WMPI Waste Coal to Clean Liquid Fuels

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1. Introduction

Co-production of fuels, chemicals and power offers an innovative, economically advantageous way to utilize waste coal through integration of three major blocks

- Gasification to produce synthesis gas
- Conversion of synthesis gas to high-value products such as liquid fuels and chemicals
- Combustion of unconverted tail gas to produce electric power and steam.

WMPI PTY, LLC (WMPI) of Gilberton, Pennsylvania advocates the advancement and commercialization of solids-gasification/liquefaction concept that high-quality environmentally friendly transportation fuel and power can be produced from coal waste.

The WMPI project utilizes waste coal containing as high as 40% ash. This high ash containing fuel requires a gasification process with high operating flexibility with high conversion rate and versatile coal feeding and slag handling systems.
The Shell Coal Gasification Process can utilize a wide range of coals including low-value high-ash coal wastes. The utilization of low-value coal wastes brings an economical advantage over traditional commercially available, but higher priced, coals.

The paper compares the waste anthracite coal with other well known coals used for many gasification studies (Pittsburgh No. 8, Illinois No. 6). The preliminary plant concept, mainly the Shell Coal Gasification Process (SCGP) and its integration into the complex plant of gas production, gas cleaning, Fischer-Tropsch synthesis, the systems for full generation of all required on-site utilities.

2. Brief Project Description

WMPI has assembled a world-class technology and engineering team to design, engineer, construct and demonstrate a clean coal power facility using coal waste as the basis to produce Ultra Clean Fuels (diesel, naphtha, jet fuel), steam and power in an unique environmentally friendly manner.

The Clean Coal Power Initiate (CCPI) project (DE-PS26-02NT41428) is sponsored by the U.S. Department of Energy, National Energy Technology Laboratory.

The team is formed by WMPI; Nexant; Shell Global Solution U.S., an international energy company with a major presence in coal gasification technology; Uhde, a global engineering company and authorized Shell Coal Gasification Process (SCGP) Technology supplier and contractor; SASOL Technology Ltd., a world leader in synthesis gas based Fischer-Tropsch

(F-T) Liquefaction Technology, and Chevron/Texaco, provider of the product work-up technology converting the raw paraffin rich F-T liquids to diesel, jet fuel and naphtha.

The Gilberton Coal-to-Power and Clean Fuels demonstration plant will convert the abundant resources of waste coal scattered across the northeastern part of the U.S.
Anthracite waste (culm) and bituminous waste (gob) have been accumulated in the State of Pennsylvania, USA, for centuries. These materials are rock & coal that contains various amount of carbon material after the chunks of saleable coal were separated out. Over one billion tons of waste coal has been piled up in 200 – 300 ft (60 to 100 m) high piles.
With beginning of 1980's the government introduced policies to favor development of facilities to convert these wastes into electric power and steam.

Circulating Fluidized Bed (CFB) boilers are used until now to process these types of wastes. The selection is based on the ability of the CFB boilers to burn a wide range of solid fuels in an efficient and environmentally acceptable manner. The principle design of the CFB boilers for waste coal does not differ to that for coal firing regarding configuration. Lower fluidizing velocity and larger size of fuel crushing, feed system and bottom ash cooling system have to be considered for the larger amount of fuel and ash, which must be processed.

The WMPI's pioneering efforts culminating in the successful operation of the Gilberton Plant was the basis to built many other CFB Power Plants for culm and gob.

The Gilberton Power Company – John B. Rich Memorial Power Station was designed to utilize the anthracite culm for power generation. The plant is equipped with two maximum 200 st/h (180 mt/h) Foster Wheeler CFB boilers capable of producing 82 MWe (gross) of power (see Figure 2).
The fuel is beneficiated from an ash content as high as 70 % in its raw state to an ash content of 40 – 50 % in its boiler ready state.
The commercial operation of the plant began in 1988 and has been operating since at a high plant availability of over 92 %. The plant produces annually almost 630,000 MWh of electric power and achieves exceptionally low emissions, better than projected in the design phase. Gilberton Power Station utilizes over 1,600 st/day and eliminates acidic discharges from the reclaimed coal waste lands.

The gasification technology with its highly advanced synthesis gas cleaning inherently produces very low emissions. The use of the abundantly available waste anthracite will simultaneously provide for land reclamation removing a nasty environmental legacy from the past mining operations.

