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Toms Creek Integrated Gasification Combined Cycle Demonstration Project

Annual Report

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1. SUMMARY

The first Annual Technical Progress Report for the period ending December 31, 1993, summarizes the work done to date by Tampella Power Corporation and Envriopower Inc.

Enviropower Inc.'s efforts were concentrated on the Toms Creek PDS (Preliminary Design and Studies). The PDS was based on a Gasification Island size providing coal gas to General Electric's frame 6(B) gas turbine. During the course of the project, the scope of the PDS was expanded to include heat and material balances and selected equipment sizing for an IGCC plant size incorporating General Electric's newly introduced 6(FA) gas turbine. The reasons for this revision were improved plant economics and performance.

Tampella Power Corporation's efforts were also concentrated on Toms Creek design. Information provided by Enviropower Inc. was used to generate more detailed heat and material balances; P&IDs; equipment and system design; and economic evaluation data. Tampella Power Corporation also performed several site specific heat and material balance calculations and economic analyses to provide the basis for evaluating alternate locations for the Project.

2. TOMS CREEK GASIFICATION PLANT DESIGN

2.1 Site Location and Conditions

The Toms Creek IGCC (Integrated Gasification Combined Cycle) plant is to be located near the Toms Creek mine and preparation plant, near Coeburn in Wise County, Virginia. The mine and associated site are owned by Virginia Iron, Coal and Coke Company (VICC), an indirect subsidiary of the Coastal Corporation.

The site and ambient conditions are summarized in Table 2.1:

Table 2.1 Toms Creek site and ambient conditions

Design site elevation	ft	2,755
Barometric pressure	psia	13.32
Average temperature	°F	59
Design temperature range	°F	16...94
Relative humidity	%	72

The plant site is located within Seismic Zone 2, which is defined as a risk zone susceptible to moderate damage.

2.2 Coal, Coke and Sorbent Specification

2.2.1. Design Coal

The design coal for the Toms Creek IGCC Demonstration Plant is VICC steam coal. All design and performance calculations are based on this coal type according to the specification of Coastal Coal Sales, Inc. The coal properties are summarized in Table 2.2.

2.2.2 Metallurgical Coke

Metallurgical coke is used as an auxiliary fuel during the start-up of the gasifier. It is used to maintain temperature and to establish the initial fluidized bed in the gasifier. The properties of coke are summarized in Table 2.3.

Table 2.3 Metallurgical Coke Properties

Moisture, % (a.r.)	2.5
Ash, % (a.r.)	10.7
Volatile Matter, % (a.r.)	3.0
Fixed Carbon, % (a.r.)	83.8
Carbon, % (d.b.)	86.5
Hydrogen, % (d.b.)	0.4
Nitrogen, % (d.b.)	0.6
Sulfur, % (d.b.)	0.8
Oxygen, % (d.b. by diff.)	0.7
Ash, (d.b.)	11.0
Higher Heating Value, Btu/lb	12,890
Particle size Average (mass mean) dia., inch	14% -70 mesh 100% -6 mesh 0.035
Bulk density, lb/cu.ft.	40 to 50

Table 2.2 VICC Steam Coal Properties

	Maximum	Minimum	Typical
Equilibrium moisture, %	2.7	1.7	2.34
Total moisture, % (a.r.)	8.0	3.0	4.24
Ash, % (d.b.)	12.0	7.0	8.94
Volatile Matter, % (a.r.)	34.0	30.0	30.12
Fixed carbon, % (a.r.)	60.0	46.0	56.7
HHV (d.b.) Btu/lb			14,030
HHV (a.r.) Btu/lb	13,500	12,500	13,430
Carbon, % (d.b.)	79.0	75.0	76.78
Hydrogen, % (d.b.)	5.50	5.00	5.06
Nitrogen, % (d.b.)	2.00	1.25	1.65
Chlorine, % (d.b.)	0.12	0.01	0.07
Sulfur, % (d.b.)	2.00	1.25	1.50
Oxygen, % (d.b. by diff.)	7.00	4.00	6.00
Ash, % (d.b.)	12.00	7.00	8.94
Grindability (HGI)	70	55	
Base/Acid Ratio	0.44	0.19	
Free Swelling Index	8	6	
Particle Size	100% <1/4"	14.5% -70 mesh	0.05 in
Initial deformation, °F	2,320	2,100	2,315
Softening, °F	2,535	2,190	2,532
Hemispherical, °F	2,700	2,240	2,625
Fluid, °F	2,800	2,500	2,771

(a.r.) = as received (d.b.) = dry basis

2.2.3 Sorbent

Dolomite is used for in-bed sulfur removal in the gasifier. The design dolomite is a locally available sorbent. The range of available dolomite properties is summarized in Table 2.4.

