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CENTER FOR ENVIRONMENT
OFFICE OF ENERGY, ENVIRONMENT, AND TECHNOLOGY

FINAL REPORT

BLAST FURNACE GAS ENGINE GENERATOR PRE-FEASIBILITY STUDY

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UNIT	DESCRIPTION
°C	Degree Celcius
Btu	British thermal unit
h	Hour
HHV	Higher heating value
HP	Horse power
Kcal	Kilogram calorie
kg	Kilogram
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
LHV	Lower heating value
mg	Milligram
mm	Millimeter
Nm^3	Normal cubic meter
ppm	Parts per million
SCF	Standard cubic feet
t	Metric ton

I. EXECUTIVE SUMMARY

Companhia Energetica de Minas Gerais (CEMIG) the electric utility and Metalsider (a large pig iron producer in the region) in the state of Minas Gerais, Brazil contacted USAID for technical assistance to develop a commercially viable electric power generating system product that uses waste blast furnace gas (BFG) to fuel an internal combustion (IC) engine generator. Recognizing the potential for mitigating greenhouse gas emissions the USAID Center for Environment's Energy Technology Innovation Project performed this pre-feasibility study.

The study, as documented in this report, assesses the potential of BFG to power internal combustion (IC) engines for electricity production. Currently, in Brazil are seventy-seven (77) producing pig iron blast furnaces which vent or flare this waste gas to the atmosphere. The gas can be used to fuel engine generators to produce electric power while at the same time reducing volatile organic compounds (VOCs) and other greenhouse gas emissions. The specific objective of this study was to assess the potential for developing a standard power generation system design which could be replicated at multiple BFG installations on a commercial basis.

The approach used in this effort was to collect existing information, identify issues that could impact the technical and economic viability, and define alternative power system configurations. The alternatives were reviewed and the best configuration was then selected for conceptual design and cost estimation.

Data collection began with meetings held in CEMIG's main office in November 1996. CEMIG provided information on their renewable energy utilization goals, the pig iron industry in Minas Gerais and the pilot testing CEMIG and Metalsider had performed. The pilot testing used BFG to fuel an engine which generated electricity. In the testing, the BFG was first sent through a gas cleaning system and then into a 156 HP, 8 cylinder, Ford engine which generated 15 kW for a number of hours without pilot or supplemental fuel. During our tour at Metalsiders facilities the test system was activated. In the test system, the BFG was cleaned in a CEMIG designed gas cleaning system prior to being combusted in a new Mercedes engine. Mercedes donated this new engine which replaced the Ford engine. Sidersa (another pig iron producer) facilities were toured in addition to Metalsiders seven blast furnaces to have a representative sample of facilities.

Internal combustion engine vendors, gas cleanup system suppliers, CO_2 removal system suppliers and industrial experts were consulted to identify similar industrial experience and issues which potentially impact the viability of the concept. The low energy content of the BFG, the variability of its flow rate and composition, and the limited information on the particulate matter in the gas were identified as concerns. However, several engine manufacturers have products which are expected to be capable of using the low energy content gas as fuel and gas cleanup systems exist which are believed to be capable of adequately cleaning the gas

Several alternative configurations besides internal combustion engines were considered: boiler and steam turbine, simple cycle gas turbine and combined cycle gas turbine. None of these currently appear to be more suitable than the IC engine approach investigated.

Equipment specifications for the gas cleaning and the power generation equipment were prepared and sent to several prescreened manufacturers. One manufacturer has done considerable groundwork for BFG applications. This vendor has experience using low energy content gas in their engines, can provide a containerized system design, and has a test program using synthetically created BFG that may allow them to make commercial guarantees. A venturi scrubbing system was determined to be the most suitable technology for gas cleaning. It is proven on similar applications and has the capability to simultaneously cool the gas to meet the engine manufacturers' specification. Thus, it appears technically feasible to design a standard system which can use BFG to generate electricity.

A summary of the overall system performance for both the base and alternative case is presented in Table ES-1. The base case at the normal full load condition fires BFG at a rate of 4,212 Nm^3/h which is approximately 86% of the BFG available for power production. Using the BFG gas, each of three engine generator sets produces 471 kW (gross) electrical output. Therefore, the facility gross electrical output is 1,413 kW. The total power plant auxiliary electrical consumption is 70 kW thus providing a net power plant output of 1,343 kW. The net output is achieved with a net heat rate of 2,926 Kcal/kWh and a net efficiency of 29.4% based on the LHV of the BFG. Considering 77 operating blast furnaces in Brazil, and assuming 1,343 kW average net output from each, there is a potential net generating capacity of over 103,000 kW by BFG. In the alternative case, the system is scaled down to include one (1) engine generator of 471 kW (gross) electrical output to meet pig-iron producer internal electrical needs only. The economics of the alternative case are assumed to be similar to the economics of the base case.

The savings in CO_2 emissions from this potential generating capacity is approximately 400,000 tons/year assuming the base case scenario and a 50-50 oil-gas generation split.

Using estimated capital and operation & maintenance (O&M) costs, net output, capacity factor, typical financial parameters and assumptions provided by CEMIG (escalation, taxes, interest rates, return on equity, etc.) for a project of this size and type in Brazil, the levelized electricity cost (LEC) was calculated. The LEC for the base case, is 7.85 cents/kWh and return on equity (ROE) is 15.7%. This value appears to be in a range which would warrant further investigation. Sensitivity analysis by varying different parameters (loan interest, term, depreciation) were carried out to examine the effects on project viability.

With the cost of electricity being in the range of values that would warrant further investigation, a product development plan was prepared. This plan indicates the steps that would be required to move the concept from its current stage to building a commercial demonstration project. The plan can serve as the framework for continuation of this study.

