at 1/4-inch round hole size to simulate gasifier feed quality and boiler feed quality.

Subsamples of the remaining eight increments collected for each barge were prepared by the Camp 1 three-stage mechanical sampling system. Composite samples for each five-barge sampling unit were prepared for analysis by combining, in order loaded, the subsamples from each of the barges retained for testing in South Africa.

Sampling at Transloading - Sampling of the three strings of five barges at Darrow, Louisiana, was conducted to determine the size consist and coal characteristics and compare them with data at the mine sampling location.

The method employed in the barge-top sampling meets or exceeds the specifications called for in the following standards for the collection of a gross sample of coal from barges: ISO 1988 Part 6.3.3, ASTM working document on manual collection (Committee D-5 on Coal Sampling) and ASTM D-2234 Part 7.1.5.2.

Eight different parallel or zigzag sampling patterns, each consisting of 27 increments, were used and were assigned at random by computer to each barge. Three increments were taken arbitrarily from each barge for an on-site screening at 1/4-inch round hole and then recombined with the other 24 to form the barge sample which was composited on a string (5-barge) basis.

The proximate analyses of the string samples from both the mine and transloading sampling programs compared very well. Overall, a moisture gain of one percent was observed during the transportation.

Sampling at Rail Car Loading - Sampling of the rail cars was conducted during offloading of the bulk carrier at Port Elizabeth, Republic of South Africa, to again determine any changes in properties and size degradation.

The sampling plan was based on stratified sampling of rail cars. Each side-dump rail car had a nominal capacity of 35 metric tons while each train of 34 cars could transport about 1200 metric tons. Typically, one train could be loaded per 8-hour shift and two tracks would keep the process going smoothly.

With only 2-shift exceptions, the partial samples were representative in terms of the minimum number of increments required by ISO 1988-1975(E) Part 3.2.2. Initially, three increments were taken from one of two diagonals across each rail car -- two for the size sample and one for the analytical sample. However, the original plan was modified after one shift by reducing the size increment from 2 to 1 and increasing the number of samplers from 2 to 4.

In total, 587 rail cars were sampled, 15 individual shift composites were mechanically sieved for size, and four partial samples were composited from the shifts for size analysis and quality in the South African laboratory.

The analytical test results on samples obtained during the loading operation at Uniontown and transloading at Darrow were compared with the rail car results at Port Elizabeth. The gross calorific value on a moisture, ash-free basis for the Port Elizabeth sample was 4% greater than the two sample analyses at the U.S. locations. This difference could be due to differences in sample preparation technique at the laboratories.

Standard coal analysis parameters were compared by the two laboratories on a split of each of the four rail car partial samples taken at Port Elizabeth. The moisture content as measured in the U.S. was lower probably due to drying out of the sample during a several month time lapse. The gross calorific value of the South African analyzed sample on a dry-coal basis appeared to be higher than the U.S. reported value by 4%.. On a moisture, ash-free basis, the difference was very small - less than 1%, probably due to differences in the calorimeters.

Sampling at Sasolburg - Due to manpower limitations and the overlapping programs between Port Elizabeth and Sasolburg, it was decided not to conduct an extensive sampling program at Sasolburg. Sasol conducted limited sampling at the railhead. At the Sigma mine stockpile, Sasol collected samples for size consist and quality. Tri-State used Sasol's size consist data for the fines generation study.

Fines Generation - A fines profile was developed from the size consist data at each location (Exhibit 21) from the Camp 1 mine to the Sigma mine stockpile. The objective was to determine the effect of rehandling on fines generation. This information is useful as a guide in estimating coal degradation to be expected during transportation and in-plant handling and hence in establishing run-of-mine size requirements to meet coarse coal requirements for gasification.

During the loading operation, the objective was to accept no more than 35.0% weight fines on a cumulative basis from the mine. To facilitate a fast response time, on-site screening at 1/4-inch round hole was employed. The fines content loaded was 37.2% weight (on-site screening) versus 35.6% weight based on average of each barge string composite sample. The average values showed a high degree of correlation.

The screen analysis for the composite sample at each location was fit statistically to smooth out variations in the observed data. For example, a 5% increase in fines content was noticed between the mine (35.6%) and Darrow transloading (40.3%) yet at the rail car sampling at Port Elizabeth, the fines content (39.9%) dropped slightly and did not change at the Sigma mine stockpile (39.8%). The screen analyses taken during the rail car unloading were rejected as non-representative since they were based on only three reported samples.

The smoothing equation was based on a log-log modification of the Gaudin-Schuhmann plot of size distribution versus cumulative weight percentage passing a given screen size. The measure of fines generation was set as the increase in cumulative weight percentage passing the 1/4-inch round hole screen.

Six stages of handling were assumed for the entire shipment and were dependent on the degree of severity of treatment at or between each location. For the shipment, the overall fines increased from 37.6% to 40.5% or 0.5% for each stage of handling. The extent of size degradation over the 4-month period was less than anticipated.

5.2 Gasification Test

During the gasification test, various samples were taken by each of the three major participants: Sasol, Lurgi, and the Tri-State team (including Kentucky Department of Energy). The specific samples taken by the Tri-State team during the 50-hour mass balance test are listed in Exhibit 22. Each group was responsible for taking the group's own samples. Tri-State team members either took samples or supervised the sampling.

The Tri-State samples, most of which ranged from 1 liter to 10 gallons in size, were subsequently split for analysis by various laboratories under contract to the project and for analysis by the Kentucky Department of Energy laboratory. These samples were taken for further testing for environmental, engineering and market purposes. Tri-State also exported 2000 gallons of stripped gas liquor for wastewater treatability tests and 200 gallons of tar and crude phenol for possible testing.

Sasol was responsible for all of the gaseous samples taken, as well as the routine operating samples and an array of samples taken as part of the test program. Lurgi, Sasol, and Tri-State took duplicate samples of many of the solid and liquid streams around the test gasifier including: raw and feed coal, ash, stripped gas liquor, tar, and crude phenols.

The Kentucky Department of Energy has been involved with chlorine corrosion problems at synthetic fuel plants and requested and was granted permission by Sasol to install material test coupon racks in the gasification system and test cooling tower loop during the tests. Sasol has not experienced significant corrosion in their system, which is primarily of mild steel construction, in over twenty-five years of operation. However, the test coal was significantly higher in chlorine than the Sasol feedstock.

Five coupon racks were installed, each containing four different alloys. Three of these were installed in the gasifier, the raw gas scrubber, and the tar separation vessel. The remaining two racks were installed in the cooling tower test loop -- one in the cool water reservoir and one in the hot water reservoir. Sasol also installed test probes and coupon racks in the gasification system and the cooling system. No significant corrosion rates were observed in the Kentucky Department of Energy test racks in the gasification system. However, significant rates were observed in the test cooling system and it was subsequently decided that such a system would not be incorporated in the Tri-State plant design. Lurgi has made the recommendation that the gasifiers but not the downstream equipment be clad against chlorine attack.

5.3 Kentucky Stockpile

A stockpile was built at Uniontown, Kentucky by compacting a 200-ton run-of-mine sample representative of the Camp 1 coal shipped to Sasolburg.

The coal sampling conducted over a one-year period employed a posthole digger or power auger. The samples were taken every one to two months (9 samples in total) at pre-selected random grid locations on the 15-foot x 15-foot top surface. The pile was compacted in one-foot intervals to a height of 5 feet. The stockpile was instrumented for thermocouples for measuring internal temperatures. A meteorological station was set up at the stockpile to gather selected data on temperature, rainfall and wind speed and direction. The coal samples were analyzed for size consist and physical and chemical properties.

The coal leaching tests were carried out in a static leaching bed constructed with a 32-gallon plastic garbage can packed with about 200 pounds of coal. The leachate was routed to a collection container for compositing and analysis. Another can was set up as a blank to collect rainfall for measurement and quality determination.

The tests conducted on the compacted stockpile resulted in the following major observations:

- No spontaneous combustion occurred in the pile as evidenced by a maximum internal temperature of 97°F in July.

- No serious oxidation occurred, except on the surface, due to successful compacting during the construction.

- Coal characteristic properties, such as gross calorific value, moisture, oxygen, caking and grindability indices, tended to be within the allowable limits of reproducibility. Moisture and oxygen contents appeared to increase and the gross calorific value and caking indices appeared to decrease, as expected, but the changes may not be statistically significant. No significant oxidation was observed by the Gieseler Plastometer test, a sensitive indication of oxidation, or by the free swelling index, a less sensitive indicator of oxidation.

- A slight oxidation of the coal was reported by Lurgi based on the following tendencies:

  - Decrease in gasification reactivity from 0.029 to 0.020

  - Decrease in caking index from 19 to 13

  - Decrease in volume increase in pressure coke from 15 to 3

  The majority of the observed decreases in characteristic values occurred during the first three to six months. Lurgi reported no change in the free swelling index through the entire year program.