Table 2.4 Dolomite Specification

$CaCO_3$, %	55.23...54.09
$MgCO_3$, %	41.51...43.90
SiO_2, %	not given
Other inert material, %	3.26...1.31

2.2.4 Metal Oxide Sorbent

The external sulfur removal system utilizes a zinc titanate based metal oxide sorbent. The sorbent formulation is proprietary, and is not available from the supplier. The sorbent components are zinc oxide, titanium dioxide, binder, and various proprietary additives. The sorbent bulk density is 80-90 lb/ft^3 and the particle size is less than 500 microns.

2.3 Scope of Plant System

2.3.1 Power Plant Configuration

The overall power plant configuration is as follows:

- The 55 MW IGCC plant is integrated with a conventional PC-fired (pulverized coal) condensing power unit to provide 190 MW at the buss bar. The steam turbine is shared between the IGCC and PC plant.
- The gas turbine is capable of combusting low BTU coal gas.
- The IGCC plant is equipped with dry fuel feeding and dry dolomite feeding systems.
- The gasifier is equipped with two cyclones and a CaS oxidizer.
- The gasification air is extracted from the gas turbine compressor and fed through

heat exchangers and a booster compressor into the gasifier.
- Gasification steam is supplied from steam turbine extraction.
- The product gas is cleaned in two steps: a regenerable sorbent based sulfur removal system followed by barrier filters.
- The tail gas from the sulfur removal system is recycled to the gasifier.
- The product gas is cooled in the gas cooler which generates saturated steam.
- A heat recovery steam generator (HRSG) generates high pressure steam at PC boiler pressure levels.
- The separate deaerator of the IGCC plant is heated by the HRSG.
- Low pressure condensate is preheated in the HRSG.

2.3.2 Scope of the Gasification Plant

The scope of plant is as follows:

- Fuel Handling System
- Fuel Feeding System
- Dolomite Feeding System
- Gasification System
- Ash Discharge System
- Gasifier Air Feeding System
- Gasifier Steam Feeding System
- Gas Cooler System
- External Sulfur Removal System
- Sorbent Feeding and Removal Systems
- Tail Gas Handling System
- Hot Gas Filter System
- Flare System
- Auxiliary Air Supply System
- Nitrogen Supply System
- Distributed Control System

2.3.3 Battery Limits of the Gasification Island

The terminal points for the battery limits between the Gasification Island and other sections of the Toms Creek power plant were identified and listed in detail. Please refer to the first Quarterly Technical Progress Report for details.

2.3.4 Balance of Plant Systems

The following Balance of Plant items and services are part of the Cogeneration Island, and will be made available for the Gasification Island during the project.

- Plant site.
- Control room.
- Motor control center room.
- Substations for electric power supply.
- UPS (uninterrupted power supply) for controls and emergency lighting.
- Plant communications system.
- Buildings (laboratory, administration, warehouse, changehouse, maintenance miscellaneous).
- Water treatment for cooling and service.
- Treated water for boiler water make-up.
- Access road and parking.
- Rail sidings.

3.0 PROCESS DESCRIPTION AND HEAT AND MATERIAL BALANCES

3.1 Process Description

The Clean Coal IV Demonstration Project utilizes a high temperature, high pressure, air-blown, fluidized bed gasification process, based on the U-GAS ® technology gasifier. The system employs one gasification train. Figure 3.1. illustrates the basic process flow schematic (excluding the PC boiler train which is site-specific for the Toms Creek case).

Crushed and dried coal is fed from the coal preparation plant to the Gasifier Island. Coal and coke (start-up fuel) are temporarily stored in day silos.