The Shell Coal Gasification Process is a versatile process producing from many different types of coals (including high ash coals) a synthesis gas, which contains mainly of hydrogen and carbon monoxide. All impurities, trace metals and undesired components are subsequently removed within several process steps to generate an ash and sulfur free synthesis gas suitable for conversion into ultra clean hydrocarbon liquids via a catalytic chemical process known as F-T synthesis provided by SASOL. Other by-products from the process include high purity CO_2, sulfur and slag. The slag has a variety of uses in the construction and building industries.

The Gilberton Coal-to-Power and Clean Fuels Plant will also test alternative feedstock's for economic purposes and fuel flexibility including other anthracite and bituminous coals plus mixtures containing petroleum coke.

3. Plant Description

The project is technically challenging; the feedstock preparation, syngas production and treatment, F-T synthesis as well as all auxiliary systems to produce the necessary utilities have to be integrated into one functional unit. Figure 1 shows the simplified Block Flow Diagram and the complexity of the demonstration plant.

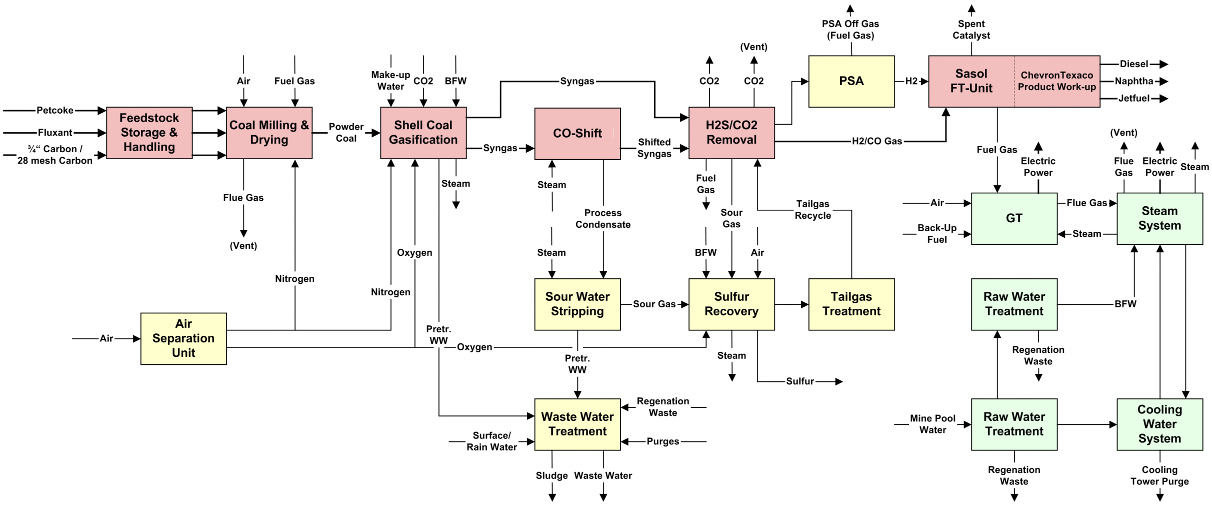


Figure 1: Simplified Block Flow Diagram

The preliminary plot plan of the Gilberton Coal-to-Power and Clean Fuels Plant is presented in Figure 2.

Feedstock Supply

Gasification is a versatile process, where many different types of coals can be processed. Coals with ash contents up to 45% (e. g. Walsum and Hugo, Germany; New Largo, South Africa) were successfully processed in pilot facilities and demonstration plant. Results have been used for the development of commercial scale gasification plants.

High ash content coals (or coal wastes) are less expensive but require alternative processing. Such processing plants (e.g., beneficiation and blending) can be installed near the operated mine. An example of such a plant is the Puertollano IGCC, where a bituminous coal with approx. 50% ash content is blended with petroleum coke by a rate 50/50% wt by mixing both streams before entering the coal mills.

Additionally, the fuel size for entrained flow gasifiers is very fine – usually <100 µm. This leads to the advantageous situation, that not only the culm with a larger particle size can be processed, but also the very fine material (tailings), which might be rejected for CFB boiler operations

The main units for the feedstock preparation, handling, storage, milling and drying are as follows:

- Culm/Tailings Processing Plant
- Feedstock Handling and Storage
- Coal Milling and Drying.

