U.S. Department of Energy
National Energy Technology Laboratory

Early Entrance Co-Production Plant – Decentralized Gasification Cogeneration Transportation Fuels and Steam From Available Feedstocks

DOE Cooperative Agreement DE-FC26-00NT40693

Quarterly Technical Progress Report
October to December 2001

Waste Processors Management, Inc.
March 2002

DISCLAIMER

ABSTRACT

Waste Processors Management, Inc. (WMPI), along with its subcontractors Texaco Power & Gasification (now ChevronTexaco), SASOL Technology Ltd., and Nexant Inc. entered into a Cooperative Agreement DE-FC26-00NT40693 with the U. S. Department of Energy (DOE), National Energy Technology Laboratory (NETL) to assess the techno-economic viability of building an Early Entrance Co-Production Plant (EECP) in the United States to produce ultra clean Fischer-Tropsch (FT) transportation fuels with either power or steam as the major co-product. The EECP design includes recovery and gasification of low-cost coal waste (culm) from physical coal cleaning operations and will assess blends of the culm with coal or petroleum coke.

The project has three phases. Phase I is the concept definition and engineering feasibility study to identify areas of technical, environmental and financial risk. Phase II is an experimental testing program designed to validate the coal waste mixture gasification performance. Phase III updates the original EECP design based on results from Phase II, to prepare a preliminary engineering design package and financial plan for obtaining private funding to build a 5,000 barrel per day (BPD) coal gasification/liquefaction plant next to an existing co-generation plant in Gilberton, Schuylkill County, Pennsylvania.

The current report is WMPI's third quarterly technical progress report. It covers the period performance from October 1, 2001 through December 31, 2001.

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Section 1 Introduction and Summary

1.1 INTRODUCTION

WMPI, along with its subcontractors Texaco (now ChevronTexaco), Sasol, and Nexant entered into a Cooperative Agreement DE-FC26-00NT40693 with the U. S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), to assess the technical and economic viability of building an Early Entrance Co-Production Plant (EECP) in the U. S. to produce ultra clean Fischer-Tropsch (FT) transportation fuels with either power or steam as the major co-product. The EECP design emphasizes on recovery and gasification of low-cost coal wastes (culm) from coal cleaning operations, and will assess blends of the culm with coal or petroleum coke as feedstocks. The project has three phases.

1.1.1 Phase I – Concept Definition and RD&T Planning

Phase I objectives include concept development, technology assessment, conceptual designs and economic evaluations of a greenfield commercial co-production plant and of a site specific demonstration EECP to be located adjacent to the existing Gilberton Power Station. There are very few expected design differences between the greenfield commercial co-production plant versus the EECP plant other than:

- The greenfield commercial plant will be a stand-alone FT/power co-production plant, potentially with larger capacity than the EECP to take full advantage of economies of scale.
- The EECP plant, on the other hand, will be a nominal 5,000 bpd plant, fully integrated into the Gilberton Power Company's Cogeneration Plant's existing infrastructure to reduce cost and minimize project risks. The Gilberton EECP plant will be designed to use eastern Pennsylvania anthracite coal waste and/or a mixture of culm and other fuels as feedstock.

Phase I includes 11 tasks and the following major deliverables.

- A project management plan.
- A process feasibility design package with sufficient details to determine order-of-magnitude cost estimates for preliminary economic and market analyses.
- A preliminary environmental and site analysis.
- A Research, Development and Testing (RD&T) plan for Phase II tasks.
- A preliminary project financing plan.

1.1.2 Phase II – R&D and Testing

The Phase II objective is to perform research, development and process performance verification testing of any design deficiencies identified in Phase I. Due to the relative maturity of the two key technologies (Texaco's coal gasification and SASOL's FT) proposed for the EECP designs, Phase II activities will focus on feedstock characterization and gasification process performance testing rather than research and development. Specific Phase II goals include:

- Characterization of anthracite culm and its mixture with other fuels as feedstocks for the Texaco gasifier.
- Gasification performance (pilot plant) testing of design anthracite culm feedstocks at an existing Texaco facility to verify its performance.

1.1.3 Phase III – Preliminary Engineering Design

The objective in Phase III is to upgrade the accuracy of the Phase I site-specific Gilberton EECP capital cost from plus or minus 35% to plus or minus 20%. The increased cost estimation accuracy is achieved by updating the Phase I inside battery limits (ISBL) processing plant design packages to incorporate Phase II findings, by refining the outside battery limits (OSBL) utility and offsite support facility design packages to include final and updated ISBL unit demands, by obtaining actual budgetary quotes for all major equipment, and by further engineering to define the actual bulk commodities requirements.

The upgraded Phase III capital cost estimate, together with the updated operating and maintenance cost estimate, are crucial elements to finalize the EECP Project Financing Plan needed to proceed with detailed engineering, procurement and construction of the EECP.

The Phase III goals and deliverables include the development of:

- Preliminary Engineering Design package of the EECP.
- A Project Financing Plan.
- An EECP Test Plan.

The project scope of work consists of sixteen tasks organized into the three phases as shown in Table 1.1. The table also shows the project team members responsible for the leading role for each task. The specific task description details were discussed in the Project Management Plan.

1.2 SUMMARY

The main technical activities performed during the current reporting period include work in the following tasks.

- Phase I Task 4 – Feasibility Design Package Development
    - Texaco's Type C Feasibility Study process design package.
    - Sasol's Feasibility Slurry-Phase Distillate Process design package.

- o Preliminary ISBL (Inside Battery Limits) heat and material balances.

Table 1-1

Scope of Work Task Summary

Phase/Task	Description	Task Leaders
Phase I	**Concept Definition and RD&T Planning**	
Task 1	Project Plan	Nexant
Task 2	Concept Definition, Design Basis & EECP Process Configuration Development	Nexant
Task 3	System Technical Assessment (Trade-off Analysis)	Nexant
Task 4	Feasibility Study Design Package Development	Nexant (w/individual Process Design package from Texaco and Sasol)
Task 5	Market Assessment	Texaco
Task 6	Preliminary Site Analysis	WMPI and Consultants
Task 7	Preliminary Environmental Assessment	WMPI and Consultants
Task 8	Economic Assessment	WMPI and Consultants
Task 9	Research Development and Test Plan	Texaco
Task 10	Preliminary Project Financing Plan	WMPI and Consultants
Task 11	Phase I - Concept Report	Nexant
Phase II	**R&D and Testing**	
Task 1	Feedstock Mix Characterization and Gasification Performance Verification	Texaco (w/ support from Nexant and WMPI)
Task 2	Update RD&T Plan	Texaco
Phase III	**EECP Engineering Design**	
Task 1	Preliminary Engineering Design Package Development	Nexant – with a) Texaco – Gasification Design Package b) Sasol – FT Design Package c) Nexant – BOP and cost estimate
Task 2	Project Financing Plan	WMPI and Consultants
Task 3	EECP Test Plan	Nexant

Section 2 Phase I Task 1 – Project Plan

TASK COMPLETED.