A belt conveyor system is provided for transferring coal and coke from their silos to the gasifier fuel feeding systems. Each of the three fuel feeding systems consists of one weighing and feeding stream. Each stream consists of a weigh hopper, a feed lock hopper, a feed surge hopper, and a gasifier injection line. Normally, all three systems will feed the coal. Each line is capable of feeding coal, coke, or a mixture of coal and coke.

Sorbent is fed to the gasifier through a feed system consisting of a sorbent weigh hopper, lock hopper, surge hopper, and injection line. Sorbent is stored in a silo.

Within the gasifier, coal reacts with steam and air in a fluidized-bed to produce a raw gas containing carbon monoxide, carbon dioxide, hydrogen, methane, steam, and nitrogen as primary constituents. Sulfur in the coal ends up primarily as hydrogen sulfide in the gas. Dolomite is fed to the gasifier to capture the hydrogen sulfide as a solid for removal with the ash. The gasifier normally operates at about 300 psi pressure and 1800°F to 1900°F temperature, while processing 430 tons of coal per day. Fine particles carried out of the gasifier are separated from the raw product gas stream and are returned to the gasifier by means of a two stage cyclone system. The agglomerated ash is removed through the bottom of the gasifier and into a lock hopper system. It is then pneumatically transferred to a storage silo for disposal. Before entering the bottom ash removal system, the ash is oxidized to a benign material which is non-hazardous by EPA leachability tests.

Air for the coal gasification is extracted from the gas turbine air compressor. The air pressure is increased to the operating requirements of the gasification system by a booster compressor. Superheated steam for the gasification process is extracted from the steam turbine.

The raw product gas leaving the cyclone system is cooled in the product gas cooler. The recovered heat is used to generate saturated steam is integrated with plant steam cycle in the gas turbine HRSG.

From the product gas cooler, the gas enters an external sulfur removal system where the balance of the sulfur specie is captured. The external sulfur removal, or polishing system, consists of two fluidized-bed reactors: a sulfider and a regenerator. Zinc titanate sorbent is used to effect the sulfur capture.

In the sulfider, zinc titanate reacts with the gaseous sulfur compounds to form zinc sulfide. The sulfided sorbent is continuously regenerated using a mixture of air and steam. The regenerator off-gas, containing sulfur dioxide, is reinjected into the gasifier where the sulfur is captured by the dolomite. Make-up zinc titanate sorbent is added to the sulfider through a lock hopper feed system, as required.

The product gas from the sulfider flows through the hot gas filter. The high temperature, high pressure filter uses ceramic candle filters as the cleaning medium. The fly ash (filter ash) is cooled, depressurized by means of a lock hopper system, and is transported to a storage silo for disposal.

The clean product gas is combusted in a gas turbine generator where approximately 60% of the IGCC plant power is produced. The hot exhaust gases from the gas turbine are directed to the heat recovery steam generator (HRSG). The superheated steam generated in the HRSG is fed to the steam turbine where the balance of power is generated. The HRSG stack emissions are within EPA guidelines.

3.2 Heat and Material Balances

Selected heat and material balance data for the Toms Creek IGCC Demonstration Project are presented in Table 3.1.

3.3 Equipment Description

Brief descriptions of the equipment for the Gasification Plant were provided in the first and second Quarterly Technical Progress Reports. For details, please refer to these reports.

3.4 Process Flowsheet and P&IDs

The preliminary process flowsheet for the Toms Creek Project was prepared. In addition, a total of 31 preliminary Piping and Instrumentation Diagrams (P&IDs) were generated.