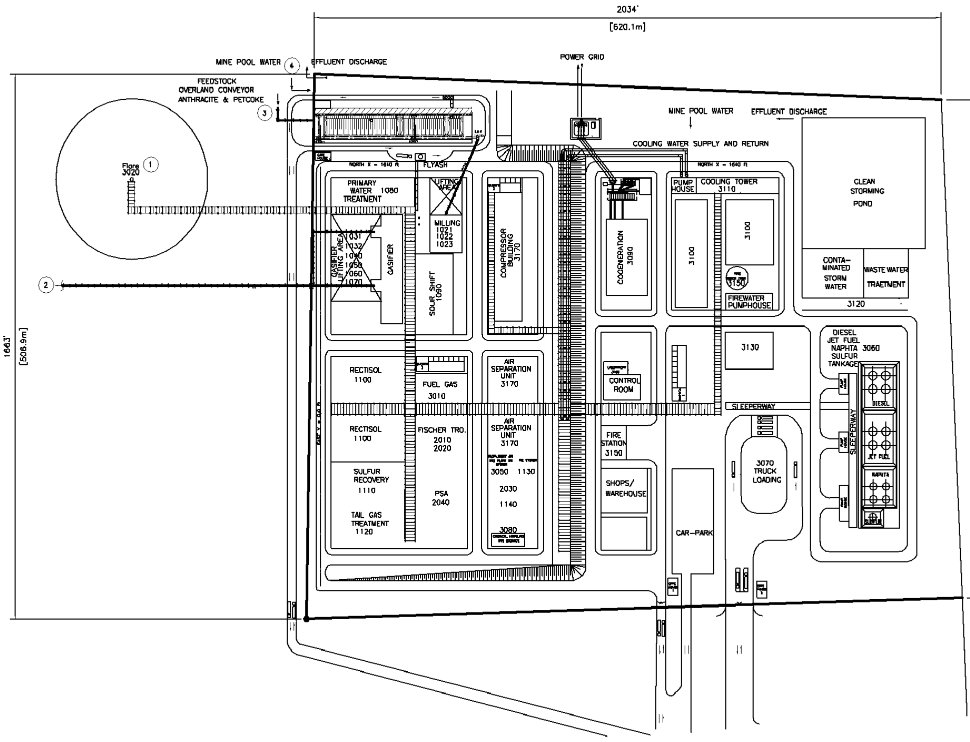


Figure 2: Plot Plan of the Co-generation Plant (Preliminary)

The *Culm/Tailings Processing Plant* is set up in such a way, that the final feedstock transported to the Gilberton Coal-to-Power and Clean Fuels Plant has following characteristic: water content < 25%; ash content approx. 40%. A new Culm/Tailings Processing Plant has to be constructed with following main steps:

a. Screening and crushing of the anthracite culm (60 – 70% ash) to ¾ inch size. Larger sizes qualified as rocks are discharged.
b. Mixing of the ¾" culm with the tailings to prepare a ¾" raw slurry feed
c. Heavy media separation with rejection of rocks. The ¾" carbon will be de-watered and mixed with the 28 mesh carbon produced in the next steps.
d. 28 mesh tailings are further processed through a Flotation Step, which produces the second stream of the feedstock – 28 mesh carbon, which is mixed with the ¾" carbon after de-watering. Rocks are rejected.

All these steps are commercially proven within preparation plants for run-of-mine coals, where the coal is blended to a pre-determined maximum size and steady quality.

The *Feedstock Handling & Storage* transports the feedstock from the Culm/Tailing Processing Plant to the Coal Milling & Drying. Additionally, a storage is anticipated for weekend outages of the Culm/Tailings Processing Plant. The transport of the anthracite feedstock is provided by conveyor belts – from the Processing Plant to the storage and from the storage to the mills. The fluxant as well as the petroleum coke are delivered by trucks, which are unloaded by separate truck unloading facilities (s. c. SAMSON feeders - see. Figure 3). The material is distributed to the storage by separate bucket elevators, conveyor belts and dump cars.