Table ES-1

Performance Data

Item	Units	Base Case	Alternative
BFG to Treatment			
Volumetric Flow Rate	Nm^3/h	4212	1404
Mass Flow Rate	Kg/h	5480	1827
Temperature	°C	130	130
LHV	$Kcal/Nm^3$	932	932
Particulate Loading	mg/Nm^3	100	100
Pressure	bar	0.95	0.95
BFG to Engine			
Flow Rate	Nm^3/h	4480	1493
Temperature	°C	43	43
Particulate Loading	mg/Nm^3	3	3
Pressure	bar	0.94	0.94
Relative Humidity	%	80	80
Engine			
BFG LHV	$10^6Kcal/h$	4.18	1.39
Auxiliary Fuel LHV	Kcal/h	0	0
Total Fuel Input LHV	$10^6Kcal/h$	4.18	1.39
Air Flow Rate	Nm^3/h	4140	1380
Power System			
Gross Power	kW	1413	471
Auxiliary Power	kW	70	23
Net Power Output	kW	1343	448
Net Plant Heat Rate	Kcal/kWh	2926	2926
Net Plant Efficiency	%	29.4	29.4

Note: The values indicated reflect full load operation at design conditions

1. Background and Introduction

This section provides background on the study, the study objective, the approach taken in the study, and concludes with a brief overview of the report organization.

1.1 BACKGROUND

In Brazil, 90% of the pig iron facilities are installed in the State of Minas Gerais, where there are 77 operating blast furnaces primarily using charcoal as the ore reductor and heat source. This process creates a low heating value (less than 1000 Kcal/Nm^3) waste gas termed blast furnace gas (BFG). Approximately 50% of the blast furnace gas is used in the process and the remaining 50% is released into the atmosphere directly or burned in flares. Besides the energy losses, this release results in a considerable amount of pollution in the surrounding region, which includes heavily populated areas.

The electric utility in the State of Minas Gerais, Brazil is CEMIG. CEMIG's main activity is the generation, transmission and distribution of electricity. CEMIG has the largest distribution network in Latin America with a concession area covering 98 percent of the state. CEMIG's installed generation capacity of 5,000 MW consists of 98 percent renewable sources (primarily hydroelectric facilities).

The company is continuously looking for new and renewable sources of energy and technologies. It also seeks to promote the use of local energy sources to supply isolated installations and communities to decrease, avoid or postpone investments on transmission lines by promoting power generation from sources closer to the consumers.

CEMIG recognized the potential of the waste BFG as a resource fitting its overall objectives. Consequently, CEMIG initiated a test program jointly with Metalsider (pig iron producer) to demonstrate firing BFG in an internal combustion engine. Initial tests were successful. The BFG, without enrichment, was fired in both Ford and Mercedes engines which produced power from a directly coupled generator.

Encouraged by the successful demonstration, CEMIG requested USAID to provide technical assistance to evaluate the technical and economic viability of the concept. The Center for Environment's Energy Technology Innovation Project (ETIP) was selected to perform a feasibility study.

1.2 STUDY OBJECTIVE

The objective of this study is to assess the potential of using waste pig iron blast furnace gas in a standard power generation system design which could be commercialized and replicated at multiple installations.

1.3 PROJECT APPROACH

The overall approach was to collect relevant information related to this effort including similar industry experience. This information was used to identify issues which could impact the technical and economic viability of the concept. Alternative power system configurations were reviewed. From these alternative configurations one option was selected to form the basis for a conceptual design and cost estimate. The estimated system cost was used as input to evaluate the cost of electric power generation and the feasibility of developing commercial projects. A product development plan was prepared to identify the steps required to develop the concept into a standard product.

1.4 REPORT ORGANIZATION

This report is divided into sections as follows:

Section 1 provides background information and an introduction to the project.

Section 2 presents the data collection activity and its assessment including the input from vendors and industry experience.

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Section 3 presents the identified issues, evaluation of alternatives and the selection of the design basis.

Section 4 presents the conceptual design of the gas cleaning and power generation systems. Performance data are provided along with a discussion of environmental considerations. Additionally, BFG beneficiation by CO_2 extraction is discussed. A description of the conceptual power generation unit is provided.

Section 5 presents the economic assumptions, estimated capital cost requirements, calculated levelized cost of electricity and a sensitivity analysis.

Section 6 presents the product development plan.

Section 7 presents the conclusions and recommendations.

The appendices contain:

- Major equipment Request for Proposals (RFPs)
- Brazil information gathering trip report
- Brazil information gathering trip pictures
- Sensitivity analysis

The RFP for the major equipment provides details on the equipment design basis summarized in the body of the report. The trip report and pictures supply additional details and information gathered on the trip to Brazil to meet with CEMIG and Metalsider. The sensitivity analysis appendix provides the base case financial model input and the results of the sensitivity analysis.

2. Information Gathered

This section presents the data collection activity and its assessment. The data collection started with a trip to Brazil which included meetings held with CEMIG, Metalsider and Sidersa. The data collection further included identification of system interfaces with CEMIG, input from equipment manufacturers and identification of US/World industry experience using BFG, all of which are reported in this section.

2.1 MEETING WITH CEMIG

Meetings were held in CEMIG's main office at 1200 Barbacena Avenue on November 4 and 6, 1996. CEMIG made a presentation describing the organization, area served, generating capabilities, renewable energy utilization goals, the pig iron industry in Minas Gerais and the tests conducted by CEMIG and Metalsider using BFG to fuel engine generators.