TABLE 3.1 TOMS CREEK HEAT AND MATERIAL BALANCE DATA

Plant Elevation	ft.	2,755
PROCESS FLOW DATA		-
Coal Feed	lb/hr	35,900
Sorbent Feed	lb/hr	6,100
Total Ash	lb/hr	9,100
Steam to Coal Prep. Plant	lb/hr	50,000
Coal Gas LHV	Btu/scf	135
POWER GENERATED		
Gas Turbine	MW	34.8
Steam Turbine (IGCC Equiv.)	MW	22.9
Auxiliary Power Consumption	MW	3.6
Net Power Production	MW	54.1
Heat Rate, (Net)	Btu/kWh	8,700
Efficiency	%	39
EMISSIONS		
SO_2	lb/MMBtu	0.056
NO_2 (with SCR)	lb/MMBtu	0.023
Particulates	lb/MMBtu	0.016

3.5 Combined Cycle System Performance Using Natural Gas

The availability of the IGCC plant using coal gas is expected to increase during each of the three years of the demonstration period. While the Gasifier Island is down, the Power Plant Island may be operating to generate power and revenue for the host site. While operating in this mode, the gas turbine will be fueled by natural gas. The system performance will be different using natural gas. The main difference for the Power Plant Island is that while the Gasifier

Island is not operating, approximately 50% of the total saturated steam, which is generated in the Product Gas Cooler, will not be available for the HRSG. Consequently, the total steam generated for the steam cycle is considerably less. Careful evaluation for the HRSG design will be required to accommodate the above two modes of operation.

Plant performance comparison of coal gas versus natural gas fired operations are summarized with the following comparative results.

- No steam generation in the product gas cooler for the natural gas fired case. This results in an approximate 40% lower overall steam generation.
- The gas turbine power generation is approximately 2%-3% lower when firing natural gas. The exhaust gas flow rate is also correspondingly lower.
- Attemperation spray is required in the superheater section of the HRSG for the natural gas fired case. This is to control final superheat temperature.
- There is a shift in heat duty toward the back-end (cold-end) of the HRSG for the natural gas fired case. The evaporator section duty also becomes larger.
- The HRSG tube surface is determined based on coal gas firing case. When firing natural gas in the gas turbine steaming may occur in the economizer section. Proper HRSG design must take this possibility into account.
- HRSG exit (stack) gas temperature will be higher for the natural gas firing case; this, however, is a site-specific determination.
- Overall power generated is about 12% less for the natural gas fired case.

4. SITE SPECIFIC ALTERNATE DESIGN CASES

4.1 Heat and Material Balances

Several site specific heat and material balance calculations were performed for evaluating alternate locations for the Project. The Gasification System performance and process flowrates changed, as a function of the coal feedstock and site elevation.

Some of the site specific design criteria which were evaluated include:

- different coal and sorbent feedstocks
- fired versus non-fired HRSG
- repowering versus greenfield plant

An example of the Gasifier system comparison using the Toms Creek design coal versus a typical mid-western high sulfur coal results in the following:

- As site elevation is decreased, the gas turbine power output increases. At lower elevations, the gas turbine air compressor has a higher mass flow. This enables higher coal gas flow rate to be effected, resulting in higher electrical power generation by the gas turbine.
- In addition to a higher sulfur content, the mid-western coal has approximately 7% lower heating value, as compared to the Toms Creek design coal.
- Coal feed rate to the gasifier is about 20% higher for the mid-western coal case.
- Due to its higher sulfur content, the sorbent feed rate is also substantially higher, for a given Ca/S molar ratio. Total ash flow, as well as, coal gas flow rates are also higher.
- Due to lower heating value of the mid-western coal, the resulting coal gas also has a lower LHV, when compared with the Toms Creek case. Coal gas efficiency (on a cold gas basis) is about 4% lower, as well.
- The higher coal gas mass flowrate for the mid-western coal case results in an approximately 10% higher power generation in the gas turbine. The steam turbine output is also higher, but this is not directly comparable to the Toms Creek design due to a difference in the steam cycle parameters (superheated steam temperature and pressure).
- The heat rates are within 100-150 Btu/kWh between the two cases. The mid-western high sulfur coal case has an approximately 0.5% higher calculated efficiency than the Toms Creek design.

4.2 Project Economics

Spread sheets were prepared showing pro-forma cash flow analyses for several candidate sites. These proprietary analyses were site specific, and were based on the heat and material balances which were calculated for each case.

5. TOMS CREEK PROJECT RECONFIGURATION

The original Toms Creek IGCC plant was based on a nominal 55 MW(e) power generation design. The plant size was comparatively small. The gas turbine, General Electric's frame 6(B) machine, is smaller and less efficient than its "FA" class counterparts. These size and efficiency limitations placed the original Toms Creek design at somewhat of a disadvantage.