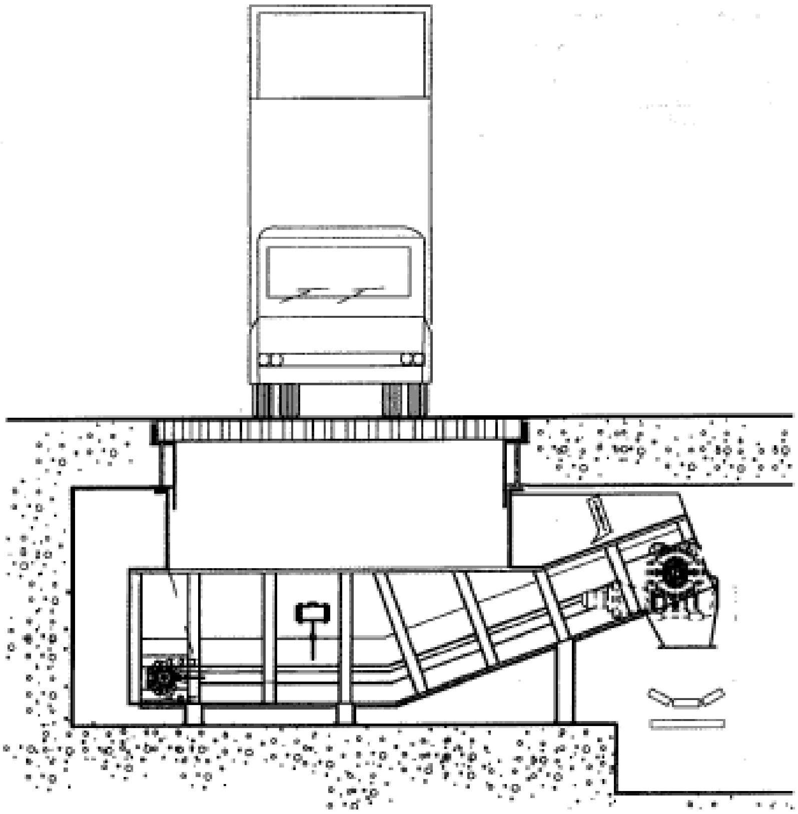


Figure 3: Truck Unloading Facility for Fluxant and Petroleum Coke (SAMSON Feeder)

The Figure 4 shows the principle arrangement of the anthracite feedstock, petroleum coke and fluxant storage.
The anthracite feedstock is transported via the overland conveyor belt to the storage and stacked by one stacker to the anthracite and petcoke area. The petcoke area is used for storage of the anthracite during time, when petcoke is not gasified.
The material is reclaimed by two reclaimers – one for anthracite feedstock and one for petroleum coke and fluxant.

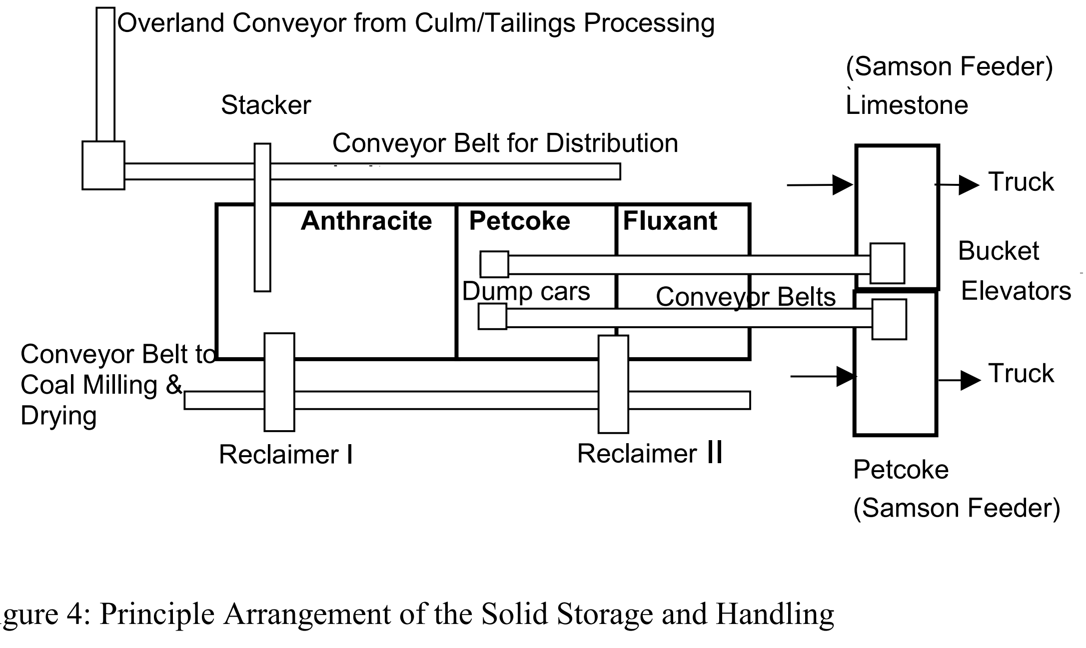


Figure 4: Principle Arrangement of the Solid Storage and Handling

In the *Coal Milling & Drying*, the coal dust for the gasifier is prepared (particles size < 100 µm; water content < 2%).
Fluxant has to be added to the feedstock in the Coal Milling and Drying Unit to adjust the ash melting behavior of the anthracite coal.
Additionally, the Gilberton Coal-to-Power and Clean Fuels Plant will be designed with a certain range of feedstock flexibility:

a. Petroleum coke
   25% of the high ash anthracite culm can be replaced by petroleum coke.
b. Higher sulfur content of coal
   In fact, that the plant will be designed for 25% of petroleum coke, the flexibility to process other coals with a higher sulfur content increases simultaneously.