- No significant size degradation occurred due to weathering. The observed degradation from 35% fines to 47% fines was due to compacting the coal during stockpile construction.

6.0 DESIGN RECOMMENDATIONS

The results of these testing activities with Camp 1 coal were used to confirm or develop design criteria for the Tri-State Synfuels Project.

The design recommendations cover the following categories: coal selection, coal preparation and handling, gasification, stripped gas liquor utilization, fines combustion and long term storage. Recommendations on characterization of export samples and the wastewater treatability study will be forthcoming as the experimental work is completed.

6.1 Coal Selection

An examination of a broad range of Illinois Basin coals resulted in selection of Camp 1 for the design and test coal. The gasifiability of the test coal was confirmed by:

- o Concluding from the Lurgi laboratory results that the Camp 1 coal is a suitable feedstock for the Lurgi pressure gasification process. Lurgi reported that the ash melting characteristics under oxidizing conditions indicated a "short" ash which means that the steam-to-oxygen ratio will have to be controlled carefully. The reactivity of the coal is typical for the Illinois Basin. The Fischer tar assay is typical, but the yield will be lower and the tar recycled will be gasified and not converted to oil. The chlorine content is significantly higher than most coals, and the gasifier, but not the downstream equipment, must be fitted with protective cladding.

6.2 Coal Preparation and Handling

The collection and shipment program provided the basis for the design of the coal preparation units by:

- o Developing conceptual coal preparation flow diagrams to limit fines generation and yet reject rock and mine gob that will arrive with the coal. The large rock and hard materials have been identified both at Camp 1 mine and Sasolburg locations and may require more attention if sent to the gasifier. These diagrams feature:

  - A rotary breaker with a 3-inch (75-millimeter) opening at the mine to reject large rock and shale pieces.

  - A rotary breaker with a 2-inch (50-millimeter) opening at the plant under Tri-State control to ensure rejection of rock and hard material such as "sulfur balls."

  - A wet-screening operation at the plant to reject mine gob and allow delivery of coal of rather constant gravity and fines specifications to the gasifier.

- o Developing a formula to predict the effect of rehandling on fines generation during coal transport and preparation. This information is useful in estimating coal degradation to be expected during transportation and in-plant handling and hence in establishing run-of-mine requirements to meet coarse coal requirements for gasification.

- o Developing design coal analysis for both coarse and fine fractions based on the analytical and size samples from the 15-barge shipment. In addition to standard ASTM-type coal analyses, design Fischer assay, trace elements, fluorine and mercury contents are provided.

6.3 Gasification

The commercial scale test results, operating experience and engineering judgments provided the basis for the design of the coal gasification unit by:

- o Confirming that medium swelling and medium caking Illinois Basin coals can be gasified in the Mark IV gasifier fitted with a distributor-stirrer. For the test, a non-caking coal was used for start-up from an empty gasifier.

- o Anticipating that coke or non-caking coals must be used for start-up of an empty gasifier since such a gasifier cannot be started up from "empty" using a swelling and caking coal.

- o Confirming that the design and performance of the distributor-stirrer was satisfactory for Illinois Basin type coals.

- o Demonstrating the need for two additional gasifiers over the 36 predicted in the April 1980 feasibility study. The 45,000 normal cubic meters per hour rate as recommended by Sasol at 26 bar pressure corresponds to about 49,100 normal cubic meters per hour in the Lurgi design when Tri-State's higher operating pressure of 31 bar is taken into account. Even with a gasifier availability as low as 80%, this would require 38 gasifiers. The design coal throughput rate per gasifier corresponds to 720 metric tons (790 short tons) as-received coal per day.

- o Determining that the Sasol test steam requirement of 2.66 tons per ton dry, ash-free coal was the same as predicted for the feasibility study. For design purposes, a steam requirement of 2.85 tons per ton dry, ash-free coal was selected to have sufficient flexibility in gasifying several different feed coals.

- o Determining that the Sasol test oxygen (100% purity basis) requirement of 0.52 ton per ton dry, ash-free coal was lower than the oxygen requirement of 0.56 ton per ton used in the feasibility study. For design purposes, an oxygen requirement of 0.56 ton per ton dry, ash-free coal was selected to have sufficient flexibility in gasifying several different feed coals.

- o Determining that the Lurgi design oxygen (100% purity basis) requirement of 0.172 volume oxygen per volume dry crude gas from the gasifier was practically the same as the Sasol test figure of 0.171 and also identical to the requirement for the feasibility study.

- o Determining that coal feed size to the gasifier should be 2 inch x 1/4 inch (50 millimeter x 6 millimeter) preferably with less than 3% fines because the throughput of the gasifier is limited by fines carryover. However, smooth operation was achieved at an average fines content of 2.6% with peaks as high as 5.4%.

- o Determining that the gasifier should be fed coal with a rather constant specific gravity to minimize adjustments to steam flow.

- o Anticipating that use of wet screening is preferred over dry screening in order to ensure close control of undersize in gasifier feed and acceptability of wet coal during expected rainfall and snowfall periods. Equipment to dry screen coal with close undersize control may be available, although its applicability for the project was not the purpose of the test.

- o Determining the amount of excess fines to be expected from run-of-mine Illinois Basin coals, considering the ability of the Lurgi gasifier to handle coal with a cutoff size of 1/4 inch (6 millimeters) with several percent fines. Options to utilize these excess fines have been examined but no final choice has been made.

- o Determining that segregation of coal and generation of fines should be minimized or avoided at every step from coal receipt through gasification bunker by proper equipment design since the process is sensitive to fines content on an average and peak basis.

- o Determining that large, heavy particles in the coal feed must be removed positively by breaking the coal in a Bradford-type breaker with 2-inch (50-millimeter) openings. The heavy, hard lumps will break very little due to their high mechanical strength in this type of coal breaker and will be rejected entirely for all practical purposes. Loss of good coal should be minimal as it will readily break to 2-inch (50-millimeter) size.

- o Anticipating that recovery of the oversize, hard, heavy material in the nominal 2 inch x 0 (50 millimeter x 0) coal is not warranted due to its low carbon content and its need for greater operating attention in the gasifier.

- Anticipating that separate storage for each coal supply is preferred over single combined storage. Intentional blending of several supply coals to smooth out expected variations in certain gasification characteristics such as free swelling and caking indices and ash fusion temperatures is not recommended by Lurgi because of the complexity of equipment, inability to predict interaction of ash quality on fusion temperatures and additional fines generation.

- Determining that gasifiers should be clad to protect against corrosion from high chlorine content coal. The design coal has a chlorine content of 0.12% weight compared with 0.06% weight chlorine in the feasibility coal.

- Confirming that dusty tar injection is feasible up to certain limits and all tar injected is gasified. For design purposes, the net make of tar was planned to be partially oxidized.

- Determining that no creosote facilities are necessary since no oil was produced directly from the test gasifier. There was no hydrocarbon phase lighter than water found in the separator though this may be due to the routing of all condensates into one separator under the conditions of the test. Any oil that may have been produced could have been dissolved in the tar.

- Determining that no shift unit is required to adjust the hydrogen-to-carbon monoxide ratio of 2.57 in the crude gas to that required for the input to the Fischer-Tropsch Synthol unit or methanol unit. The feasibility study ratio was 2.26.

- Determining the hydrogen sulfide removal and sulfur recovery units must handle about 50% more sulfur than planned for in the feasibility study since the hydrogen sulfide content of the crude gas is higher due to higher sulfur in the design coal.

- Determining that an increase in frequency of monitoring and quality control measures is required over the Sasolburg and Secunda measures due to coal characteristics.

6.4 Stripped Gas Liquor Utilization

The cooling tower test provided the basis for rejecting direct utilization of stripped gas liquor for plant cooling purposes by:

- Demonstrating the occurrence of extensive corrosion in the test equipment due to the high chlorine content of the coal and failure of the biological system due to buildup of ammonium chloride which exceeded the tolerance of the bacteria.

The method planned for handling of the gas liquor is conventional activated sludge treatment, mixed media filtration, effluent polishing with activated carbon, and pH control before discharge to large water sources.

6.5 Fines Combustion

Laboratory examination of the fines provided the design criteria for combustion and handling by:

- Determining Camp 1 raw fines or washed fines are suitable as a potential fuel source in cyclone (wet bottom) and pulverized (dry bottom) furnace boilers.
- Identifying:
  - Nearby utilities with proper combustion equipment to handle fines.
  - Several requirements for design of storage, handling and transportation systems for fine coal to overcome problems with retained moisture content.