5.1 GE's 6(FA) Gas Turbine

During the ASME Turbo Expo '93, May 24-27, 1993, in Cincinnati, Ohio, General Electric's Industrial and Power Systems division announced the introduction of the 6(FA) gas turbine. This gas turbine was an evolution of GE's F technology for advance gas turbines. The gas turbine performance characteristics are indicated in Table 5.1. GE also announced, that pending DOE approval, this gas turbine would be used on the Sierra Pacific project, another Clean Coal Technology IV IGCC Demonstration Plant.

5.2 Toms Creek Configuration Change

A Power Sales Agreement could not be reached using the original Toms Creek Plant configuration because, among other reasons, the utility felt that the cost of electricity from this project was too high. The cost of electricity from the reconfigured project is lower due to the following reasons:

a) Economies of scale

- The specific plant cost, $/kW, is reduced with increasing plant size and power output.

b) Improved gas turbine efficiency

- The gas turbine efficiency is improved mainly due to a higher combustion temperature.

TABLE 1
GE GAS TURBINE PERFORMANCE DATA

GE GAS TURBINE SIZE	6(FA)
Scale Factor Based on 7(FA)	0.69
Output (kW)	70,140
Heat Rate (BTU/kWh)LHV	9,980
Efficiency (%)	34.2
Pressure Ratio	14.6
Firing Temperature (°F)	2,350
Exhaust Flow (lb/hr)	1,591,000
Exhaust Temperature (°F)	1,107
Turbine Speed (rpm)	5,235
Basis: ISO, Dry, Natural Gas, Methane, Standard Inlet & Exhaust Pressure Drops	

c) Improved steam cycle efficiency

- The gas turbine exhaust temperature is higher, thereby allowing for higher steam temperature design and improved steam cycle efficiency.

A request modify the Cooperative Agreement was made to incorporate the larger for the GE 6(FA) gas turbine into the Toms Creek Project.

5.3 Toms Creek Plant Size Comparison

Replacing the smaller, less efficient Frame 6 (B) gas turbine with the new Frame 6 (FA) increases the net power production from a nominal 55 MW to 105 MW. The coal feed rate correspondingly increases from 430 tpd to 740 tpd. All process flows and equipment sizes are also increased accordingly.

Enviropower Inc. prepared an abbreviated version of the PDS document, called the mini-PDS, for the larger Toms Creek Gasification Plant size. Preliminary heat and material balances were made and equipment was resized.

Selected process parameters for the original and revised Toms Creek IGCC plant configurations are compared in Table 5.2. There is an approximately 10% increase in net plant efficiency for the revised configuration. Using this increased plant size, the pressure vessels become larger due to an increased through-put, but are still dimensioned for shop fabrication and over-the-road shipment.

The preliminary cost estimate for the enlarged demonstration plant was prepared by factoring the estimates from the original plant.

5.4 Technical Risk for IGCC Plant Scale-Up

Along with the benefits of a larger sized and more efficient plant (i.e. reduced specific plant cost - $/KW, higher efficiency gas turbine, and improved steam cycle -higher superheated steam temperature), there is an associated technical risk with scale-up.

Technical risks for a larger gasifier island design were evaluated, based on feasibility of scale-up in the following areas:

a) Feed systems
b) Gasifier design and gasification process

c) Ash removal system
d) Gas cooling system
e) External sulfur removal system design
f) Hot gas filter system
g) Shop versus field fabrication of pressure vessels

The conclusion of the technical risk assessment was that the gasifier island scale-up was reasonable according to good engineering practice, and that the technical risks were within acceptable limits.

5.5 Steam Cycle Design

The higher exhaust temperature of the 6(FA) gas turbine (1100°F versus 1000°F for the 6(B) gas turbine) allows for a higher superheated steam temperature design. This improves the steam cycle efficiency. In addition, the plant size may be sufficiently large to consider a reheat steam cycle.

Computer models of the HRSG design for multi-pressure configuration was made, and a software program using MathCad was generated. Economic evaluation of the reheat steam cycle was started.