2.1.1 CEMIG Background Information

CEMIG's primary function is the generation, transmission, and distribution of electricity. CEMIG has some gas distribution and other minor interests. The following are additional facts provided about CEMIG:

- 5000 MW installed capacity (98% renewable - hydro and wind)
- 96% of state population served
- 67% of the energy in the state is consumed by industry
- Best managed and strongest company in the State
- Distribution system is the largest in Latin America
- Natural gas became available mid-1996
- CEMIG's ownership
  - 45% State Owned
  - 25% Foreign Investors
  - 30% Others

CEMIG is continuously looking for new and renewable energy sources (wind, solar, biomass and hydro). In this pursuit, they have established the following company guidelines:

- Promote the use of local energy sources to supply isolated properties/communities to avoid or postpone investments on transmission lines.
- Diversify the State's energy potential through adaptation of new sources and technologies.

2.1.2 Pig Iron Industry Background

The following information was provided on the pig iron industry in the State of Minas Gerais for the year 1995:

Ownership:	All privately owned
Existing companies:	68 (82 total in Brazil)
Producing companies:	47 (55 total in Brazil)
Existing blast furnaces:	124 (141 total in Brazil)
Producing blast furnaces:	63 (77 total in Brazil)
Total blast furnaces at producing companies:	104
Pig iron production:	4.1 X 10^6 t (80% of total Brazil production)
Pig iron production installed capacity:	6.9 X 10^6 t (80% of total Brazil installed capacity)
Average capacity factor:	59% (All existing companies) 67% (Operating companies)
Capacity factor range:	11% to 113%.
Main production cities:	
- Sete Lagoas:	1.8 X 10^6 t (44%)
- Divinopolis:	553,168 t (14%)

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Blast furnace capacity range:	40 to 330 t/day (Most from 100 to 160 t/day)
Blast furnaces per company:	1 to 7 (Most 1 or 2)
Energy consumption:	
Charcoal:	3.1 X 10^6 t (770 kg/t pig iron)
Coke:	111,967 t (28 kg/t pig iron)
Electricity:	324,700 MWh (80 kWh/t pig iron)
Blast furnace gas production:	9.36 X $10^9 m^3$/year (2,300 Nm^3/t pig iron)
Released (waste) blast furnace gas:	3.92 X 10^9 Nm^3/year (42% of produced gas)

2.1.3 CEMIG/ Metalsider Experimental Work

The idea to use waste BFG in internal combustion engines to generate power originated three years ago. The first experimental work started 6-7 months ago with a Ford engine. This Ford engine is a 156 HP, V8, Otto cycle. The engine generated 15 kW for several hours on BFG, but failed later due to inadequate gas cleaning. The CEMIG/ Metalsider team is now using a new six cylinder, 120 HP Mercedes engine designed for natural gas (NG) firing with minor adjustments to accept BFG. The Mercedes Company donated this engine for the experimental work. The generator (supplied by CEMIG) was previously used at one of CEMIG's facilities. No compressor was required to inject gas into the test engine. The total test hours for the engines operating on BFG are:

- Ford: 60 hours
- Mercedes: 10-12 hours

The original gas cleaning system which consisted of cyclones plus an oil filter was inadequate and limited the operating time. The current system has a cyclone, multi-stage scrubbers, a demister, an oil bath moisture separator and a paper filter. This system seems to be working satisfactorily.

To provide a more complete understanding of the concept, details on the process, and how it was integrated with the blast furnace operation, CEMIG provided a process flow diagram (PFD). The PFD contained key information about the condition of the BFG at various points in the system and a schematic of the gas cleaning system used to remove the particulate for the internal combustion engine protection.

The CEMIG/ Metalsider team plans additional testing with the Mercedes engine to obtain more reliable and consistent results eventually leading to commercialization. The potential benefits of commercialization to CEMIG and Metalsider are as follows:

- CEMIG gains distributed capacity with little capital investment
- Brazilian pig iron producers become more competitive with Chinese pig iron producers

2.2 MEETINGS WITH METALSIDER AND SIDERSA

2.2.1 Metalsider

Metalsider has 7 blast furnaces in the city of Betim, near Belo Horizonte, the capital of Minas Gerais. Two are out of service; the capacities of the five operating units are 4 x 140 t/d and 1 x 90 t/d. The 140 t/d unit which has the test engine/generator set and a second 140 t/d unit were toured by the project team.

Metalsider's process as it relates to this application was described as follows: The gas exits the blast furnace at 1500 mm H_2O pressure and an average temperature of 150 °C. It passes through two dry cyclones to remove particulate matter. The clean gas from the cyclones is controlled by a flow regulating damper to provide approximately 60 percent to glendon (stoves) which preheat the air injected into the blast furnace with the remaining 40 percent directed to a flare stack.

BFG for the test engine/generator set is taken from the flare stack before the flare burner. The gas at this point is on average at a temperature of 130°C, pressure of 300 mm H_2O and contains 100 mg/Nm^3 of particulate matter (dust). The gas is put through a cleaning system consisting of the following pieces of equipment, arranged in series: a dry cyclone, two water spray tower scrubbers, a demister, an oil filter and a paper filter. The BFG entering the engine is at a temperature of 25°C and a pressure of -300 mm H_2O (the engine actually draws the gas in at slightly negative pressure).

While the team was present, the test system was activated and operated for several minutes. The generator was out of service and had been disconnected from the engine. Load on the engine was applied by a lever arm which provided resistance (torque) on the engine output shaft. No enrichment, starting or pilot fuel was used to start or operate the engine.