6.6 Coal Storage

The tests conducted on the compacted stockpile at Uniontown provided the basis for the design of long term storage by:

- Demonstrating that macrochanges in ASTM physical and chemical properties due to weathering and leaching were minimal with the exception of chloride losses as sodium chloride. The chemical and physical composition of the Camp 1 coal is estimated for design purposes to remain unchanged with the exception of sodium chloride.
- Demonstrating that leaching of salt and trace metals will occur due to rainwater leaching and provision should be made in the design to contain and treat the leachate with the identified composition.
- Demonstrating that macrochanges in the gasification characteristics of reactivity, caking and pressure coke expansion for the Camp I coal did not impact the test results at Sasolburg because these characteristics showed no significant changes over the corresponding stockpile sampling and test periods.

  However, in the event that freshly mined coal is fed to the gasifier, several results would be expected:

  - A lower oxygen consumption would result due to the higher reactivity.
  - A higher volume increase in (more brittle) pressure coke would be compensated by the higher caking index.

- o Demonstrating that compaction of the coal is successful in preventing spontaneous ignition and should be adequate for construction of a safe dead storage pile. However, additional fines will be created which represent lost gasification feed.

7.0 CONCLUSIONS

A thorough commercial testing program has been carried out to define the technological aspects and set the coal-related technical and environmental design criteria for the Tri-State Synfuels Project not only in the areas of gasification but also selection, preparation and handling, stripped gas liquor cleanup, fines combustion and long term storage. Further, a wide range of other Illinois Basin coals has been characterized and ranked during the supplemental testing program which provides a good data base for the Tri-State Synfuels Project needs.

The testing activities with Kentucky 9 coal confirmed that medium swelling and caking Illinois Basin coal can be successfully gasified in a Lurgi Mark IV gasifier, modified with a distributor-stirrer, at commercially acceptable loads.

The tests demonstrated that the Lurgi gasifier requires coarse-screened coal with no more than three percent fines. Since Illinois Basin run-of-mine coals typically contain more fines than the Lurgi gasifier can accept and the steam generation facilities require, an excess of fines will exist and must be disposed of by other means.

Dusty tar recycle has been demonstrated and is an essential requirement of the process.

The tests have confirmed that the design basis used by Lurgi is sound and information has been obtained on which Lurgi would be able to provide process guarantees for a plant to gasify Kentucky 9 and similar coal in coarse-screened form.

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2. Gasoline from Coal - The Pioneering South African Experience, J. C. Hoogendoorn, Sasol Ltd., Johannesburg, Republic of South Africa, Energy Progress, March 1982, Volume 2, No. 1 p. 32.

3. Sasol Two and Three, J. R. Joiner and J. J. Kovach, Fluor Engineers and Constructors, Inc., Santa Ana, California, Energy Progress, June 1982, Volume 2, No 2, p. 66.

4. Tri-State Synfuels Project Review, Commercial Scale Coal Test, Volume 14, June 1982.

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9. Processing of American Coals in a Lurgi Gasifier, Paul F. H. Rudolph, Lurgi Kohle und Mineraloeltechnik, GmbH, Frankfurt am Main, West Germany, The Sixth Synthetic Pipeline Gas Symposium, Chicago, Illinois, October 28-30, 1974.

10. Gasification of U.S.-Western and Eastern Coals in the Lurgi Dry-Ash and the British Gas/Lurgi Slagging Gasifiers, Paul F. H. Rudolph, Peter K. Herbert and Helmut Vierrath, Lurgi Kohle und Mineraloeltechnik, GmbH, Frankfurt am Main, West Germany, Coal Technology '81, Houston, Texas, November 17-19, 1981.

EXHIBI

LURGI GASIFICATION TESTS OF U.S.A. COALS

LOCATION	DATE	SPONSOR	PROJECT	COAL	TEST GASIFIER
Westfield, Scotland	1973-4	American Gas Association/Office of Coal Research	Trials	Montana Rosebud	Mark II
				Illinois 5	Mark II
				Illinois 6	Mark II
				Pittsburgh 8	Mark II
Sasolburg, Republic of South Africa	1974	ANG Coal Gasification	Great Plains Gasification	North Dakota Lignite	Mark III
	1977	Carter Oil	Exxon East Texas	East Texas Lignite	Mark III
	1981	Panhandle Eastern Pipeline	WyCoal Gas	Wyoming Sub-Bituminous	Mark IV
	1981	Texas Eastern Texas Gas	Tri-State Synfuels	Kentucky 9	Mark IV Modified
	1982	Phillips Coal	Texas Gasification	East Texas Lignite	Mark IV