A Project Management Plan was prepared, issued and approved by DOE. A copy was submitted to the AAD Document Control Office of DOE/NETL on May 15, 2001.

This plan provides a road map for the overall project execution delineating the project:

- Objectives.
- Detailed work breakdown structure and obligated deliverables.
- Technical and management approach.
- Control plan – scheduling, budget and reporting.
- Administration details.

Section 3 Phase I Task 2 – Concept Definition, Design Basis & EECP Process Configuration

TASK COMPLETED.

3.1 EECP concept and process configuration defined, giving full considerations of:

- WMPI's feedstock availability and quality (e.g., ash content, composition and anticipated fusion temperature.)
- Desired mode of operation for Texaco's gasification process in handling the design project feed mix.
- Design consideration of Sasol's Low-Temperature FT (LTFT) process giving the estimated design syngas feed.
- System integration and site-related issues (e.g., syngas clean up, utility availability.)

3.2 Gilberton EECP Design Basis established, and a Basic Engineering Design Data (BEDD) package was developed to guide the overall process design development regarding:

- Plant capacity
- Site data
- Feedstock properties
- Product specifications
- Battery limits and offsite utility specifications

3.3 Project Instruction of Equipment Code of Accounts established.

Details of the above were reported in the April to June 2001 Quarterly Technical Progress Report.

EECP process configurations will be discussed in more details as part of the Phase 1 Task 4 activity.

Section 4 Phase I Task 3 – System Technical Assessment

Under this task 1) technical design issues/systems (e.g., ash fusion characteristics of EECP feed mix) identified in Phase 1 Task 2 were assessed in more detail, and 2) preliminary heat, material and utility balance sensitivity analyses were carried out, based on process performance estimates and utility demands from Texaco and Sasol for the gasification and FT synthesis section respectively, to continuously optimize the overall EECP process plant design and preliminary economics, and to provide preliminary emission and cost data needed for Phase I Tasks 7 and 8 planning.

Current sensitivity analysis activities included assessment of:

- The Base Case, stand-alone 5000 bpd Greenfield EECP plant with 2 separate gasification trains, in comparison with a reduced capacity design with only a single gasification train operating at a higher tail gas recycling ratio for FT synthesis.

- An integrated design with sending portion of the unconverted FT tail gas to the existing Gilberton cogen plant as auxiliary feed.

Section 5 Phase I Task 4 – Feasibility Design Package Development

Under this task, feasibility study process design packages are to be developed for the EECP gasification island, FT synthesis and offsite utility plants by Texaco, Sasol and Nexant respectively. With most of the major EECP processing plants already identified, Texaco has developed a gasification island Type C Feasibility Study package, and Sasol, the Slurry-Phase Distillate Process Feasibility Study package, for the WMPI EECP plant. Offsite utility plant designs are under development by Nexant.

Both the Texaco Type C Feasibility Study and Sasol Slurry-Phase Distillate Process Feasibility Study design package are considered CONFIDENTIAL. They are documented as separate reports having the following Table of Contents breakdown: Project Summary, Process Description, Process Flow Diagrams, Heat and Material Balances, Sized Equipment List, Utility Summary, Catalyst and Chemicals, Preliminary Cost Estimates and Plot Plan.

Both the Texaco Type C and Sasol's Feasibility Study packages are fairly comprehensive. A summary of their results is presented in this section. The overall design package, in its entirety, can be reviewed by DOE/NETL at the WMPI office, with permission from Texaco and Sasol as required.

Nexant's offsite design and balance of plant activity will be reported in the next quarterly technical report.

5.1 Overall EECP Configuration

Figure 5-1 shows the overall WMPI EECP block flow configuration.

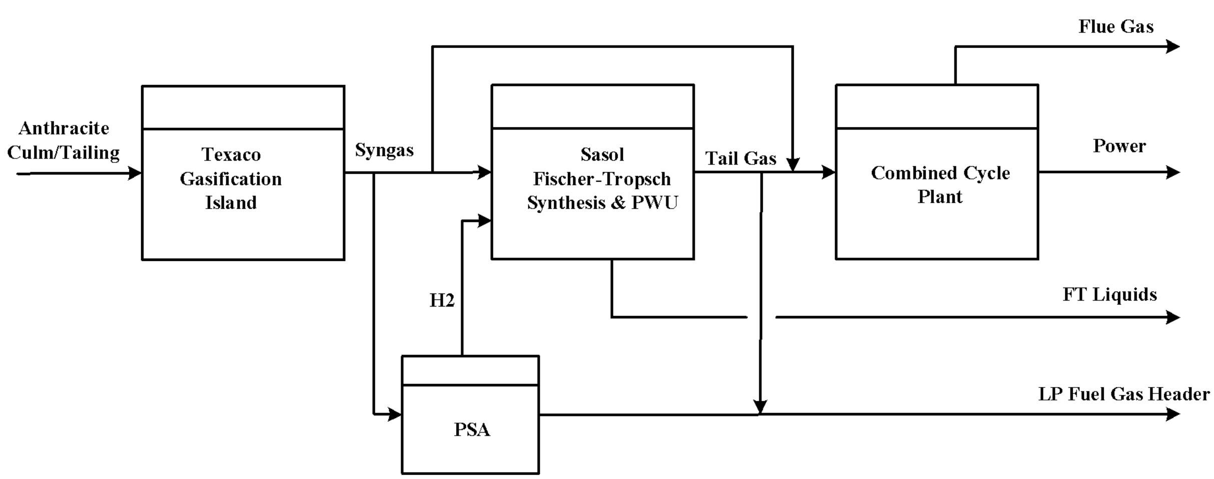

Figure 5-1 Overall EECP Process Configuration

The EECP plant consists of two main process sections: Texaco Gasification, and Sasol FT Synthesis and product work up (PWU). It is designed to use anthracite culm of 20% ash as the primary feed. The design has the operation flexibility of feeding in 25% petroleum coke as feed.