The following information on the Metalsider blast furnace operation was provided:

- 4-5 years between rebuilds and 3 months to rebuild (replace refractory)
- Operation is continuous at 100% for 24 hr/day and 365 day/yr except for rebuilds
- Average annual capacity factor is approximately 90%
- Life span of air blowers, heavy parts and piping is 20 years
- CEMIG provides 13.8 kV electrical supply to Metalsider

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2.2.2 Sidersa

Sidersa has blast furnace capacities of 1 x 280 t/d, 2 x 140 t/d and 1 x 120 t/d. The 280 t/d facility was visited. The following comments apply to that facility:

- Typically 8 years between rebuilds
- One year to rebuild
- 60% of BFG available for power production (due to improved glendon efficiency)
- Sidersa has different BFG composition than Metalsider (due to use of 20% petroleum coke versus charcoal)
- Air flow to the process is controlled to maintain the ratio of $CO/CO_2 = 1$ or the ratio of $CO_2/(CO+CO_2) = 0.5$
- Iron ore is dried before it is fed to the furnace
- Petroleum coke contains approximately 1% sulfur; charcoal has very low sulfur content
- Particulate removal is by dry cyclones followed by a water spray washer
- Outside wall of the blast furnace is cooled with recirculated water

2.3 ENGINE GENERATOR SYSTEM INTERFACES

The following interfaces for the power generation system were discussed and agreed to with CEMIG.

2.3.1 BFG Supply

The BFG supply would be taken from the flare stack. This would require a tie-in to the stack and the necessary duct work and dampers.

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2.3.2 Generating Voltage Level

The project investigators were to determine which alternative is more cost effective: generating at 460V and stepping up to 13.8 kV or generating at 13.8 kV.

2.3.3 Connection to Grid

According to CEMIG, the existing power feed line at 13.8 kV to the blast furnace facilities can take the on-site generated power backfed through the existing equipment. CEMIG will provide any additional equipment required to meter the electricity supplied to the grid. The study capital cost estimates should cover transformers, synchronization equipment, relays, and protection equipment required.

2.3.4 Waste Water

It was assumed that waste water streams produced in the system will be recycled to the blast furnace operation for treatment/discharge. Due to the relatively small waste water flows from the power plant there should be very little or no impact to the existing systems normal operation.

2.3.5 Combustion Exhaust Gases

The exhaust gas composition from the combustion engine will satisfy environmental regulations and will be discharged to atmosphere through a new exhaust stack sized to meet environmental requirements.

2.3.6 Cooling Water

Makeup for the cooling water system will be supplied from the existing water supply system. No new pumping or treatment equipment is assumed to be required.

2.4 INPUT FROM MANUFACTURERS

Internal combustion engine manufacturers, gas cleanup system suppliers, CO_2 removal system suppliers and knowledgeable individuals were consulted to help identify similar industrial experience. The information obtained was used to:

- Identify and assess issues potentially impacting the technical and economic viability of the concept
- Guide in the preparation of specifications to request budgetary quotations from vendors on equipment appropriate for a standard power system design.

2.4.1 Engine Manufacturers

A recent unrelated Bechtel study has researched the most qualified (low Btu gas experience) engine generator manufacturers. This research was used as a guide to establish a list of manufacturers to contact. The following is the list of engine manufacturers developed and consulted. These consultations were used to determine the companies relevant experience and willingness to supply a quotation on the engine generator(s) for the study:

- Caterpillar
- Cooper Industries
- Jenbacher
- Fairbanks-Morse
- Wartsila
- Waukesha

All six vendors provided information on their experience relative to firing low Btu gas and other relevant information, but only Cooper Industries, Jenbacher, and Fairbanks-Morse have submitted quotations.

None of the manufacturers contacted has direct experience burning pig iron BFG (Jenbacher comes closest), consequently, this fuel is considered experimental by them and requires testing before the manufacturer will provide performance guarantees. After initial review of the BFG analysis, the vendors felt they could use the BFG as fuel for their engines with supplemental fuel. If supplemental fuel is determined to be required, Jenbacher and Caterpillar would use a natural gas or liquified petroleum gas (LPG) supplement for their single fuel (gas only) engines. Fairbanks-Morse would require a 6% light fuel oil supplement for their dual fuel engine. Cooper Industries would use 1% natural gas, LPG or light fuel oil supplement for their dual fuel engine.

Discussions with Jenbacher revealed details on their experience and previous interest in this potential market. They have a significant amount of relevant commercial and test facility experience firing gases of similar heating value and composition. Their facility in Austria, has equipment to synthetically reproduce BFG and they have a test engine which will allow them to provide commercial guarantees based on the synthetically produced BFG. Jenbacher planned engine testing in Austria, on a synthetically produced BFG, prior to our contact. This testing was planned based on their independent identification of the pig-iron industry as a potential market they want to pursue in Brazil.

After further review of the specified gas analysis we sent, Jenbacher expressed confidence that their engines could run on this gas without supplemental fuel, if the hydrogen level is maintained above 5.5%. If the hydrogen (H_2) level drops below 5%, a minimum 20% supplement by LPG or a 30-40% supplement with natural gas would be required. Hydrogen (H_2) adds to the overall heating value of the gas and accelerates combustion of slow burning components, but it can promote backfiring and engine knocking. Jenbacher will need the full range of potential BFG compositions and subsequent testing to guarantee their engine can run on BFG without supplemental fuel. Due to the wide variation in the responses on the amount of supplemental fuel that may be required from manufacturers, this issue was identified as a key issue to be resolved in Section 3. Because of the potential economic impact of supplemental fuel being required Jenbacher was very interested and had been pursuing the idea of BFG enrichment by CO_2 removal.

2.4.1 Gas Cleaning Vendors

The following gas cleaning vendors were consulted for relevant experience and willingness to consider providing a quote for the project:

- Belco
- Air Pol, Inc.
- Griffin Environmental Co., Inc.
- Anderson 2000
- Torit Products
- Clean Gas Systems
- MAC Environmental
- GMD Environmental
- D.R. Technology, Incorporated
- Perry Equipment Corporation (PECO)

More complete information about the nature of the BFG and the cleaning requirements is required before the design of the gas cleaning system can be completed. A decision must be made on whether or not removal of aggressive components (sulfides, organic droplets, halides, metallurgical fumes, or alkalis) is required. The particle size distribution needs to be defined for accurate prediction of gas cleaning equipment performance. The Particulate Matter (PM) collection system must be carefully reviewed to determine the need for explosion proof electricals, relief venting and/or explosion suppression devices. With these decisions, a final design can be established for the BFG cleaning equipment.