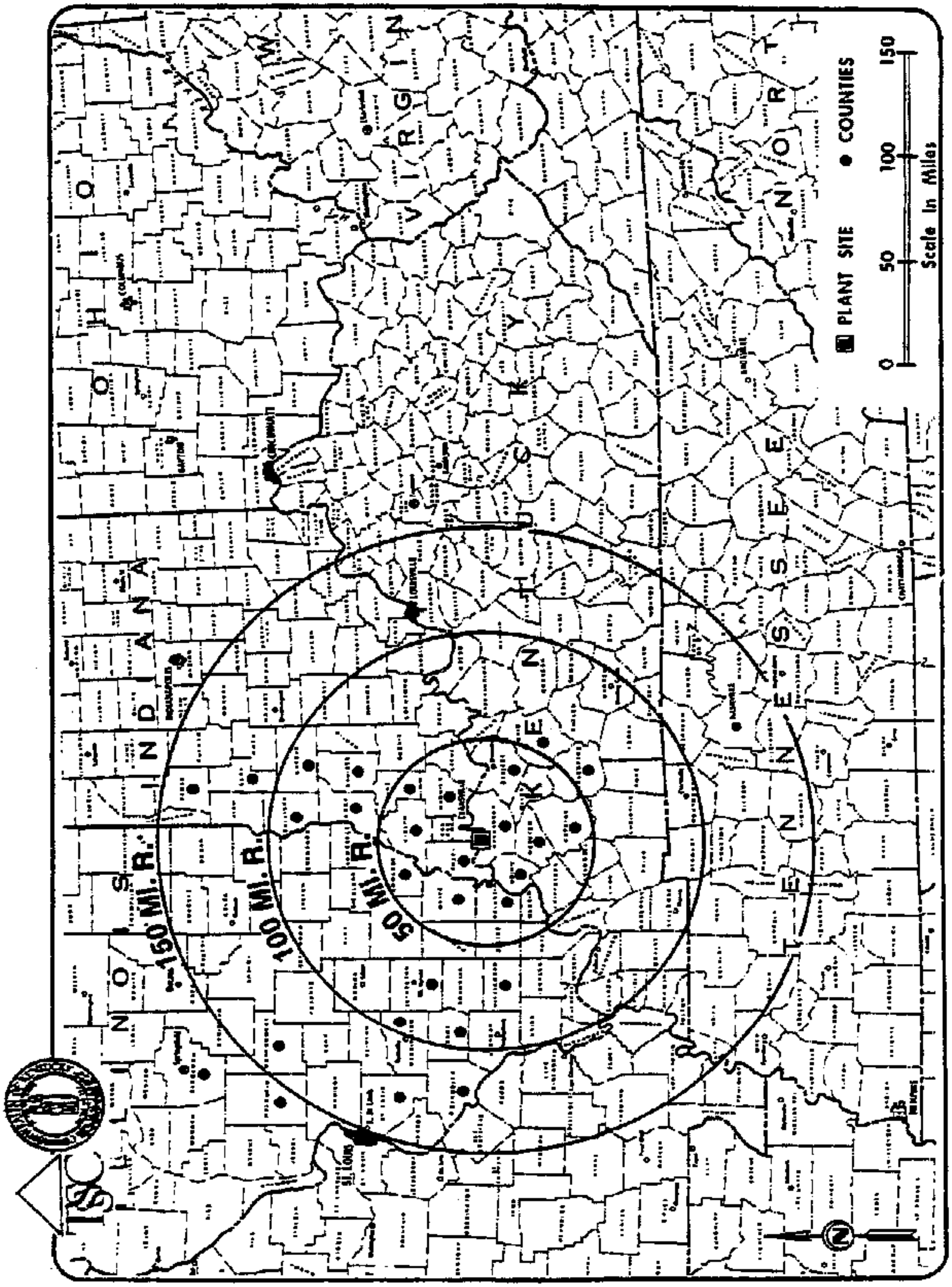
EXHIBIT 2

TSC

COST OF KENTUCKY COAL GASIFICATION TEST PROGRAM

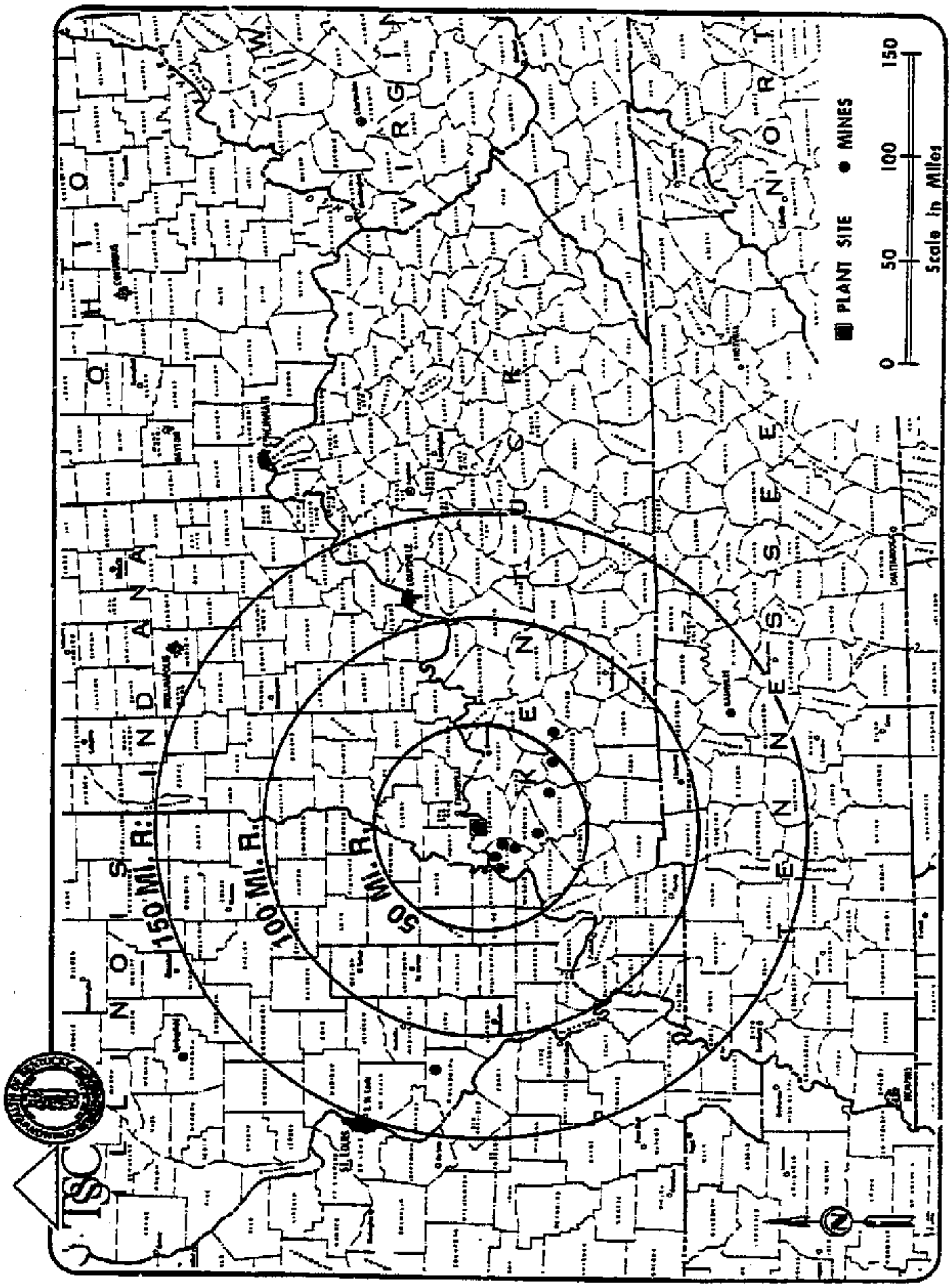
COMPONENT	$ MILLION
COAL	0.6
COAL TRANSPORTATION	1.6
COAL TESTING	1.8
TOTAL	4.0

EXHIBIT 3



ILLINOIS BASIN COUNTIES FOR INITIAL COAL QUALITY EVALUATION

EXHIBIT 4



CANDIDATE MINES FOR SUPPLY OF TEST COAL

EXHIBIT 5

TEST COAL CHARACTERISTICS
KENTUCKY 9 - CAMP 1 MINE

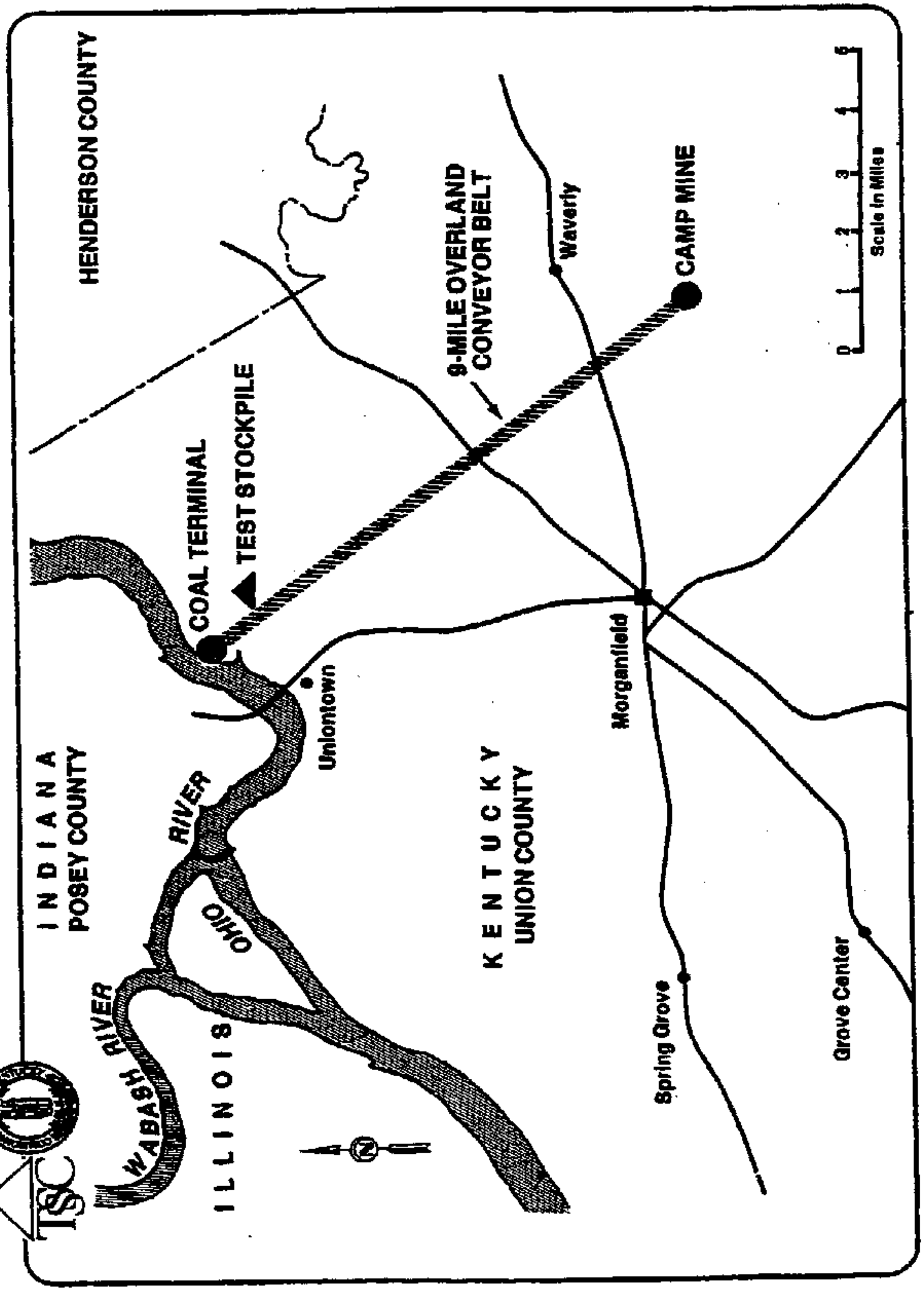
	% WEIGHT
PROXIMATE (DRY BASIS)	
ASH	18.61
VOLATILE MATTER	37.35
FIXED CARBON	44.04
	100.00
ULTIMATE (DRY BASIS)	
CARBON	64.79
HYDROGEN	4.43
NITROGEN	1.38
CHLORINE	0.12
SULFUR	4.18
ASH	18.61
OXYGEN	6.49
	100.00
HIGHER HEATING VALUE (DRY BASIS), Btu/lb	11,704

TEST COAL CHARACTERISTICS (continued)

SULFUR FORMS (DRY BASIS)	**% WEIGHT**	
PYRITIC	2.47	
SULFATE	0.02	
ORGANIC	1.69	
	4.18	
FREE SWELLING INDEX	3½ - 4½	
CAKING NUMBER (DAMM)	12-23	
CHAR REACTIVITY		
Nmilliliter CO/gm char/sec	0.027	
ASH FUSION TEMPERATURES, °F	**REDUCING**	**OXIDIZING**
INITIAL DEFORMATION	2020	2310
SOFTENING (H = W)	2090	2370
SOFTENING (H = ½W)	2140	2405
FLUID	2220	2460