5.2 Texaco Gasification Feasibility Design

Texaco provided a Type C Feasibility Study Package as their input to Phase I EECP process design. The major results from the Texaco study are reported here. The detailed feasibility study contains material confidential to Texaco, and if desired the DOE can inspect the report separately from the Quarterly Report.

The overall EECP gasification island block diagram is shown below, Figure 5-2.

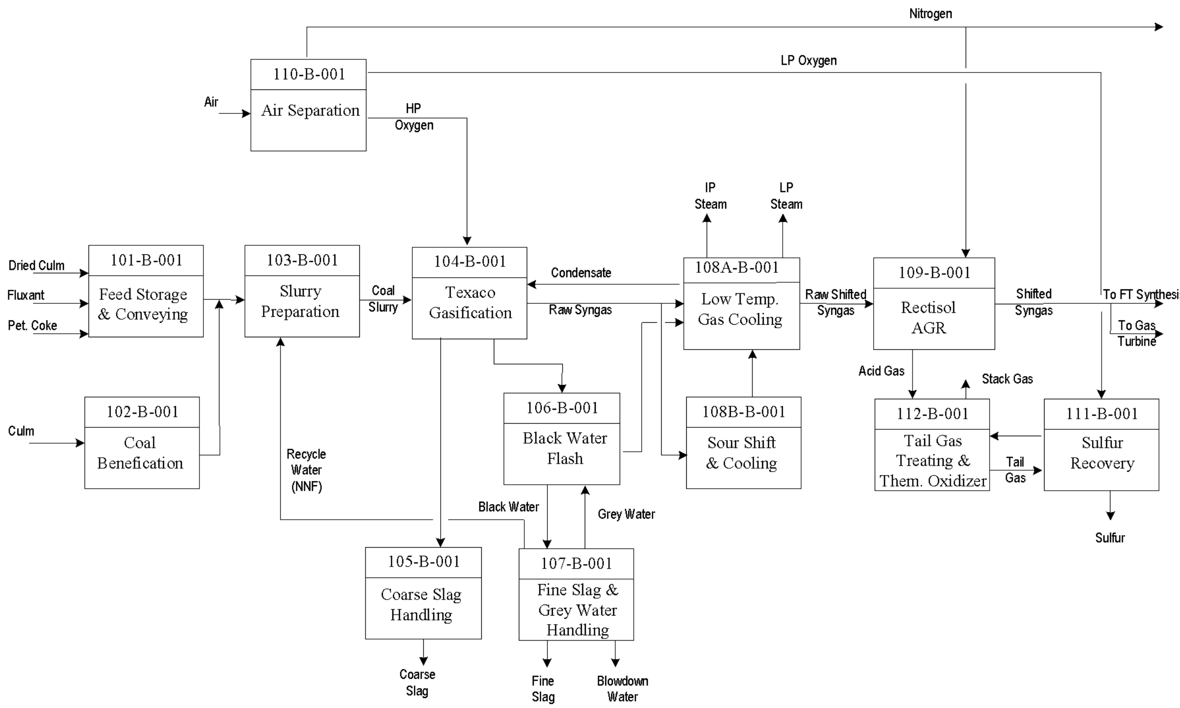

Figure 5-2 EECP Block Flow Diagram – Gasification Section

It consists a total of eleven major processing plants of which Coal Beneficiation (Plant 102B-001) design is the responsibility of WMPI. Other processing plants within the gasification island include:

- Feed Storage and Conveying
- Slurry Preparation, Gasification
- Slag Handling
- Black Water Flash
- Black Water Filtration

- Sour Shift and Low Temperature Gas Cooling
- Rectisol Acid Gas Removal
- Air Separation Unit
- Sulfur Recovery
- Tail Gas Treating

The overall Texaco Type C design includes process performance and cost data for the air separation plant and the Rectisol acid gas removal plant from BOC Gases and Lotepro Corporation respectively.

The gasification island processed 3534 tons (dry) per day of beneficiated coal, along with 246 tons per day of fluxant, and generates 194.6 MMSCFD of clean shifted (mostly hydrogen and carbon monoxide) syngas for the downstream Sasol F T synthesis. The estimated product syngas composition leaving the gasification island is noted below.

Table 5-1
Estimated Gasification Product Syngas

PRODUCT COMPOSITION	Mol Percent
Carbon Monoxide	38.085
Hydrogen	56.360
Carbon Dioxide	2.997
Methane	0.019
Argon	1.130
Nitrogen	1.397
Methanol	0.012
TOTAL	100.000

The gasification plant also produces 803 tons per day of slag and 201 tons per day of soot, and it is designed for a high annual availability of 85%.

5.2.1 Gasification Process Flow Diagrams

The Type C Feasibility Study Package includes simplified process flow diagrams for the 12 processing plants listed.

101-B-001	Feed Storage and Conveying
103-B-001	Slurry Preparation
104-B-001	Gasification
105-B-001	Coarse Slag Handling
106-B-001	Black Water Flash
107-B-001	Fine Slag Handling
108-B-001	Sour Shift and Low Temperature Gas Cooling

109-B-001	Rectisol Acid Gas Removal
110-B-001	Air Separation Unit
111-B-001	Sulfur Recover
112-B-001	Tail Gas Treating
112-B-002	Tail Gas Treating

5.2.2 Gasification Process Description

The major gasification plants are described below. Plant Numbers, e.g., 101-B-001, refer to the block diagram, Figure 5-2.

5.2.2.1 Storage, Conveying and Slurry Preparation (101-B-001, 103-B-001)

The main feed is a beneficiated coal slurry from the WMPI beneficiation plant. Additional coal and/or petroleum coke plus fluxant will be added prior to the gasification unit. Storage bins and silos are provided for additional dry coal, coke and two types of fluxant. The beneficiated coal slurry is pumped into a premix tank. The slurry is then pumped to a grinding mill where additional coal/coke plus fluxant are added. The slurry is collected in the mill discharge tank. The mill discharge tank slurry is pumped to the slurry run tank. The slurry run tank capacity is approximately 8 hours of full rate operation. The slurry charge pumps pump the slurry from the slurry run tank to the gasifier. These pumps supply a steady, controlled flow of slurry to the gasifier feed injector.