The vendors supply a broad range of gas cleaning equipment. The equipment types that were discussed included wet scrubbers, dry filters and electrostatic precipitators. All three equipment types have been used for blast furnace gases and similar applications such as: coke ovens, cupolas, BOF, and open hearth furnaces. This equipment is capable of

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removing PM from the BFG to the specifications required by the engine manufacturers. However, there are significant considerations among the various types.

2.4.1.1 Wet Scrubbers

Spray tower type scrubbers are not effective in removing PM in the low micron size range and can be rejected for this application. Wet venturi type scrubbers are effective in removing PM above 2 to 3 micron size at moderate pressure drops (300 mm H_2O). Increasingly higher pressure drops are required for removal of smaller sized PM. The temperature of the clean gas discharged from a wet venturi scrubber will be lowered to the adiabatic saturation temperature. Additives can be used with wet venturi scrubbers to react with and remove sulfides, halides and alkalis. Wet type scrubbers may require high cost alloy metal construction to avoid corrosive attack.

2.4.1.2 Dry Filters

Fabric filter type cleaners (bag houses) are effective in removing PM down to 1 micron size at low pressure drops (150 mm H_2O). Most fabric filters quoted for this application would be a pulse type which would inject small amounts of compressed air into the BFG during the cleaning cycle. This should be reviewed for its effect on safety and on engine performance. The performance of most bags and cartridges in filters can be severely compromised by particles which have strong cohesive or adhesive properties or by moisture or oil, typically referred to as blinding. Cartridge type filters are capable of removing sub-micron PM but are suitable only for low particulate loadings and typically are used as a final filter. Some cartridges, coalescing filters, are designed to remove moisture droplets and oil mists. These may find application between a wet scrubber and the engine. The temperature of the clean gas discharged from a dry type collector will be approximately the same as the entering temperature.

2.4.1.3 Electrostatic Precipitators (ESPs)

There are both dry and wet type ESPs. The dry types perform in a similar way to bag houses and venturi scrubbers but would not be competitive in these small sizes, particularly if the PM is of small size and contains any appreciable amount of carbon. Wet electrostatic precipitators would likely perform well in this application because they are effective in removing PM down to sub-micron sizes and they are capable of removing fumes and mists. However, they cost 5 to 10 times more than fabric filters and are not considered for this reason.

2.4.2 CO_2 Removal Vendors

The following vendors were consulted on removing CO_2 from the BFG:

- Praxair
- Dow Chemical Gas/Spec
- Chemical Design, Inc.
- WR Grace (Davidson Division)
- Union Carbide
- UOP
- Wittemann Co.

The most significant findings are:

- The BFG is not a good candidate for CO_2 removal because:
  - CO_2 concentration is far from optimal
  - Gas pressure is low
  - Other gases will be removed along with the CO_2 (poor selectivity)
  - Gas temperature is high and therefore would require cooling

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- Amine systems are capable of accomplishing the removal but, they typically require gas compression to 1 to 2 bar, regeneration requires a steam supply (boiler), gas impurities can cause high operating costs and small systems are relatively expensive.
- The CO_2 concentration is too high for a molecular sieve application and too low for a membrane application.
- Production of food grade CO_2 is not practical in this size range due to economic reasons and potential contamination by components in the BFG.

2.5 US/WORLD INDUSTRIAL EXPERIENCE USING BFG

In contrast to the situation in Brazil, most of the pig-iron producers around the World are larger and integrated with further steel processing. These factors improve the economics of using the Rankine and Combined cycle power generation technologies. The primary advantages/differences for these large integrated systems over the smaller non-integrated systems in Brazil are:

- Allows use of the waste BFG in steel making versus flaring
- Allows potential for burning BFG without supplemental fuel in combustion turbines by blending waste gases from steel production to improve the gas heating value
- BFG composition, pressure and temperature are different than BFG in Brazil due to process differences and ore reductors used
- Larger volumes of BFG improve the economics of cleaning and compressing the gas for use in combustion turbines
- Uses for process steam favor use of Rankine cycle or Combined cycle configurations

2.5.1 Input from Industry Experience

A number of companies/consultants were contacted to review their knowledge and experience with BFG or similar fuels. The key findings from these discussions are as follows:

- Manufacturers do not have a commercial product available and are typically not interested or can not justify taking the steps to commercialize a product suitable to burn an untested fuel gas.
- The estimated cost to build an engine generator to burn BFG without the testing required for guarantees was provided.
- Study results and related experience on the use of waste BFG at a few non-integrated pig-iron producers facilities in the U.S. were provided.

The first key finding is a result of the fact that engine manufacturers will not provide commercial guarantees for untested fuel gases which are substantially different in composition than previously tested fuels. Generally, the manufacturers must test their engine on the specific gas before being able to make commercial guarantees. This process may take several million dollars to bring the product to commercial viability and these costs cannot be covered by sales of a small number of engines (less than a couple hundred). They could be covered by sales of a couple thousand engines.