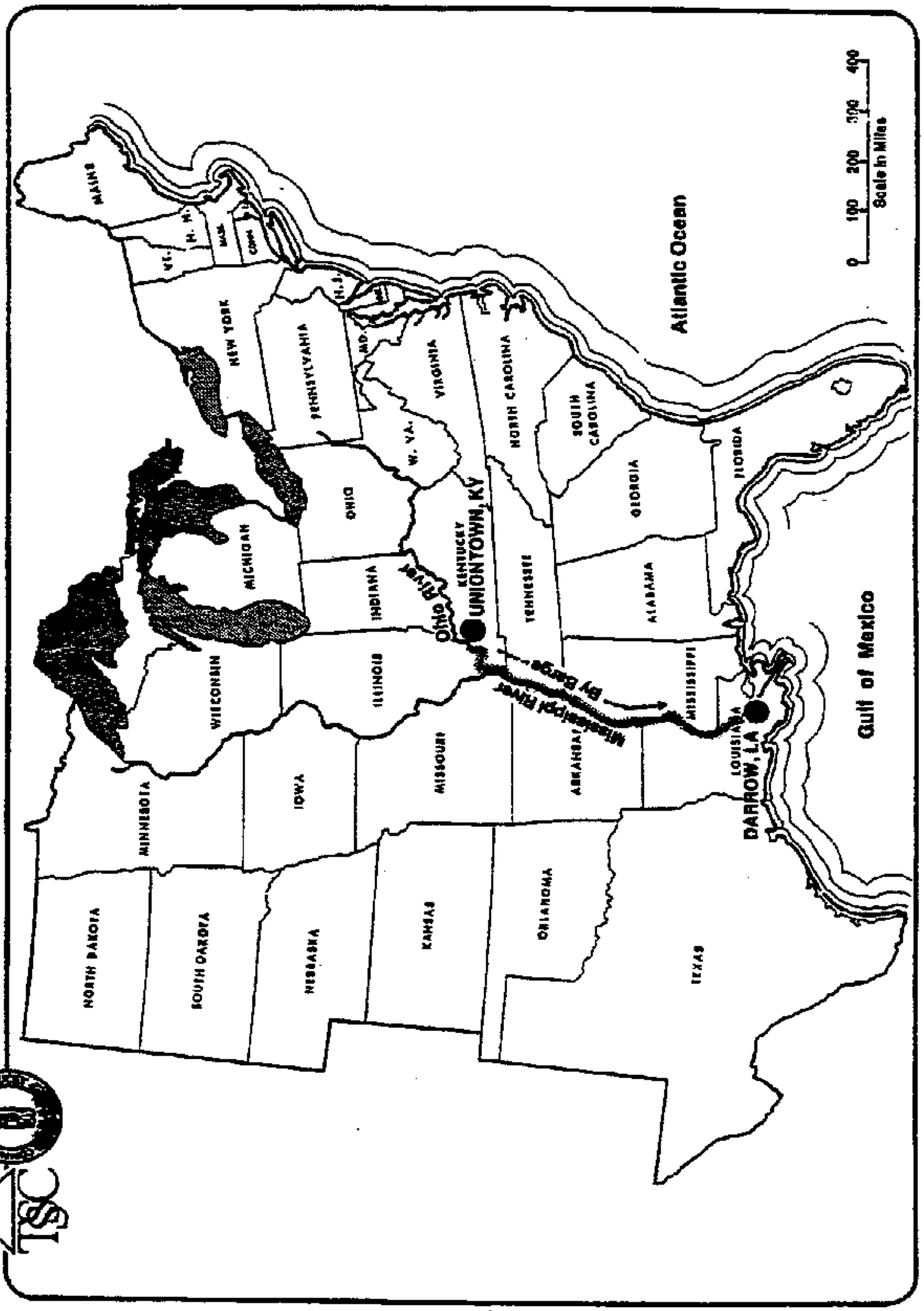
EXHIBIT 5
(continued)