5.2.2.2 Gasification (104-B-001)

The Texaco gasifier is a pressurized entrained flow reactor with a low residence time and a liquid feed. It is a non-catalytic process involving the reaction of hydrocarbon materials with oxygen at high temperatures and pressure under conditions of insufficient oxygen for complete combustion (partial oxidation).

The partial oxidation produces a gaseous product (syngas) consisting primarily of hydrogen and carbon monoxide with lesser amounts of water vapor, carbon dioxide, hydrogen sulfide, methane, and nitrogen. Traces of carbonyl sulfide and ammonia are also formed. The high temperature eliminates formation of tars, phenols, or other hydrocarbons. Ash from the feed is melted to form a glassy slag.

Oxygen for gasification is supplied by the air separation unit at 95 mol% purity. The coal slurry and oxygen are introduced at the top of the refractory-lined combustion section of the gasifier. The hot syngas leaving the combustion section is cooled by direct contact with water in the quench section of the gasifier. Liquid slag from the combustion section is frozen and fractured by contact with water. The coarse fraction of the slag is then removed through a water-filled lockhopper system.

The quenched syngas exits the gasifier and is scrubbed by further water contact to remove entrained particulate. The particulate-free syngas is routed to the sour shift and low temperature gas cooling section. The scrubbing water is routed to the black water flash section for cooling, and then to the black water filtration section.

5.2.2.3 Slag and Black Water Handling (105-B-001, 106-B-001, 107-B-001)

Coarse slag flows by gravity from the quench section of the gasifier into a lockhopper. The lockhopper is automatically isolated from the gasifier at regular intervals, depressured, and emptied onto a drag conveyor. Water in the lockhopper is replaced with cooled grey water from the lockhopper flush drum and the system is repressurized. The material is screened to reduce moisture, and sent to disposal offsite. The reclaimed water is sent to the vacuum flash drum in the black water flash section of the plant.

Gasification blowdown water containing solids is called black water. The black water flash section concentrates solids and removes dissolved syngas from the black water. The black water is flashed in two stages, a low-pressure flash and a vacuum flash. Gas is routed to the sulfur recovery unit and thermal oxidizer in the tail gas treating unit since they contain traces of hydrogen sulfide and ammonia. The cooled black water is sent a filtration step. Black water is routed to a gravity settler in the fine slag handling section to remove solids.

The fine slag handling section processes flashed black water from the black water flash section. The vacuum flashed bottoms stream is pumped to a gravity settler. The solids-concentrated water from the gravity settler is pumped to a rotary drum filter. The filter cake is discharged from the filter for disposal offsite. Filtrate is pumped to a vacuum flash drum.

5.2.2.4 Sour Shift and Low Temperature Gas Cooling (108-B-001)

The sour shift and low temperature gas cooling section shifts a portion of the syngas, cools it, utilizes its useful heat, and condenses and removes the water prior to acid gas removal (AGR).

Preheated syngas from the syngas scrubber is sent to the sour shift reactor. In the shift reaction, carbon monoxide and water are converted to hydrogen and carbon dioxide. The reaction is exothermic and the recovered heat is used to preheat the feed and to superheat saturated steam generated further down the cooling train. The shifted syngas is cooled to approximately the same temperature of the unshifted syngas, and the two streams are combined and sent to the condensate knockout drum. Condensed water is removed in the steam generator knockout drum.

5.2.2.5 Acid Gas Removal (109-B-001)

The Rectisol acid gas removal section processes the cooled shifted dried raw syngas from the sour shift and low temperature gas cooling. Clean shifted syngas leaves Rectisol acid gas removal for the Fischer Tropsch unit with essentially all of the sulfur removed from the syngas.

Methanol is used as a solvent to remove the H_2S and COS from the syngas in the Wash Column. The solvent is stripped of CO_2 with nitrogen to concentrate the H_2S. The acid gases are then stripped from the methanol in the regenerator column. The lean methanol is pumped back to the wash column. The acid gas is sent to the feed absorber in the tail gas treating unit. CO-rich tail gas consisting mostly of CO_2 with some CO and H_2 is routed to a thermal oxidizer in the tail gas-treating unit. LP purge gas is also sent to the thermal oxidizer, and an intermittent purge of sour water is sent to the sulfur recovery unit.

5.2.2.6 Air Separation Unit (110-B-001)

The air separation unit supplies high-pressure oxygen to the gasifier. It also provides nitrogen for the acid gas removal and for other plant services. Low-pressure oxygen is available for the sulfur recovery unit, when required. High-pressure nitrogen is provided for shutdown operations such as purging the gasifier. The air separation unit also provides plant air and nitrogen for offsite units.

5.2.2.7 Sulfur Recovery and Tail Gas Treating Units (111-B-001), (112-B-001 and 002)

The acid gas stream from the tail gas-treating unit, sour gases from the black water flash, and flashed gas from Rectisol purge are processed to recover elemental sulfur as a byproduct. Uncondensed gas is sent to the tail gas treating unit.

The tail gas treating unit processes gas from the acid gas removal and sulfur recovery units. The gas is heated and reacted in the tail gas reactor. Then the gas is cooled and CO_2 removed with amine, which is later regenerated. Overhead gas from the amine stripper with concentrated H_2S is sent to the sulfur recovery unit.

5.2.3 Gasification Energy and Material Balance

Texaco provided major process stream data for heat and materials balances for each processing plants. The data are for normal (design basis) operations to produce the clean shifted syngas suited to the Fischer Tropsch process. These data are integral parts of the overall Type C package.

5.2.4 Gasification Equipment List

Texaco prepared a list of major equipment with engineering specification to allow cost estimation of the gasification facilities. The detailed list will be used for project cost estimation by Nexant as the engineering effort proceeds.

5.2.5 Gasification Utilities Requirements

Texaco's feasibility study includes estimates for major utilities required for operations. The requirements are for electric power, steam and water. Results are summarized below.