Shell Coal Gasification Process (SCGP)

Shell's experience with gasification dates back to the 1950's when the first gasification unit was commissioned with oil as feedstock. There are now over 150 Shell Gasification Process (SGP) gasifiers licensed world-wide. The experience gained on oil gasification provided a firm theoretical and practical base for the start of the coal gasification development in 1972.

As start of the development an analysis was made of the different options for configuring a coal gasification process, considering the following criteria:

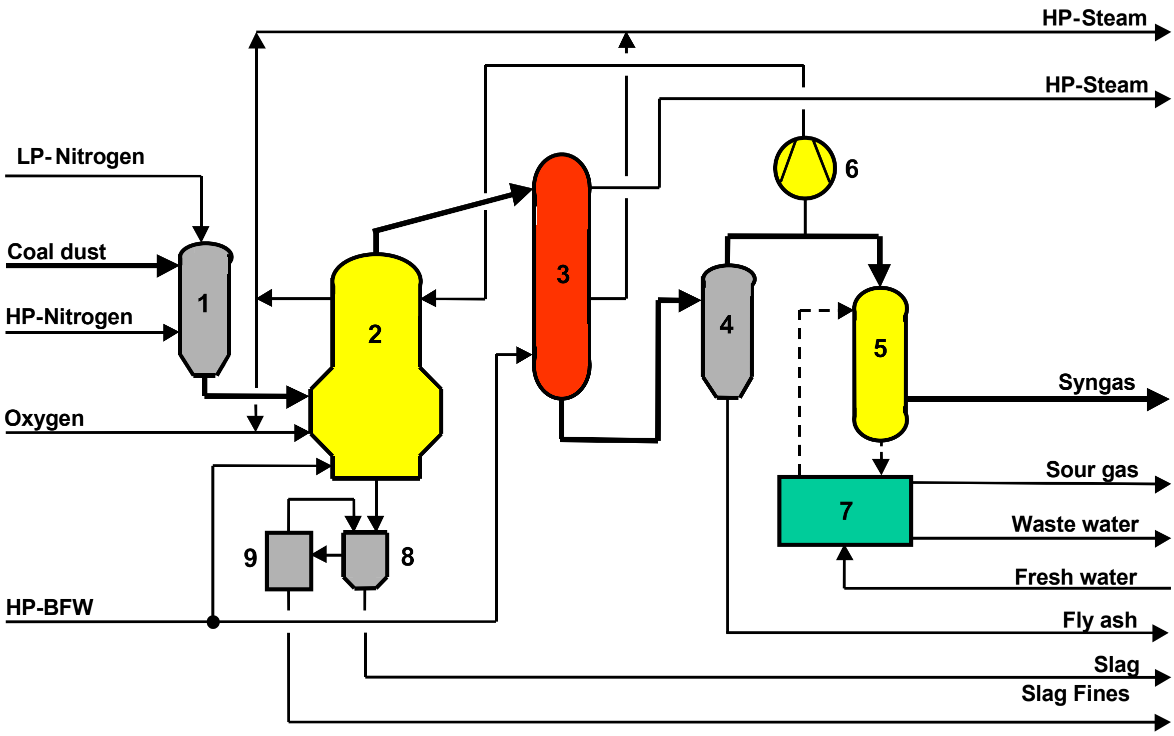
- Coal feed; essentially any coal world-wide can be used. The process is required to be able to gasify all ranks of coal from lignite to anthracite and including refinery residue of petroleum coke.
- Environmentally sound.
- High temperature gasification; to prevent formation of organic by-products such as tars and phenols and to maximize carbon conversion.
- High reliability.
- High efficiency.
- High throughput per gasifier; given the large scale and type of potential applications, throughputs of at least 2000 t/d of coal were envisaged.