EXHIBIT 6



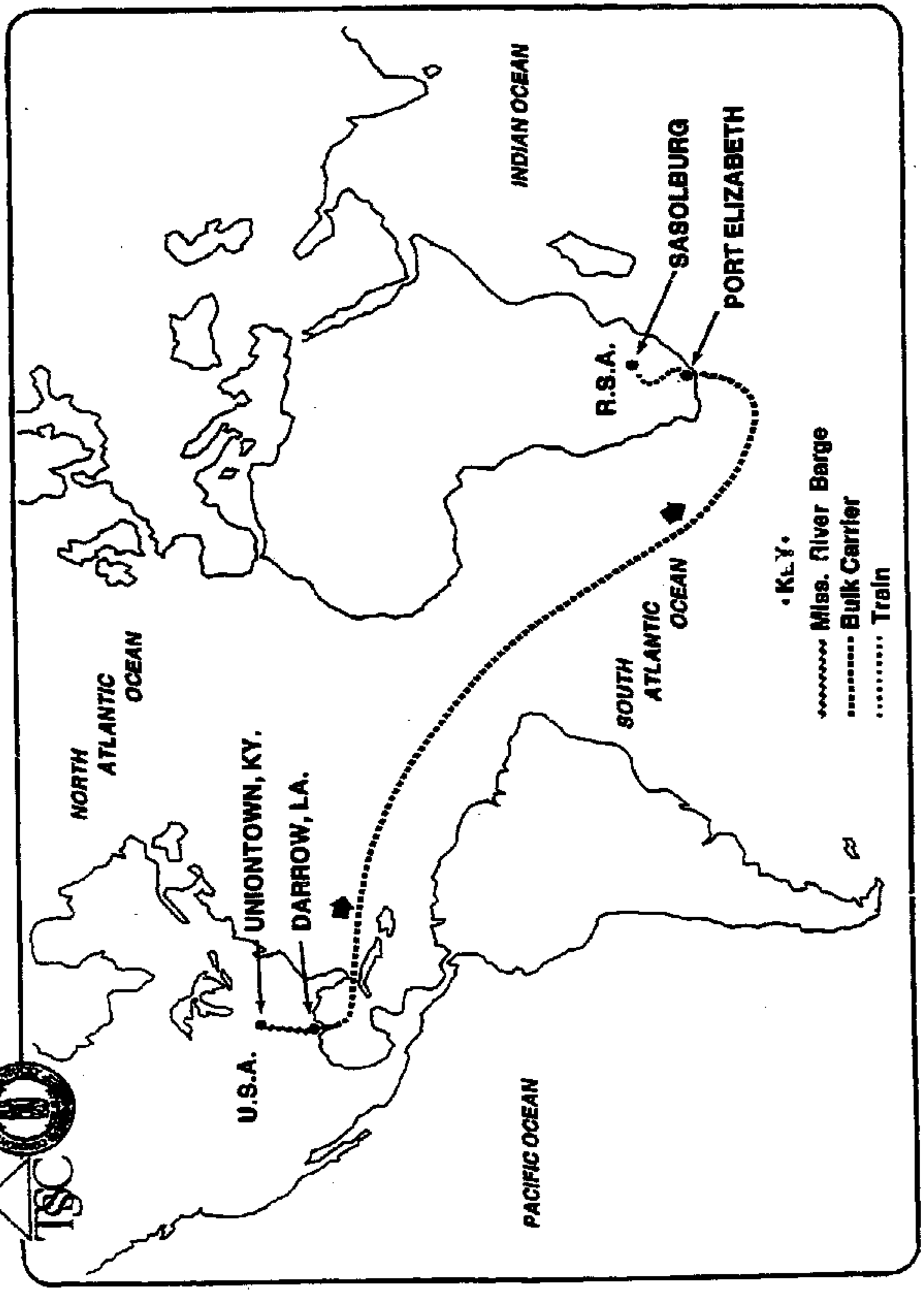
CAMP 1 MINE AND LOADING TERMINAL

EXHIBIT 7



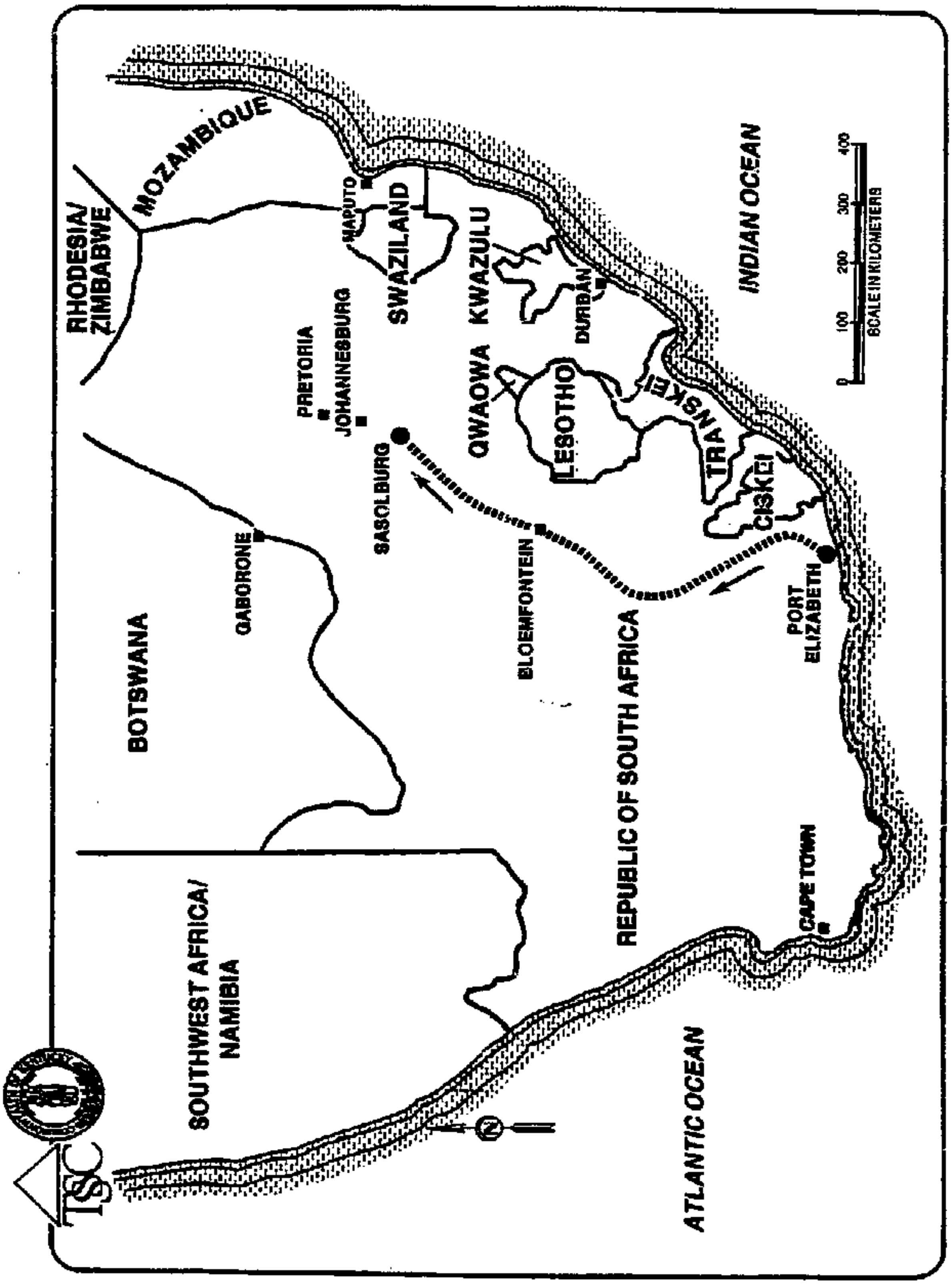
BARGE ROUTE

EXHIBIT 8



COAL SHIPMENT TO SOUTH AFRICA

EXHIBIT 9



RAIL SHIPMENT TO SASOLBURG

EXHIBIT 10

COAL GASIFICATION TEST PLAN

Run Description	Coal Size Inch x Inch	Fine Content %W (-1/4 Inch)	Screening	Operation Days
Start-up	2 x 1/4	-	Dry	-
Mechanical Checkout	2 x 1/4	-	Dry	-
Optimization	2 x 1/4	-	Dry	3
Mass and Heat Balance	2 x 1/4	-	Dry	2
High Load Test	2 x 0	5%	Dry	1
	2 x 0	10%	Dry	1
	2 x 0	15%	Dry	1
	2 x 0	20%	Dry	1
High Load Test	2 x 1/8	-	Wet	1
TOTAL PLANNED RUNS				10