Therefore, one company's experience has been that manufacturers are not interested in developing non-commercial equipment. Same company has experience in purchasing components and building their own engines for low Btu gas applications because of their experience in not being able to interest engine manufacturers in some of their projects. This company provided estimated costs for conversion of a standard engine generator set to burn BFG to be approximately:

- $400/KW for a suitable standard engine/generator set
- 20-25% for engine conversion to BFG firing capability

- $1,000-$1,500/KW for total plant installed cost (less development and financing costs)

Another company, one of the largest industrial gas producers in the world, was contacted because they recently performed a study on the use of waste BFG at one of the few non-integrated pig-iron producers facilities in the U.S. They also are currently involved in the installation of a package boiler and steam turbine generator plant at the Wheeling Pittsburgh Steel, Mingo Junction Facility. The study performed for ACME Steel (non-integrated pig-iron producer) concluded that the Rankine cycle configuration (approximately 20 MW) was more economical overall than other technologies. The other studies they have performed (facilities in the power generation size range of 10-30 MW) also concluded that the Rankine cycle configuration was the best technology. However, these facilities had use for process steam which improved the economics of the Rankine cycle. They noted that there are much larger applications in Japan where ABB is installing combustion turbines to burn a mixture of BFG and Coke oven gas.

3. Issues, Alternative Designs and Design Basis

This section identifies the issues from the information gathered and assessed. It also provides the background and evaluation of alternative designs information. Finally, this section concludes with the identification of the design basis for the study.

3.1 Issues

The information from CEMIG, Metalsider, equipment manufacturers, and industry experts identifies and assesses issues impacting the technical and economic viability of burning surplus BFG in internal combustion engines.

3.1.1 Variability in BFG Flow Rate

The BFG flow rate can vary due to changes in operating conditions of the blast furnace. The use of a gas holder or accumulator was suggested as a potential means of providing a constant flow rate to the engine generator system. Moderate flow rate changes would not affect the gas cleaning systems under consideration, namely baghouse collectors and scrubbers. The engine and its control system will be selected so that sustained operation is maintained over the expected range of BFG flow rates which may require a constant bleed of BFG to the flare and sending BFG flow surges to the flare. The engine generator selected for the conceptual design can accommodate some variability in BFG flow rate. Therefore, it was decided that a gas holder would not be part of the conceptual design at this time. It will be necessary, however, to evaluate the gas holder option when the system dynamics (BFG flow rate variability) can be better characterized.

3.1.2 Variability in BFG Heating Value

For engines to operate properly, the fuel must meet a minimum heating value requirement of approximately 700 to 1,100 $Kcal/Nm^3$. This minimum varies from manufacturer to manufacturer. Therefore, it is important to ascertain the expected lowest heating value of the BFG during Phase II. If it is below the limit for the engine, supplemental fuel will have to be added. It may be necessary to operate with a continuous pilot of supplemental fuel to beneficiate the BFG and ensure there is a safe operating margin. The manufacturers gave a wide range of supplemental fuel requirements (from 1% to 40% on a volume basis), and as stated previously, ultimately Jenbacher expressed confidence that with average BFG conditions maintained and hydrogen level above 5.5%, their engine would be able to operate without any supplemental fuel. Due to the significant economic impact, the requirement for supplemental fuel needs to be clearly defined in Phase II.

3.1.3 Variability in BFG Composition with Charcoal Feed

The combustible components of BFG are primarily CO and H_2. The engine could experience operating problems even with BFG of sufficiently high heating value, if the H_2 level is not within a range suitable for the engine. The reason for the potential problems are the combustion characteristics of the H_2. Specifically, there is benefit gained by the combustion acceleration characteristics of the H_2 which make it advantageous to keep the level above 5.5%. Maintenance of this level of H_2 aids to accelerate the combustion of the slower burning BFG components (i.e. CO). Additionally, there is concern if the level is too high (not specifically defined, but probably above 10-20%) the H_2 promotes knocking (detonation at multiple points) and backfiring.

3.1.4 Variability in BFG Composition when Coke is used in Furnace

The BFG from a blast furnace that uses coke in the charge will differ from the BFG from a furnace that uses only charcoal. The engine should perform satisfactorily on either BFG as long as the heating value and H_2 criteria are satisfied.

3.1.5 Sulfur Content of BFG

Charcoal has a very low sulfur content and the BFG resulting from its use is expected to have a sulfur content low enough to meet the engine specifications (this has to be verified by measuring the sulfur content of the BFG). The coke used in the blast furnace at Sidersa reportedly had a 1% sulfur content. The sulfur content in the resulting BFG from Sidersa's operations may exceed the engine specifications and, consequently, require sulfur removal. Sulfur in BFG would be in the reduced form, H_2S, which is more difficult to remove than sulfur from a boiler which is in the oxidized form, SO_2. This issue will require further investigation in Phase II.

3.1.6 Aggressive Component in BFG

The aggressive components (Na_2O, K_2O and Cl) are not expected to be an issue because they will be removed by the gas cleaning system to levels below the levels required by engine manufacturer specifications.

3.1.7 Limited Engine Test Data

The test data for the experimental operation of the engine at Metalsider was limited. It was reported that the Ford engine failed prematurely due to inadequate gas cleaning, but the operation of the test engines met the important objective of demonstrating that BFG could be burned in an internal combustion engine to generate power. The engine manufacturers will have to run additional tests and the full-scale demonstration facility will have to be operated to confirm the pilot project findings.

3.1.8 Environmental Considerations

A review was performed on the expected demonstration unit emissions versus the applicable regulations. The results of the review are presented in Table 4-4. Based on environmental regulations reviewed applicable to this proposed concept in Brazil, the conceptual design of the demonstration unit will meet these regulations without additional emissions controls or treatment.

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3.1.9 Safety

The BFG is toxic. Furthermore, if mixed with air it could form an explosive mixture. The BFG appears to be handled in a safe manner at the pig iron facilities and similar gases have been used safely in process and power generation applications elsewhere. The power generation facility design will be reviewed to ensure it meets high safety standards considering the toxicity and explosive potential of the gas.