Table 5-2
Summary of Gasification Utilities

Item	Rate lb/h	Duty/Quantity
Electric Power		67,300 kW
Cooling Water	29.7 million	429 MMBtu/h
Boiler Feedwater Consumption	73,000	
Steam Condensate Heating/Cooling	1.33 million	141 MMBtu/h
High Pressure Steam, 1,500 psig	(2,910)	(1.6 MMBtu/h)
High Pressure Steam, 700 psig	139,000	135 MMBtu/h
Medium, Intermediate, and Low Pressure Steam	450,000	455 MMBtu/h
Note: ( ) denotes imported steam, other steam is exported		

For reference, the air separation unit consumes 54,000 of the total electric requirement.

Initial and annual chemical and catalyst requirements for gasification were also provided by Texaco for use in overall cost estimation.

5.2.6 Gasification Effluents

Gasification, with the designated cleaning steps is an inherently clean process. The plant produces minimal air emissions, and liquid and solid effluent streams as presented below.

The only air emissions for the gasification plant are from the thermal oxidizer in the tail gas-treating unit. The thermal oxidizer exhaust is estimated to be about 620,000 lb/h. The exhaust gas composition is estimated as listed below.

Table 5-3
Gasification Air Emissions

Effluent	Lbmol/h
Carbon Dioxide	8,640
Water	1,590
Nitrogen	7,100
Oxygen	310
SOx	0.1

Liquid effluent streams leaving the gasification unit are the water left with the slag and ash filter cake, gray water blowdown and cold condensate discharge. The acid gas removal unit also has a wastewater blowdown. Liquids from the blowdown streams total about 150,000 lb/h, which is treated prior to any release.

The gasification plant produces slag from the coal ash and flux, with small amounts of unconverted carbon. These solids leave the plant in a coarse fraction and a fine fraction that is a wet filter cake. A breakdown of the expected solid wastes is shown below.

Table 5-4
Gasification Solid Wastes Summary

Coarse Fraction (Slag) Solids	Quantity
Solids Rate, moisture-free basis, Ib/hr	67,000
Solids Composition	
• Carbon (wt%)	3.7
• Ash (wt%)	96.3
Water Content (wt%)	50
Fine Fraction (Ash, Filter Cake) Solids	
Solids Rate, moisture-free basis, Ib/hr	16,750
Solids Composition	
• Carbon (wt%)	11.0
• Ash (wt%)	89.0
Water Content (wt%)	70

5.2.7 Miscellaneous

Texaco provided preliminary estimates of cost, operating labor, project schedule and the gasification island plot plan as part of the overall Type C Feasibility Design package.

5.3 Sasol Slurry-Phase Distillate Process Feasibility Study

Sasol has prepared a Feasibility Design Package for the Fischer-Tropsch unit and the associated product work-up processing plant. The overall block flow diagram is shown below, Figure 5-3.

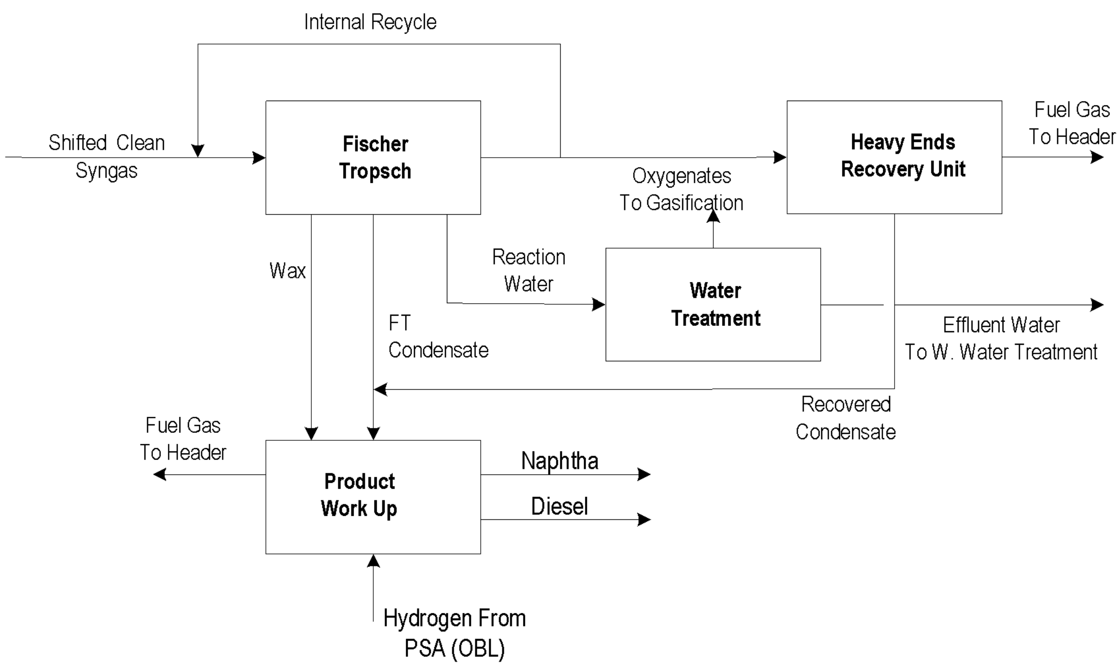

Figure 5-3 EECP Block Flow Diagram – FT and PWU Section

The Sasol EECP feasibility study scope includes the following process units:

- Plant 201 Fischer-Tropsch Synthesis Unit (including the Catalyst Reduction and Heavy Ends Recovery)
- Plant 202 Product Work-Up Unit
- Plant 203 Effluent Water Primary Treatment Unit

The Fischer-Tropsch (FT) Synthesis Unit processes 185.7 MMSCFD (9246 kmol/hr) of the clean shifted syngas (Table 5-1) from the gasification island. A small side stream of this syngas was taken from the gasification island and sent onto an offsite PSA unit to produce hydrogen required for FT product work-up.

The iron based Sasol Low-Temperature FT Slurry-Phase Distillate Process with internal recycle for selected for the EECP design. The recycle ratio was set at 1.2. For turndown design case, one gasifier is shut down, reducing the syngas flow to 50% of the base case. The recycle stream is kept constant during turndown, thus increasing the recycle ratio from 1.2 to 2.4.

For EECP, fresh unreduced catalyst will be imported and delivered on site. The supplied catalyst will be reduced in the catalyst reduction unit. In the reduction reactor, the catalyst is first reduced and then conditioned. Hydrogen with a similar quality as for the FT product work-up unit is used for the reduction and conditioning process, but standard refinery hydrogen quality (typical 99.9vol%) is also acceptable.