Weighing these factors led to the basic concept of the SCGP (see Figure 5):

- Pressurized: compact equipment.
- Entrained flow: compact gasifier.
- Oxygen blown: compact equipment, a high gasification efficiency and minimization of non ($CO + H_2$) content of syngas.
- Opposed multiple burners: good mixing, high conversion, easier scale-up.
- Gasifier membrane wall (water cooled), which envelopes the reaction zone: gasifier design independently from the selected coal type and its gasification temperature.
- Dry feed of pulverized coal: size range of coal no issue, high efficiency for high to medium ash content and/or low rank coals. The carrier medium of the pulverized coal can be selected as needed for the final use of the synthesis gas. For the case of use for Fischer-Tropsch synthesis, CO_2 may be used instead of nitrogen.

The coal reacts in the gasifier with oxygen and steam to syngas. Simultaneously the mineral compounds of the coal form liquid slag and a certain part of fly ash. The syngas leaving the gasifier at the top is quenched with cooled and dust free syngas supplied from the *Dry Solids Removal* section via *Quench Gas Compressor*. The further cooling of the gas takes place in the *Syngas Cooler*. The majority of the slag leaves the gasifier via its bottom as molten slag.

This slag is subsequently quenched and shattered to small glassy granulates in the slag bath filled with water.



1 Coal feeding	4 Dry solids removal	7 Water treatment
2 Gasification	5 Wet scrubbing	8 Slag removal
3 Syngas cooling	6 Gas quench	9 Slag water treatment

Figure 5: Flow Diagram SCGP Process

The gasifier itself is a membrane wall reactor installed inside a pressure vessel. Within the membrane wall a forced water circulation is maintained. The absorbed heat is removed to produce steam. The *Syngas Cooler* is of the water pipe type, containing a evaporating and superheating section.
The fly ash carried with the syngas is removed in the *Dry Solids Removal* section by a high pressure high temperature ceramic filter and is discharged to a storage via a lockhopper system. After stripping and cooling, the fly ash is sent to the fly ash storage and disposal facilities.
The virtually dust free syngas is further scrubbed in the *Wet Scrubbing* section to lower its dust content and halide content as well as to saturate it with water to the extent possible.
The slag collected in the slagbath is discharged via a lockhopper system and than separated from the water via a dragchain. The transportation to the storage takes place by a conveyor belt. The heat absorbed in the slagbath is removed via a slagbath-water circulation loop with external coolers.
In order to prevent build-up of trace components in the slag removal and wet scrubbing systems, both systems are provided with a water bleed. This bleed is first stripped and subsequently clarified in the *Primary Water Treatment*. The solids are recycled as slurry to the *Coal Handling* system and added to the main coal stream.
The waste water and stripper off-gas have to be further treated in the *Sulfur Recovery Unit*.

Gas Treatment
The syngas leaving the gasification section is almost free of particles. All impurities, which might poison the catalyst of the F-T unit and which will lower the efficiency of the F-T liquefaction, have to be removed. Additionally, the syngas has to be conditioned such, that a certain ratio of CO/H_2 is adjusted. Thus, the syngas is partly treated in the catalytic CO shift conversion (in the presence of steam) to increase the hydrogen concentration of the syngas. The process is optimized by the installation of a closed water cycle between syngas saturator and syngas cooler.
As the syngas still contains H_2S, COS and HCN, a Rectisol unit is selected to remove the remaining impurities to a low level, acceptable for the downstream units. Two different CO_2 stream are generated – one stream almost free of CO and a CO-rich stream used as fuel gas in the Coal Milling & Drying. The CO free stream is used as transport gas for the powder coal into the gasifier and as blow back gas for the candle filter, which removes the fly ash from the raw synthesis gas leaving the gasifier. Also the production of foodgrate CO_2 or the "underground" sequestration might be considered in future.
A Claus plant is selected to convert the H_2S and COS into elemental sulfur and to destruct the NH_3 from the stripping section. This sulfur has a high quality and is for sale.
The tail gas from the Claus plant is recycled back to the low pressure column of the Rectisol unit after the SO_2 is converted into H_2S in the catalytic hydrogenation reactor.

Fischer-Tropsch Synthesis and Product Work-up
This plant section consists of the following units
- SASOL's Fischer-Tropsch Synthesis (including the Catalyst Reduction and the Heavy Ends Recovery)
- ChevronTexaco's Product Work-up Section
- Effluent Water Primary Treatment Section

The F-T synthesis processes the clean syngas (shifted) for clean fuel production. A small side stream of this syngas is sent onto a PSA unit to recover hydrogen for the wax hydrocracking in the Product work-up unit.
The iron based SASOL Low-Temperature F-T Slurry-Phase Distillate Process with internal recycle is selected. Fresh unreduced iron catalyst is first reduced in the reduction reactor using 99.99% pure hydrogen from the PSA unit. The F-T unit is expected to produce three different products – diesel, naphtha and jet fuel. The current design maximizes the diesel production, while potential future options include producing LPG and alcohols by adding further separation steps and appropriate offsite storage facilities.
For the Gilberton Coal-to-Power and Clean Fuels Plant, the LPG containing stream is used as fuel gas and the oxygenate-rich stream is used as fuel for the Coal Milling & Drying.