SIMPLIFIED BLOCK FLOW DIAGRAM OF LURGI SASOL ONE PLANT

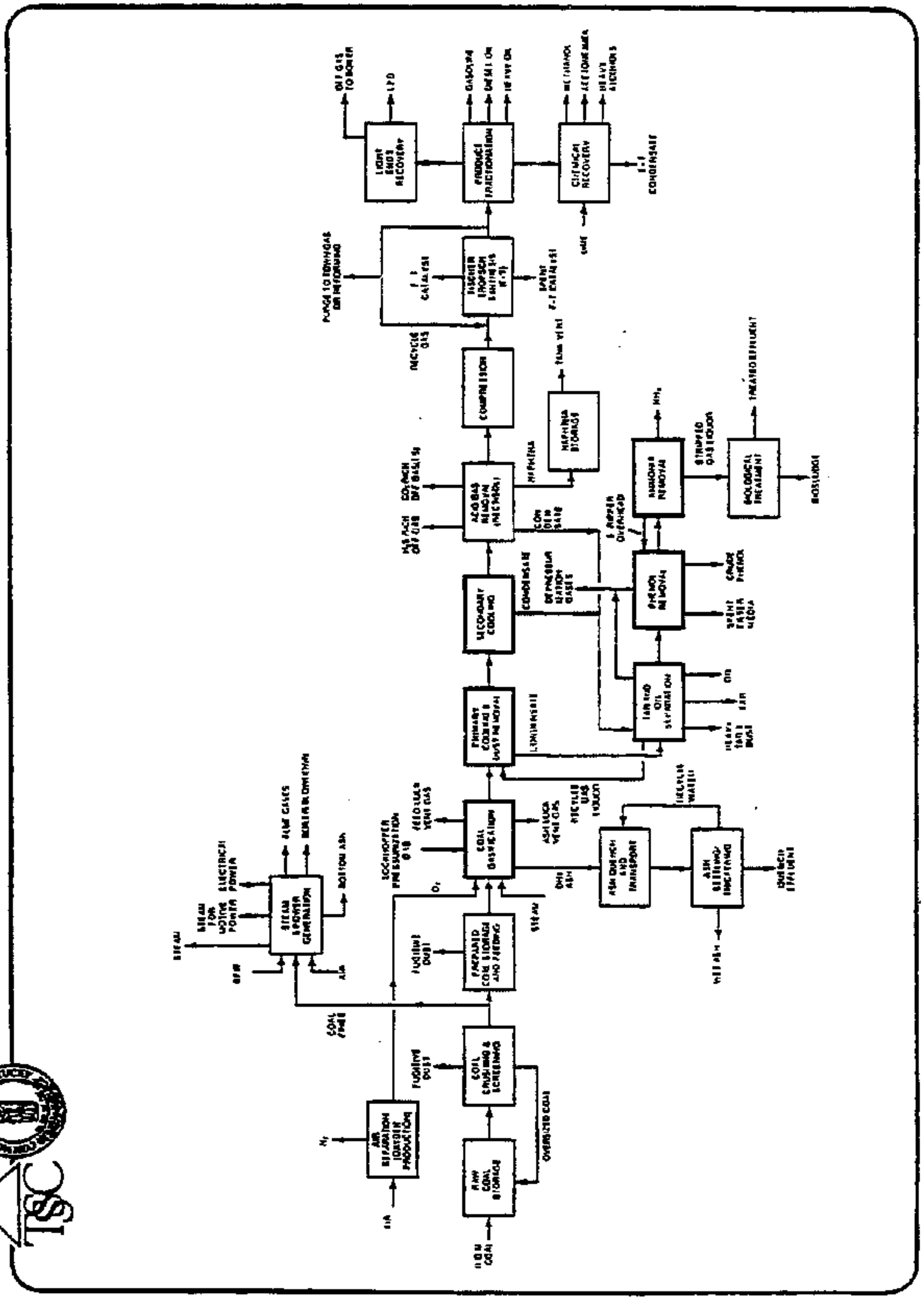
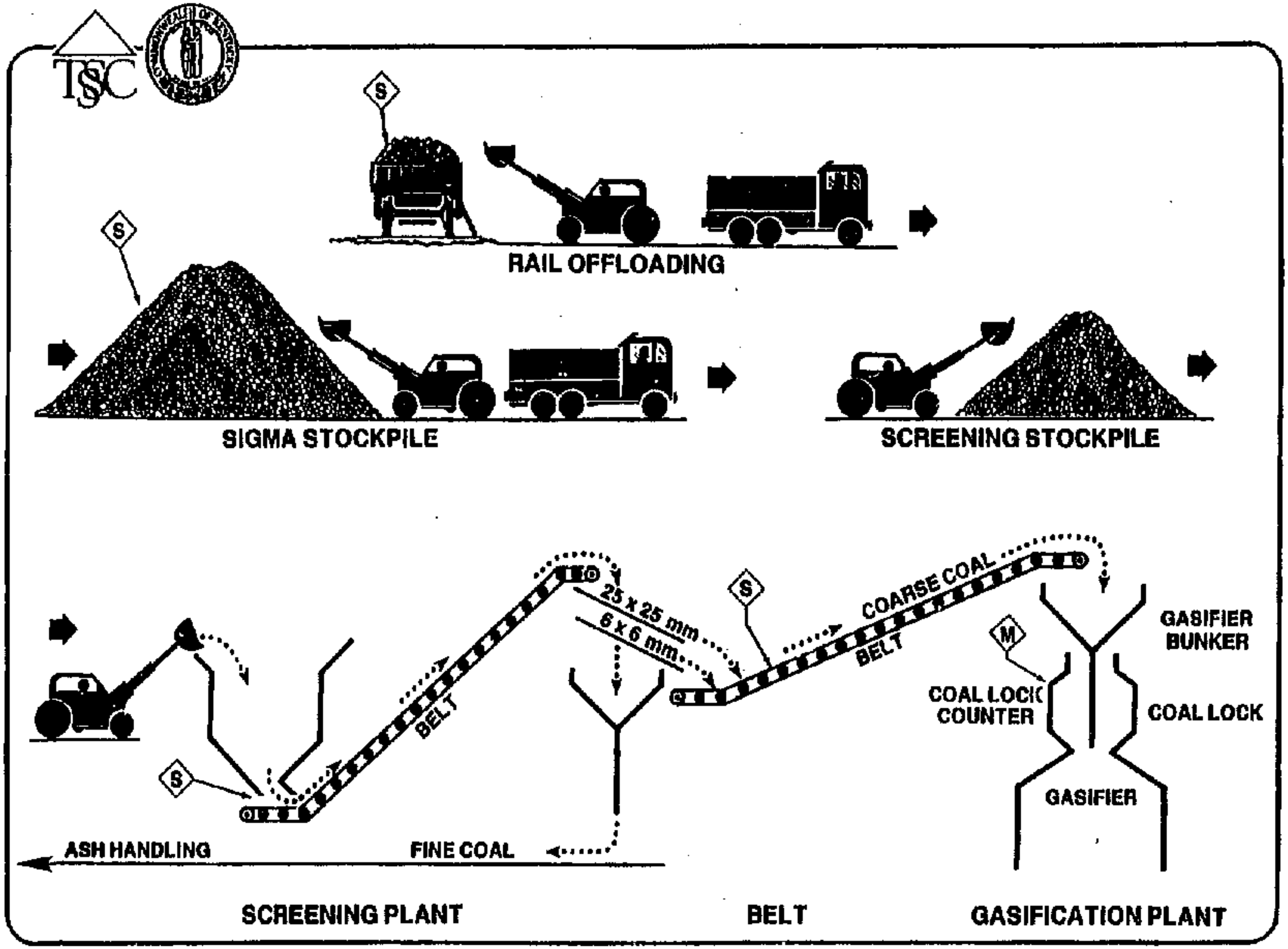
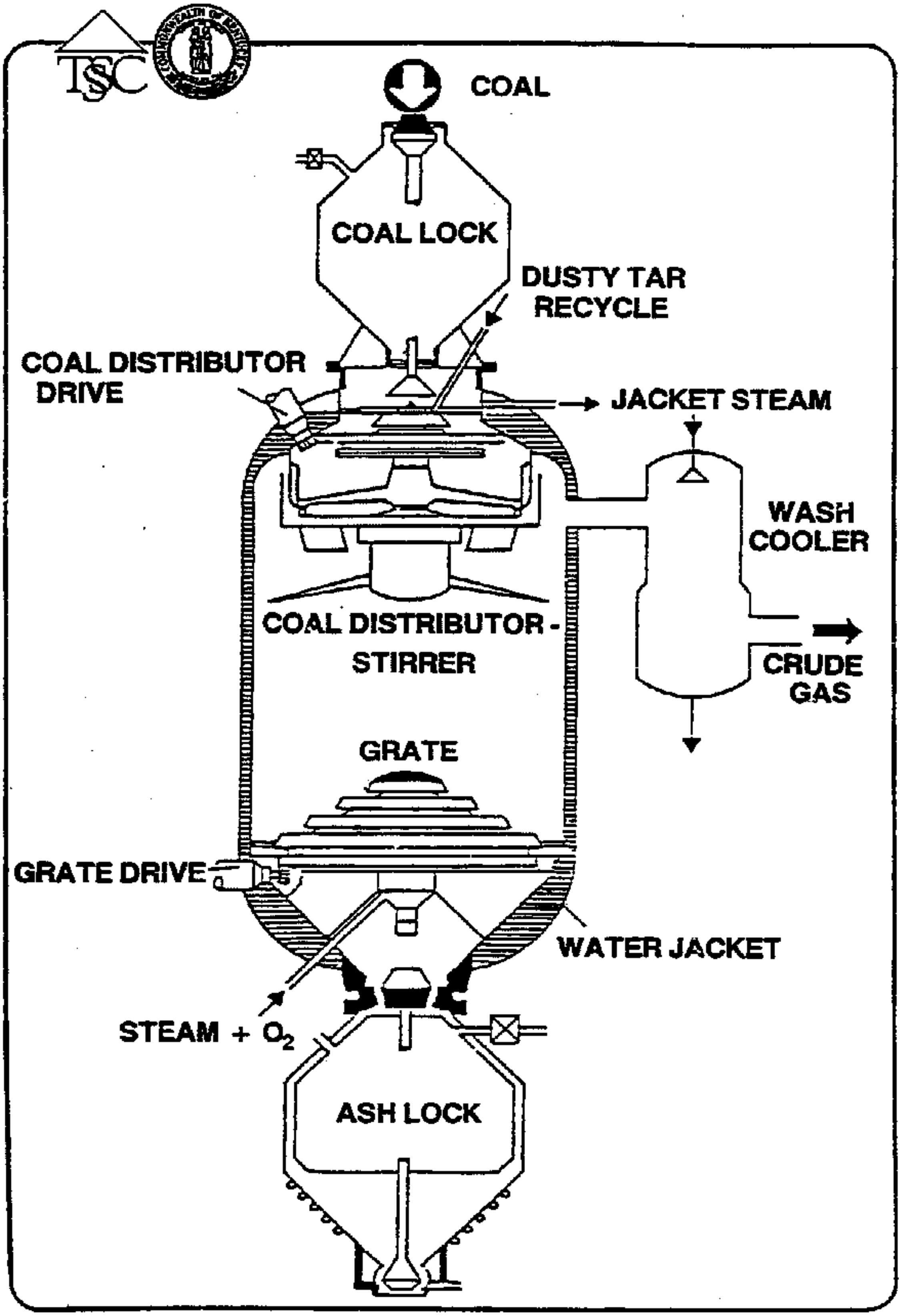


EXHIBIT 12



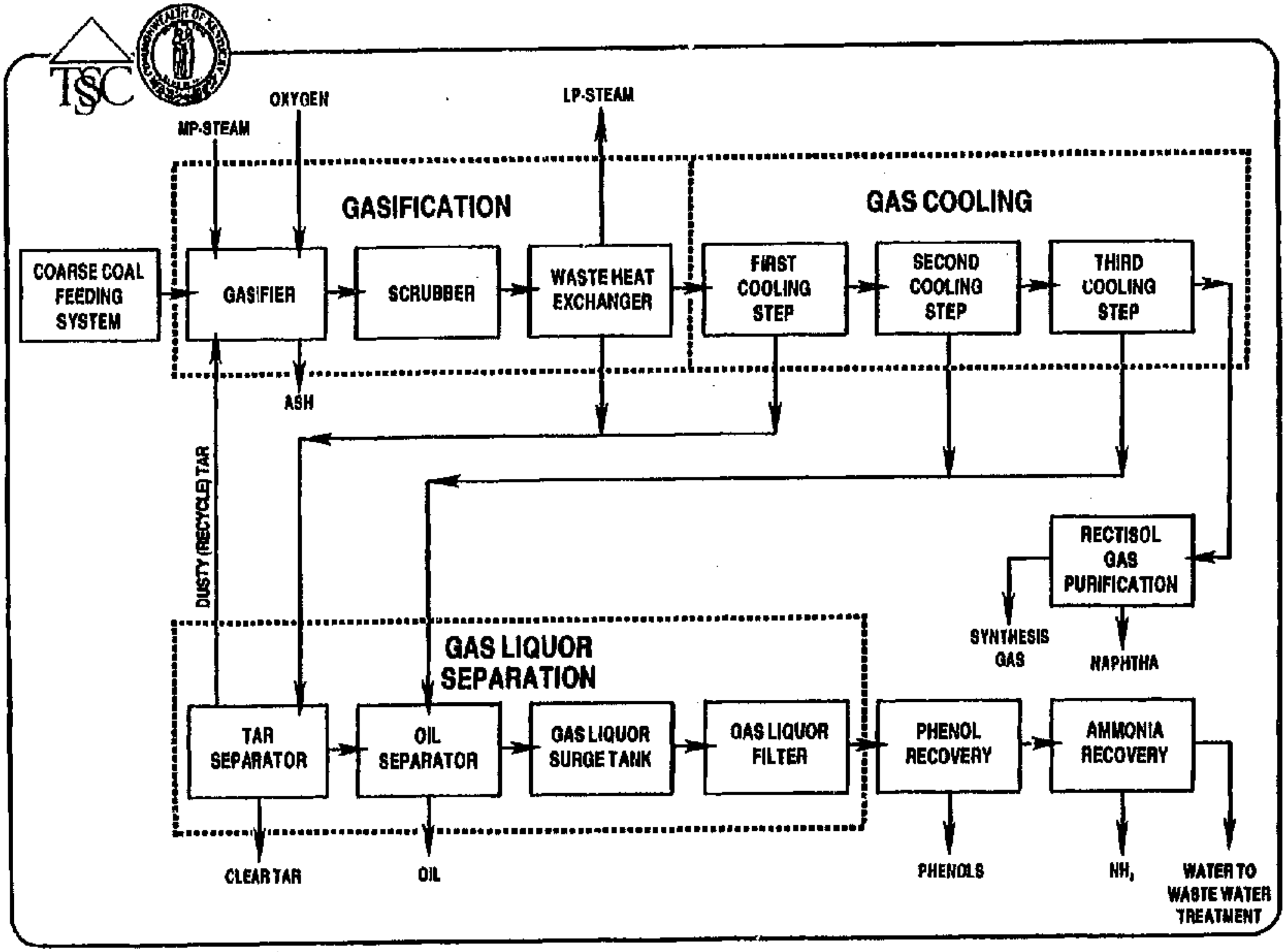
S/ OL TEST COAL HANDLING AND EPARATION FLOWSHEET