The Sasol FT plant is expected to produce a total of 5030 bbl/day of FT liquids consisting of 3745 bbl/day of diesel and 1285 bbl/day of naphtha. These FT fuels are unique, being almost entirely sulfur, aromatics and nitrogen free.

The expected product quality for the diesel and naphtha is given in the tables below.

Table 5-5
Typical FT Naphtha Quality

Density @ 20 °C (kg/m^3)	670-690
ASTM D86 Distillation (°C) 10% 50% 90% 98%	 62 102 136 146
PMCC Flash Point (°C)	-37
Reid Vapour Pressure (psi)	10 max
Sulfur (ppmw)	<10
RON Clear	<40
COMPOSITION (%) Paraffins Olefins Napthenes Aromatics	 >90 1 <5 1

Kg/m^3 = 62.43 lb/ft^3

Table 5-6
Typical FT Diesel Quality

Density @ 20 °C (kg/m^3)	760-790
ASTM D86 Distillation (°C) (Note 3) 10% (Note 1) 50% 90%	 192 267 329
Viscosity @ 40 °C (cSt)	2.4
Cetane Number	>70
Sulfur (ppmw)	<10
PMCC Flash Point (°C)	55 min
Cloud Point (°C)	-15 to -20 (Note 2)
Cold Filter Plugging Point	(Note 2)
Aromatics (Wt%)	<1
Color (ASTM D1500/91)	<1

Notes:
1. Dependant on RVP specification
2. Will depend on market requirements
3. Diesel yield based on ASTM D86 IBP=146°C, 95% = 340°C

The present product information is preliminary. The product specifications will be revised/confirmed after future evaluations of marketing requirements and actual process yields. Currently, the plant is designed to maximize diesel production with naphtha as by-product. No other by-products are produced in the base case. Potential future options include producing LPG and alcohols by adding further separation steps and appropriate offsite storage facilities. For the current EECP design, the LPG containing stream is used as fuel and the oxygenate-rich stream is recycled to the Texaco gasifiers.

5.3.1 Process Flow Diagrams

Figure 5-3 presents the overall Sasol FT process block flow diagram. Sasol's Feasibility Study Design Package includes simplified process flow diagrams listed below.

Drawing No.	Description
• 201-B-001	Catalyst Reduction
• 201-B-002	FT Synthesis
• 202-B-001	CO_2 stripping
• 202-B-002	Condensate Hydrotreating
• 202-B-003	Wax Hydrocracking
• 202-B-004	Hydrogen recycle
• 202-B-005	Product Fractionation
• 202-B-006	Naphtha Stripping
• 203-B-001	Reaction Water degassing
• 203-B-002	Primary Distillation

5.3.2 Process Description

The processes for Fischer-Tropsch Synthesis – Plant 201, Product Work-Up – Plant 202, and Effluent Water Primary Treatment – Plant 203 are described in the next sections.

5.3.2.1 Fischer-Tropsch Synthesis – Plant 201

The Fischer-Tropsch synthesis plant consists of 2 units: a catalyst reduction unit and the Fischer-Tropsch synthesis unit.

The Catalyst Reduction Unit activates batches of catalyst to supply material for start-up and the online renewal of catalyst.

The Fischer-Tropsch Synthesis Unit converts synthesis gas to primary products: wax, hydrocarbon condensate, tail gas, and reaction water. The wax and hydrocarbon condensate streams are fed to the product work-up unit for further processing into final products (Plant 202). The tail gas is sent to a Heavy End Recovery (HER) unit, recovering mainly C5+ components. The dry tail gas stream from the HER Unit is sent to the high pressure (HP) fuel gas system. The reaction water by-product stream is sent to the effluent water primary treatment unit (Plant 203).

Catalyst Reduction Unit (201-B-001)
Precipitated Iron Catalyst is delivered to the site. (Catalyst preparation is outside the scope of this study.) Enough catalyst is produced to replace part of the FT reactors inventory per week.

The catalyst reduction unit is a twice per week batch operation. Pure hydrogen and syngas are required for the catalyst reduction and conditioning operation. During the reduction and conditioning steps, FT wax and condensate are produced, as well as reaction water. The products are sent to their respective processing units (product work-up and effluent water primary treatment).

Fischer-Tropsch Synthesis Unit (201-B-002)
The Fischer-Tropsch unit consists of the following.

- Fischer-Tropsch reactor
- Primary product recovery
- Heavy Ends Recovery (HER)
- Medium pressure steam system

The detailed design of the Fischer–Tropsch reactor system is confidential and proprietary. In the study, the system will provide the required conversion of syngas to primary Fischer-Tropsch products. Syngas from the gasifier plant is combined with recycle gas from the recycle compressor and fed to the total feed pre-heater before entering the reactor. In the reactor, the total feed gas, comprising mostly of CO and H_2, is converted to hydrocarbon chains via the Fischer-Tropsch synthesis reaction.

The wax product from the reactor system is sent to a wax cooler. The cooled wax is fed to a surge drum, from where it is filtered through a wax separation package.

The reactor overhead stream is cooled in an air-cooled heat exchanger to 70°C. The resultant stream consists of three phases: hydrocarbon condensate, reaction water, and vapor (unreacted feed and vapor products), which are separated in a 3-phase separator drum. Hydrocarbon condensate is sent to the product work-up unit (Plant 202) for recovery and upgrading. The reaction water stream is sent to the effluent water primary treatment unit (Plant 203).

Part of the overhead vapor from the separator drum is used as recycle to increase conversion in the FT reactor, while the balance is fed to the HER. The C5+ condensate is recovered in this unit and is sent to the product work-up unit. The dry tail gas is sent to the high pressure fuel gas header and is used to drive gas turbines in the power plant.

The major products of the unit are:

- Wax to product work-up (Plant 202)
- Unstabilized hydrocarbon condensate to product work-up (Plant 202)
- Reaction water to effluent water primary treatment unit (Plant 203)

- Tail gas to HP fuel system

Steam system
The process steam system removes the net heat of reaction from the FT reactor by circulating boiler feed water (BFW) through internal coils in the reactor where it is partially vaporized. The resultant steam/water mixture is collected in the steam drum. The steam drum and circulating BFW pump sizing is based on the design cooling capacity of the reactor cooling system.