3.1.10 Tie-in to Existing System

In order to tie into the existing system, the BFG flow to the flare must be completely stopped and the ductwork and equipment near the tie-in point have to be purged. This will require a stop in pig iron production or a diversion of the BFG to the flare. With careful planning (prefabrication, set up preparation during operation, etc.) the tie-in could be accomplished in a 2 to 3 day time period. If pig iron production can not be stopped, a hot tap or diversion of the BFG may be evaluated as an alternative.

3.1.11 Reduced and Sporadic BFG Flow to the Flare

With the power generation system in place, the BFG flow to the flare will be substantially reduced compared with the current operation and may fluctuate more than in the existing operation. The flare system design has to be reviewed to determine what modifications are required to operate satisfactorily under the new conditions..

3.1.12 Use of LPG as Supplemental Fuel

CEMIG indicated that it is prohibited to use LPG in engine generators without written approval from Brazil's National Fuel Department (DNC). Use of LPG must be proven to be essential to the systems operation to be approved. If LPG is determined to be required by the system, application for approval to use LPG will take place.

3.2 Evaluation of Alternatives

This section describes the evaluation of alternative configurations to produce power from the blast furnace gas. The alternatives considered are as follows:

- Boiler and Steam Turbine (Rankine Cycle)
- Simple Cycle Gas Turbine
- Combined Cycle Gas Turbine
- Internal Combustion Engine

3.2.1 Boiler and Steam Turbine

The Rankine cycle refers to the power generation cycle which consists of a boiler and steam turbine generator along with all auxiliary equipment required to support the two primary components. Steam generated in a boiler drives a steam turbine coupled to a generator to produce electrical power.

The advantage of the boiler/steam turbine option is that the technology is well proven, the systems required are well established and package units are commercially available. To review this alternative, a company specializing in small packaged Rankine cycle power plant systems was requested to quote. This company provided a detailed quote that was higher in cost/KW and lower in overall electricity production (approximately half the output of the engine generators from the same quantity of BFG). Additionally, because of the number, size and complexity of the supporting systems, the operation and maintenance (O&M) requires significant resources. Due to the high capital cost, high O&M costs and lower output, it was decided not to review this alternative further.

3.2.2 Simple Cycle Gas Turbine

Gas turbines operate on a Brayton cycle. A gas turbine plant typically consists of a package unit containing a compressor, combustion chamber, power turbine and generator supported by auxiliary systems and equipment. Combustion air is compressed in an axialflow unit. The gaseous fuels are at high pressure (~325 psig) or also compressed to be delivered to the combustion chamber. Fuel clean-up requirements are very stringent to avoid erosion, corrosion or deposition on gas path parts. In a simple cycle the hot exhaust gases are rejected to the atmosphere without using another cycle to recover heat for additional electricity generation.

There is little experience on firing gas with heating values as low as the BFG in gas turbines, particularly with small units. It is likely the BFG would have to be enriched to above 1,335 Kcal/Nm^3 to be used in these units. Additionally, at this size range, the internal combustion engines are generally more efficient than combustion turbines. For these reasons, the simple cycle combustion turbine alternative was not reviewed further.

3.2.3 Combined Cycle Gas Turbines

Combined cycle refers to a power cycle with a gas turbine and steam turbine combined in a series arrangement in which the hot exhaust gas from the gas turbine flow to a heat recovery steam generator (HRSG) for steam production. The steam produced in the HRSG is used to drive the steam turbine. Electric generators, driven by both the gas and steam turbines, produce electric power. Combined cycle plants are more efficient than simple cycle plants but are more complex and have higher capital and O&M costs.

There is little development activity in combined cycle units below 5 MW capacity. Those that are available have high unit costs and lower efficiencies compared with higher capacity units. The combined cycle alternative, although having the potential for better efficiency than the IC engines, has the same disadvantages (stringent gas cleaning requirements, fuel gas compression requirements, little experience on this or similar type fuels and relatively certain enrichment requirements) as the simple cycle gas turbine. Given the combined cycle complexity and high O&M costs it was decided not to review it further.

3.2.4 Internal Combustion Engine

Internal combustion engines are of the reciprocating type and operate on either the Otto or Diesel cycle. Otto engines are essentially mixture engines in which an explosive fuel-air mixture is externally made in a carburetor or mixing valve and introduced into a cylinder where it is compressed. The compression temperature is kept below the fuel ignition temperature and the ignition is by an electric spark. Diesel engines are of the injection type in which air alone is compressed and fuel is injected into the combustion chamber towards the end of the compression stroke. Compression temperature must exceed the ignition temperature of the fuel. For low-Btu gases, typically spark ignition is used. The expansion of the products of combustion drives the pistons which in turn rotate the engine shaft. In this study, the engine shaft is coupled to a generator which converts the shaft power to electrical power.

Heat recovery steam generation from the engine exhaust and the engine water jacket can be used to boost overall thermal efficiency, but in this study there is no specific use for the steam and addition of a steam turbine generator would add complexity and would not be practical. The efficiency of internal combustion engines without heat recovery is somewhat higher than that of small simple cycle gas turbines. They are capable of operating on low-Btu gases in the heating value range of BFG, but may require enrichment of the gas. Due to clear advantages of the IC engine over the Rankine cycle, the simple cycle, and the combined cycle it was selected as the preferred technology for the study.

3.3 Design Basis and Recommendation of Host Site

3.3.1 Design Basis

A design basis was developed to establish a standard internal combustion power generation system design that could be replicated at multiple installations. According to CEMIG, a blast furnace capacity of 140 t/d is fairly representative of the furnaces in Minas

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Gerais and the operation at Metalsider is typical of the industry. Therefore, the design basis was developed primarily by using the operating conditions of Metalsider's 140 t/d unit. The design basis is given in Table 3-1.