Off-Sites & Utilities
The Gilberton Coal-to-Power and Clean Fuels Plant is designed as a stand-alone plant. This leads to site specifics and special adjustments for following areas:
- ***Mine pool water*** is used as plant make-up water.
  In general, a two step make-up water treatment is anticipated
  - to provide water for the cooling tower make-up and for boiler feed water preparation; This step consists of flocculation and sedimentation to remove heavy metals.
  - to prepare the boiler feed water for the steam cycle of the Heat Recovery Steam Generator, the gasifier and syngas cooler; A reverse osmosis plant and a demin water plant (ion exchange) is anticipated.

In total, approx. 4,000 gpm of mine pool water is expected to cover the plant water requirements.

- ***Electric power export and supply capacity*** of the grid limits the power export.
  The Gilberton Coal-to-Power and Clean Fuels Plant will be connected to the 69 kV Gilberton tap in parallel to the Gilberton Power Company – John B. Rich Memorial Power Station.
  The size of the tap is limited to 120 MWe. The electrical power generation of the CFB boilers amounts to 80 MWe. The power generation between both power plants can be optimized and used for peak load generation.
  First investigations show, that the power supply from the grid is limited to 20 MWe. This requires special measures for start-up of big power consumers inside of the demonstration plant – mainly ASU: air compressor(s).

- ***Fuel gas*** utilization inside the plant requires optimum solution for all operating cases.
  The Gilberton Coal-to-Power and Clean Fuels Plant produces fuel gases, which can be used for drying in the Coal Milling & Drying and heating in the Product work-up section.
  The fuel gases, which can not be utilized during plant operation has to be burnt in the gas turbine or in the Heat recovery Steam Generator.

- ***Transportation*** of solids (petroleum coke, fluxant, slag, sulfur etc.) and the ultra clean fuels (diesel, naphtha, jet fuel) requires optimum traffic concept and site connection to the public infrastructure.

In general, the following utilities units are considered – Air Separation Unit, Sour Water Stripper, Waste Water Treatment; Cooling Water System (Tower).

The demonstration plant concept is flexible for any integration into existing chemical or other industrial complexes for future projects.

4. Projected Overall Plant Summary

The gas produced by the SCGP process mainly consists of carbon monoxide and hydrogen (together nearly 90 %vol). Minor components include carbon dioxide, nitrogen and gaseous water and depending from the feedstock sulfur components (H_2S and COS) as well as trace of methane.
The final feedstock analysis of the WMPI anthracite culm differs significantly from other coal types. Table 1 compares the WMPI anthracite with the coals Pittsburgh no. 8 and Illinois no. 6, for which many gasification studies were made in the past. A higher nitrogen and CO_2 content can be noted from the syngas analysis. This increase is given by the higher amount of ash in the feedstock – first for transportation (nitrogen) and second for melting of the ash (CO_2). Thus, a higher oxygen consumption is anticipated.

Table 1: Comparison between WMPI-anthracite, Pittsburgh no. 8 and Illinois no. 6

		WMPI	**Pittsburgh no. 8**	**Illinois no. 6**
C	lb/lb dry	54.42	77.83	69.50
H	lb/lb dry	1.74	5.15	5.33
O	lb/lb dry	2.92	5.71	10.03
N	lb/lb dry	0.65	1.50	1.25
S	lb/lb dry	0.29	2.25	3.86
Ash	lb/lb dry	39.99	7.56	10.04
Fluxant	-	Yes	No	No
HHV	BTU/lb dry	8,340	13,984	12,774
Syngas Composition (based on nitrogen feeding system)				
H_2	Mole %	15.10	30.60	30.74
CO	Mole %	71.86	58.67	57.96
CO_2	Mole %	4.45	2.33	2.20
H_2S	Mole %	0.13	0.60	1.13
COS	Mole %	0.01	0.07	0.13
N_2, Ar	Mole %	7.10	4.57	4.78
Traces	Mole %	0.04	0.04	0.06
H_2O	Mole %	1.31	3.12	3.00
Main Consumption Figures				
Oxygen Consumption	st O_2/st coal waf	1,18	0.97	0.88
Gasification Steam Consumption	st steam/st coal waf	-	0.19	0.12

The WMPI CCPI design work has begun. The preliminary overall plant data are summarized in Table 2.