The FT Synthesis unit is the sole producer of intermediate pressure (IP) steam at 150 psig. After supplying several consumers within the FT battery limits, the net production is exported to the IP steam header.

Catalyst Loading and Unloading System
Catalyst is loaded from the reduction reactor to the catalyst-mixing drum using high pressure nitrogen. In the catalyst-mixing drum, the reduced catalyst is mixed with wax. This slurry is then fed to the reactor.

Spent catalyst is unloaded from the reactor to the catalyst slurry hopper by pressure differential. The system is designed for unloading of part of the reactor inventory as required. The spent catalyst and wax are separated to produce a dry filter cake for disposal.

5.3.2.2 Product Work-Up Unit – Plant 202

The product work-up unit consists of the following operations: condensate hydrotreating, wax hydrocracking and product fractionation. The unit converts the hydrocarbon condensate and wax streams from the FT synthesis unit into premium quality petrochemical naphtha and a diesel blend, with diesel production maximized by design. The operation also produces light end hydrocarbon materials, which are consumed as fuel within the plant. The system components are briefly described next.

CO_2 Stripping (202-B-001)
The unstabilized condensate from the FT synthesis unit and recovered condensate from the HER Unit are sent to a CO_2 stripper column(202-C-006). In the column, CO_2 is stripped from the liquid feed and the feed is stabilized.

Condensate Hydrotreating (202-B-002)
The stabilized hydrocarbon condensate is hydrotreated to saturate the olefins and remove the oxygenate-containing compounds. The condensate is sent to an intermediate storage drum that provides surge capacity for the condensate pumps. The condensate stream pressure is then raised to reactor loop pressure by the condensate charge pumps and the condensate is combined with the preheated hydrogen-rich recycle gas. The condensate and gas-mixture is heated to the required temperature by heat exchange with the reactor product and a fired heater. The condensate stream is then hydrotreated in the hydrotreater reactor.

Product from the hydrotreater reactor is cooled in the feed/product exchanger before being combined with the hydrocracker product for final cooling and product fractionation.

The recycle gas circuit supplies both the condensate and wax reactor loops with hydrogen-rich gas for hydrotreating and hydrocracking. Hydrogen quench is used between the catalyst beds of the reactors to control the catalyst bed temperature.

Wax Hydrocracking (202-B-003)
Wax from the FT synthesis unit is cracked to yield naphtha and diesel as final products. Wax is fed to a surge drum, which protects the feed pumps and allows the removal of gases. Unreacted wax from the product fractionator is recycled back to the surge drum for further cracking in the reactor. The wax stream pressure is raised to reactor loop pressure by the wax charge pump and is combined with preheated hydrogen-rich recycle gas. The wax- and gas mixture is preheated by heat exchange with reactor product and finally heated to reaction temperature in a fired heater.

The reactor system is a single reactor containing more than one catalyst beds, with intermediate quench zones, quench gas distributors and liquid collection/ redistribution trays.

The hydrocracker reactor product is used to preheat the hydrocracker feed, recycle gas and low pressure separator liquid before combining with hydrotreater reactor product and final cooling occurs in the reactor product cooler.

After final reactor product cooling, the three-phase stream passes to the high-pressure separator where the gas, hydrocarbon liquid and water are separated. Hydrocarbon liquid from the high pressure separator is sent to the low pressure separator to remove off-gasses and any remaining free water. The liquid is then heated by exchange with the reactor product and partially vaporized in a fired heater before entering the product fractionator.

Hydrogen Recycle (202-B-004)
The hydrogen rich gas from the high-pressure separator is recycled to the hydrotreater and hydrocracker reactors via the recycle gas compressor. A small purge is removed to reduce the build-up of inerts. The hydrogen partial pressure in the reactors is maintained by feeding make-up hydrogen to the recycle loop with the make-up hydrogen compressors. The hydrogen is supplied from an external source and is not included in the scope of this study.

Product Fractionation (202-B-005)
The product fractionator separates the hydrotreater and hydrocracker reactor products by steam stripping. The following streams are separated.

- Offgas to fuel gas system

- Unstabilized naphtha
- Diesel
- Unreacted bottoms recycle
- Waste water

Offgas from the overheads drum is routed to the PSA offgas compressor (Nexant's scope) and is eventually discharged into the low pressure fuel gas system. The diesel is separated in a side stripper before being cooled and pumped to storage. Bottoms residue is recycled to the reactor loop.

Naphtha Stripping (202-B-006)
Naphtha is sent to a stabilizer column, which separates light hydrocarbon ends from the naphtha. The light ends are fed to the low presssure fuel system and the product naphtha is pumped to storage. The column could be modified in future to produce a liquid LPG product.

5.3.2.3 Effluent Water Primary Treatment Unit – Plant 203

The reaction water from the FT synthesis unit contains oxygenates, including alcohols, ketones, aldehydes and carboxylic acids, which are by-products of the synthesis reaction. The effluent water primary treatment unit removes the non-acid chemicals so that the effluent water can be sent to bio-treatment and disposal. The chemicals are recycled to gasification for disposal and their energy content.

The effluent water primary treatment unit consists of a degassing drum, an equalization tank, an oil coalescer package, a primary separation column and water coolers. The column is designed to achieve a total non-acid chemical specification of 50 ppm in the bottoms product.

Reaction Water Degassing (203-B-001)
Reaction water from the FT synthesis unit is combined with the water from the HER unit and sent to a degassing drum. Most of the dissolved gasses evolve in the degassing drum and the vent-gas is sent to a fired heater for destruction. Further degassing occurs in the water equalization tank that has a capability of 8 hours to facilitate start-up of the primary column. In the equalization tank a floating skimmer removes any oil floating on the surface and sends it to the slops drum.

Primary Distillation (203-B-002)
The fractionation of the non-acid chemicals and water is non-trivial due to the non-ideality of the system. Heavy alcohols accumulate in the column and then separate as a separate alcohol phase. This alcohol phase is removed by a side draw and combined with the condensed overhead stream to produce a chemical-rich stream with water content of between 25% and 30%.

5.3.3 Energy and Material Balance

Sasol provided major process stream flow data for heat and materials balances within each processing plants. These data are integral parts of the overall Feasibility Study Design package.