EXHIBIT 13



LURGI-PRESSURE GASIFIER

EXHIBIT



GENERAL PROCESS BLOCK FLOW DIAGRAM FOR TRI-STATE SYNFUELS PROJECT

EXHIBIT 15

TEST OPERATING AND FLOW PARAMETERS

YIELDS AND CONSUMPTION

Crude Gas/Coal (as received)[1]	1636 Nm^3/metric ton
100% Oxygen/Crude Gas	.1708 Nm^3/Nm^3
HP Steam/Coal (as received)	1.61 metric ton/metric ton

TEMPERATURES AND PRESSURES

Gasifier Gas Outlet	540-570 °C
Gasifier Pressure	26.5 bar

FLOWS (MASS BALANCE CONDITION)

96.3% Oxygen	6016 Nm^3/hr
HP Steam	34.61 metric tons/hr
Crude Gas	34,200 Nm^3/hr
Oil	no oil produced
Clean Tar	0.89 metric ton/hr
Water in Tar	0.18 metric ton/hr
Total Dusty Tar[1]	1.42 metric tons/hr
Gas Liquor	32.00 metric tons/hr
Dust in Tar	0.35 metric ton/hr

[1]Without tar recirculation

Source: "Coal Gasification Test for Tri-State Synfuels Company: Summary" 1981, Sasol Technology (Proprietary) Limited

EXHIBIT 16

TSC

CRUDE GAS COMPOSITION

	% Volume
CO_2	30.62
CO	15.90
CH_4	9.41
H_2	40.80
C_2+	0.90
N_2	0.48
H_2S	1.53
Argon	0.36
	100.00

Source: "Coal Gasification Test for Tri-State Synfuels Company: Summary" 1981, Sasol Technology (Proprietary) Limited

EXHIBIT 17

TAR AND GAS LIQUOR CHARACTERISTICS

TAR

Density (Tar + MIT + H_2O)[1] 70°C	1.18 kg/liter
Clean Tar 70°C	1.07 kg/liter
Heating Value (HHV clean)	38,070 kJ/kg

GAS LIQUOR

pH	9.1
Total Phenols	3450 ppm
Total NH_3	8542 ppm

[1]MIT - Material Insoluble in Toluene

Source: "Coal Gasification Test for Tri-State Synfuels Company: Summary" 1981, Sasol Technology (Proprietary) Limited

EXHIBIT 1c

SIMPLIFIED CORRECTED MASS AND ENERGY BALANCES

	TOTAL mt/hr	C mt/hr	H_2 mt/hr	O mt/hr	C kmol/hr	H_2 kmol/hr	O kmol/hr	HHV Megawatts
DAF COAL	15.9	12.4	0.9	1.6	1033	450	100	165
ASH	3.2							
MOISTURE	1.7		0.2	1.5		100	100	
JACKET WATER + DESUPERHEATER WATER	7.7		0.9	6.9		450	400	
HP STEAM	34.6		3.9	30.7		1950	1950	
OXYGEN (6016 N m^3/hr)	8.6			8.3			519	
TOTAL STEAM DECOMPOSED	(-10.1)							
	71.7	12.4	5.9	49.0	1033	2950	3119	165
RAW GAS	33.1	10.8	1.9	18.8		950	1163	111
BY-PRODUCTS	1.4	1.5	0.1	0.1		50	6	15
GAS LIQUOR	33.9		3.9	30.1		1950	1950	2
ASH 2 % C	3.3	0.1						1
	71.7	12.4	5.9	49.0	1033	2950	3119	129

RAW GAS + COAL LOCK GAS	34,400 Nm^3/hr	TOTAL COAL AR	20.6 mt/hr	HEAT LOSS 26
OXYGEN	6016 Nm^3/hr	RAW GAS + COAL LOCK GAS / COAL AR	1864 Nm^3/mt	
O_2 / RAW GAS + COAL LOCK GAS	0.175 Nm^3/Nm^3	STEAM DECOMPOSITION	24%	
STEAM / O_2	7.03 kg/Nm^3			

Source: "Coal Gasification Test for Tri-State Synfuels Company: Summary" 1981, Sasol Technology (Proprietary) Limited

EXHIBIT 19

COAL SAMPLING

LOCATION	OPERATION	PURPOSE	SAMPLING METHOD
Morganfield and Uniontown, Kentucky	Mine, Belt and Barge Loading	Lot Quality Quality Size Control	Mechanical from Belt Diversion of Primary Increment
Darrow, Louisiana	Transloading to Bulk Carrier	Quality Size	Barge-top - Manual
Port Elizabeth, Republic of South Africa	Rail Car Loading	Quality Size	Stratified Rail Car - Manual
Sasolburg, Republic of South Africa	Rail Car Unloading Stockpile	Quality Size	Front-end Loader - Manual Stockpile - Manual
Uniontown, Kentucky	Test Stockpile	Quality Size Leach	Stockpile - Mechanized Auger

EXHIBIT 20

BARGE SHIPMENT
LABORATORY TEST WORK SCOPE

- Screen Analysis
- Proximate Analysis
- Ultimate Analysis
- Ash Fusion Temperatures
- Gross Calorific Value
- Sulfur Forms
- Alkali Content
- Water Soluble Alkali
- Equilibrium Moisture
- Hardgrove Grindability
- Tumbler
- Free Swelling Index
- Caking (Damm) Number
- Fischer Assay
- Specific Gravity
- Trace Elements - Atomic Absorption
- Trace Elements - Spark Source Mass Spectrography
- Trace Elements - X-ray
- Boron
- Mercury
- Fluorine
- Ash Minerals
- Petrographic
- Leaching - ASTM, RCRA
- Leachate - ASTM, RCRA
- Sole Oven
- Gieseler Plastometer
- Reactivity
- Pressure Reick Degassing
- Disintegration During Carbonization
- Volume Increase of Pressure Coke

EXHIBIT 21

FINES GENERATION DURING COAL SHIPMENT

(Weight Percentage Passing ¼-Inch Round Hole Screen)

LOCATION	HANDLING OPERATION	FINES, % WEIGHT CONTROL	ON-SITE	COMPOSITE	STATISTICAL	HANDLING STAGES
Morganfield and Uniontown, Kentucky	Mine, Belt and Barge Loading	35.0	37.2	35.6	37.6	0
Darrow, Louisiana	Barge Transloading to Bulk Carrier	—	36.4	40.3	38.1	1
Port Elizabeth, Republic of South Africa	Rail Car Loading	—	ND	39.9	39.5	4
Sasolburg, Republic of South Africa	Rail Car Unloading	—	ND	48.8 (a)	40.0	5
Sigma Mine, Republic of South Africa	Stockpile	—	ND	39.8	40.5	6

ND = Not Determined
(a) = Eliminated data because only three samples were taken

EXHIBIT 2[illegible]

TRI-STATE SAMPLES TAKEN DURING MASS BALANCE COAL GASIFICATION TEST

COAL
- RUN-OF-MINE
- SCREENED

GAS LIQUOR
- RAW
- DEPHENOLIZED
- STRIPPED

TAR
- CLEAN
- DUSTY

CRUDE PHENOL

ASH

F-T CATALYST LEACHATE

MISCELLANEOUS