Table 2: Plant Summary (Preliminary) – Consumption and Production Figures

		WMPI	Remark
Major Consumables			
Coal	st/day	6,150	40% ash on dry basis, 25% moisture
Fluxant	st/day	335	
Make-up F-T Catalyst	st/year	520	
Major Products			
Fischer-Tropsch Liquids	bbl/day	> 5,000	Diesel, naphtha, jet fuel
Power Export	MWe net	50	
Slag	st/day, dry	2,040	
Fly ash	st/day, dry	172	
Sulfur	st/day	25	
CO_2	st/day	2,860	

The plant will be designed to meet or exceed all existing environmental emission requirements.

5. Outlook

WMPI's plan to commercialize the coal waste gasification/liquefaction concept for clean fuels production will bring substantial socioeconomic and environmental benefits to the coal regions:

a. Economical benefits
   - Re- energizing U.S. coal production industry.
   - Creation of high-quality jobs, improve job security and productivity, and results in Numerous spin-off benefits throughout the economy
   - Revitalization of communities in coal producing regions across the country.
   - Diversifying of U.S. domestic sources of energy.

b. Environmental benefits
   - Coal wastes that have blighted the landscapes of coal producing regions for decades would be utilized for production of value-added products, while concomitantly reclaiming the land. Additionally, the Gilberton Coal-to-Power and Clean Fuels Plant reduces waste disposal from operating mines.

   - The produced F-T liquids are clean burning fuels, superior in property than their petroleum based counterparts. They are essentially free of sulfur and nitrogen, and their usage as transportation fuels or as feedstock to produce chemicals (naphtha steam reforming for olefin production) would help in reducing overall greenhouse gases emissions.

   - Both the Ultra Clean Fuels and power can be produced in an environmentally friendly manner than conventional coal based power production of electricity for electric "non-polluting" cars.

   - The Gilberton Coal-to-Power and Clean Fuels Plant is environmentally clean with minimum emissions of sulfur (sulfur removal over 99.8 %), NOx, effluents (SCR used for even lowering the emission) and solid wastes (recycling of solids to the process considered as technically feasible). The demonstration plant design will also have the option to capture CO_2. Depending on future incentives to sequester CO_2, the demonstration plant could dispose of the CO_2 in nearby coal seams or other geological formations (depending on local specifics for other plants).

To summarize, WMPI's technology has a number of attractive features that enable to meet the DOE objectives and to be attractive for future customers:

- Performance
  The Gilberton Coal-to-Power and Clean Fuels Plant is expected to produce 5,038 barrels per day of ultra-clean fuels and approx. 55 MW of power. The net efficiency calculation has to consider the multiple products, but based on total energy input divided by the total usable energy output, the estimated net efficiency is about 42 %.

- Economical, easily marketed electric power
  Depending on the specific market needs, the plant design can be adjusted to maximize the mix of electric power and other products, or the design might be revised to increase peaking operation capabilities to sell this power at premium prices.

- Advanced Technology
  The plant design might be adjusted to advanced turbines and power cycles with adding high efficiency fuel cells as hybrid systems.

- Operability, Reliability and Scale
  The demonstration plant will be operated and maintained by craft workers experienced in other power plants, chemical plants and from petroleum industries. Health and safety, State and local permitting and reporting will be comparable to existing plants.
  The demonstration scale is estimated to be an economical choice at many locations with similarities to the Gilberton sit. Alternatively, the same technology could be scaled much larger for installation at large mine-mouth power plants if the market is favorable.

- Near term Marketability
  All international markets for electric power and fuels are growing. Coal is the largest long-term resource available to fuel economic growth, but its environmental issues including CO_2, must be resolved.

With the WMPI concept for the Gilberton Coal-to-Power and Clean Fuels Plant is commercially proven. The optimal integration within the set investment limits is one of the current tasks for the project team. This task will end in the financial closure of the project by the year 2004. After that, the plant is turning from the development and design phase into detailed engineering, procurement and construction.

The demonstration technology of the Gilberton Coal-to-Power and Clean Fuels Plant provides many answers to economic and environmental questions and a path forward that enables coal to continue as secure and economical source of energy.