5.3.4 Major Equipment List

Sasol prepared major equipment lists for Plants 201, 202, and 203. The lists contain equipment sizing, design criteria and materials of construction. The lists will be used for project cost estimation by Nexant as the engineering effort proceeds.

5.3.5 FT Plant Utilities

Sasol's feasibility study includes estimate of major utilities for operations of the FT synthesis facility, with sufficient details for Nexant to proceed with overall EECP balance of plant.

5.3.6 FT Plant Effluent Summary

The various effluents produced in the FT operation include tail gases, which are sent to the overall plant fuel system as follows:

- Dry tail gas from the HER Unit is sent to a high-pressure fuel gas header at ~ 300 psig with the following flow rate and composition.

Table 5-7
Typical Tail Gas Composition

Total flow rate (Nm^3/h)	73682
LHV (MW)	208.5
Composition	**Mole%**
Water	0.04
Hydrogen	38.84
Carbon Monoxide	28.19
Carbon Dioxide	21.74
Argon	3.17
Methane	2.63
Ethylene	0.20
Ethane	0.08
Propylene	0.44
Propane	0.12
1-Butene	0.18
n-Butane	0.11
C5+	0.34
Nitrogen	3.92

Nm^3/h = 37.34 SCF/h

- Fuel gas from the following sources: wax vents, CO_2 stripper overheads, H_2 purge from recycle loop, LP separator overheads and naphtha stabilizer overheads is sent onto a low-pressure (LP) fuel gas header at ~ 100 psig. This fuel gas is used internally for the fired heater burners in the product work-up unit. The LP fuel gas composition is presented in Table 5-8.

Table 5-8
LP Fuel Gas Composition

Total flow rate (Nm^3/h)	838
LHV (MW)	8.8
Composition	**Mole%**
Water	1.43
Hydrogen	63.46
Carbon Monoxide	1.84
Carbon Dioxide	6.10
Argon	0.29
Methane	0.35
Ethylene	0.07
Ethane	0.55
Propylene	0.15
Propane	7.63
1-Butene	0.04
n-Butane	13.71
C5+	4.12
Nitrogen	0.25

- Offgas from FT wax drums and the product fractionator overheads is discharged at a low pressure of 7.5 psig and sent to the PSA offgas compressor to be compressed with the PSA offgas to the LP fuel gas header pressure. The offgas composition is shown in Table 5-9

Table 5-9
Offgas Composition

Total flow rate (Nm^3/h)	254
LHV (MW)	2.9
Composition	**Mole%**
Water	13.12
Hydrogen	21.76
Carb.Monoxid	11.67
Carb.Dioxide	17.00
Argon	1.72
Methane	1.79
Ethylene	0.18
Ethane	1.32
Propylene	0.55
Propane	11.02
1-Butene	0.27
n-Butane	10.65
C5+	7.41
Nitrogen	1.54

Other effluents produced in the FT operation include:

- FT spent catalyst, which can be recycled (under investigation) to the gasifiers as a fluxant.

- An alcohol-rich (50% low molecular weight alcohols of methanol, ethanol, 1-propanol) stream from the primary distillation column, which could be recovered either as a product or sent onto the gasifiers as auxiliary fuels.

- Effluent water from the bottoms of the primary distillation column and a sour water stream from a Product Work-Up separator, which are sent onto water treatment facility.

5.3.7 Miscellaneous

Sasol provided preliminary estimates of catalyst and chemicals, start-up commodities, preliminary cost and labor requirements as part of their Feasibility Study Design Package.

Section 6 Phase I Task 5 – Market Analysis

TASK COMPLETED.

Purvin & Gertz, Inc. completed this task under a subcontract to Texaco. Final report was delivered to WMPI. The report contains sensitivity business information that WMPI would prefer not to report it in writing. Under an agreement, DOE can review the report and its findings with WMPI.

Section 7 Phase I Task 6 – Preliminary Site Analysis

Under this task, WMPI will assess the site-specific project requirements to include:

- Raw material availability
- Site transportation accessibility
- Supporting utility services
- Land availability and cost
- Construction and skilled labor availability

As part of this Task 6, Nexant, with support from Bechtel personnel, helped with examining alternative modes of transporting large process vessels to the EECP site near the existing Gilberton cogen plant. Results were discussed in the July/September 2001 Quarterly Technical Progress Report. Sasol's slurry phase FT reactor is expected to be over 18 feet in diameter. Its dimensions and weight are important parameters governing how the vessel should be most cost effectively fabricated and transported to site.

8.1 BIWEEKLY PROJECT STATUS REPORT

Informal Biweekly Project Status Reports are transmitted to keep the DOE Project Manager updated of all work in progress.

8.2 PROJECT MILESTONE PLAN AND LOG

Project Milestone Plan and Milestone Log are submitted on time as prescribed by the contract to keep DOE management informed of work-in-progress and accomplishments against major project milestones planned.

Section 9 Experimental

EXECUTIVE SUMMARY

9.1 EXPERIMENTAL

9.2 RESULTS AND DISCUSSION

9.3 CONCLUSION

9.4 REFERENCE

NOT APPLICABLE - The current project is a design feasibility and economics study, leading to detailed engineering, construction and operation of an EECP plant. It's not a typical research and development (R&D) project where a topical report format described in this section applied. There was no experimental work performed. This section is included only to fulfill DOE's prescribed reporting format.

List of Acronyms and Abbreviations

AGR	Acid Gas Removal
ASTM	American Standard Testing Methods
BEDD	Basic Engineering Design Data
BOC	British Oxygen Company
BPD	Barrel Per Day
BFW	Boiler Feed Water
DOE	U.S. Department of Energy
EECP	Early Entrance Co-Production Plant
FT	Fischer-Tropsch
HER	Heavy End Recovery
HP	High Pressure
IP	Intermediate Pressure
ISBL	Inside Battery Limits
LHV	Lower-Heating Value
LP	Low Pressure
LTFT	Low-Temperature Fischer-Tropsch
MMSCFD	Million Standard Cubic Feet Per Day
MW	Mega Watt
NETL	National Energy Technology Laboratory
OSBL	Outside Battery Limits
PMCC	Pensky-Martens Closed Cup
PSA	Pressure Swing Absorption
PWU	Product Work Up
RD&T	Research, Development & Testing
RON	Research Octane Number
RVP	Reid Vapor Pressure
WMPI	Waste Processors Management, Inc.