3.3.2 Recommendation of Host Site

Although no other sites were evaluated in detail at this point, Metalsider is recommended for the demonstration project host site for the following reasons:

- The design basis of the conceptual plant is based on Metalsider's 140 t/d blast furnace.
- Metalsider has a keen interest in this technology and can be expected to be a cooperative partner in the continued development of this technology.
- Metalsider has an established working relationship with CEMIG.
- The facility layout considerations at the Metalsider 140 t/d unit will accommodate a demonstration facility.
- Metalsider has three additional operating 140 t/d blast furnaces which could host the 2nd, 3rd and 4th units. No other single company has this potential for follow-on units.

Table 3-1

DESIGN BASIS

Plant Location and Environmental Conditions

Location	Betim, Brazil
Elevation	800 meters
Barometric pressure:	13.36 meters
Ambient air temperature (average)	21°C
Ambient air temperature (extremes)	0°C to 37°C (min and max)

Blast Furnace Gas (average conditions as received at system boundary)

Percentage of total BFG	40
Available flow rate:	4,900 Nm^3/hour
Pressure in duct:	300 mm H_20 (0.427 psi)
Temperature:	130°C (max 180°C)
Dust loading:	100 mg/Nm^3 (40 ppm by wt)
Particle size distribution:	Unknown

Average blast furnace dry gas composition (may contain 3% H_20)

Component	Volume %(ave)
O_2	0
CO_2	16
CO	24
H_2	5
CH_4	1
N_2	54

Electricity Production

Voltage to Grid	13.8 kV
Voltage of Blast Furnace Equipment	480 V or lower

4. Conceptual Design

This section presents the conceptual design of the gas cleaning and power generation systems starting with the major component selection. A system description, equipment list, single line diagram, performance data, and project schedule are provided to complete the description of the conceptual power generation unit. Discussions on product packaging and construction issues, environmental considerations, and BFG beneficiation by CO_2 extraction provide additional insight into issues reviewed in developing the product conceptual design.

4.1 Major Component Selection

4.1.1 Gas Cleaning Equipment

Of the ten gas cleaning equipment suppliers contacted by telephone, two immediately declined to quote and one other, PECO, supplies equipment suitable only for tail end cleanup. The remaining seven vendors requested to receive the specification (presented in Appendix B). After reviewing the specification, three more vendors declined to quote, two supplied budget quotations on filtration equipment and two supplied budget quotations on scrubbing equipment.

The budget quotations were analyzed and discussion on key points of the analysis is provided below.

4.1.1.1 Scrubbing Equipment

The scrubbing equipment quoted was of the venturi type and the quotations from both vendors were in the same price range. Venturi scrubbers have been used commercially to clean BFG and syngas of similar characteristics to BFG. One vendor has an operating venturi scrubber on syngas. This vendor provided an alternative design with side discharge which is more suitable for the study proposed conceptual design versus the more typical top discharge. It is likely that most other vendors could supply side discharge if requested. The clean gas discharged from the venturi scrubber is at its adiabatic saturation temperature which meets the engine manufacturers gas inlet temperature specifications.

4.1.1.2 Filtration Equipment

The filtration equipment (pulse jet baghouses) were approximately one-half the cost of the scrubbing equipment. The baghouses require a source of compressed air to reverse pulse clean the bags. This would require a separate air compression system. During the pulse a potentially explosive mixture of BFG and air would form momentarily in a portion of the baghouse. This could be overcome by more expensive baghouse designs which either shake the bags to clean them or compress some of the clean gas and use the compressed gas to pulse the bags. The temperature of the clean gas discharging from the baghouse would be approximately the same as that entering. To meet the engine specifications, the gas would have to be cooled to approximately 45°C . This would require either an indirect heat exchanger or a water wash system similar to a scrubber. The baghouse pressure drop of 6 inches H_2O is only one-half to one-third that of the venturi scrubber.

4.1.1.3 Gas Cleaning Equipment Selection

The venturi scrubber was selected for the gas cleaning function because it is proven on similar applications and because it will simultaneously cool the gas. No vendor selection was necessary at this time because both offerings were comparable. A blower will be required to boost the clean gas pressure to overcome some of the venturi pressure drop and to meet engine fuel inlet pressure specifications (A blower would also be required with filtration equipment).

4.1.2 Engine Generator Set

As noted in Section 2, a list was made of the most experienced manufacturers and all six were contacted. All initially showed interest, and shared their experiences and knowledge. Wartsila wanted to review the specification before committing to quote and ultimately declined to quote due to lack of experience and current work load. Caterpillar and Waukesha eventually declined to quote. Both appeared to have internal organizational difficulties in addressing our request because of the developmental nature of the project and their distributor based sales organization.

Cooper Industries, Fairbanks-Morse and Jenbacher all planned to submit complete quotes, but only Jenbacher and Fairbanks-Morse did. Cooper Industries provided a two page budgetary quote which covered the full technical scope requested and expressed their intention to follow-up later with a complete quotation. They used a single engine with a 13.8kV generator and provided a complete pre-engineered building with their packaged engine generator set to meet the specified requirements. Fairbanks-Morse provided a complete quotation package, but only quoted the engine and generator sets without considering the packaging or containerization requested. Jenbacher provided a complete quotation for a containerized unit. This unit best meets the study objective of having a standard power generation system design which could be commercialized and replicated at multiple installations.

The budget quotations were analyzed and discussion on key points of the analysis are provided below.

4.1.2.1 Packaging

The goal of a standard system commercialized and replicated at multiple installations drives the requirement of minimal engineering and field installation. This led to the request for maximum packaging or containerization. The manufacturers were also requested to make an economic decision on generating at 480V and providing the additional cost of a step-up transformer or generating at 13.8kV. The manufacturers explained that a 13.8kV generator in this size range is somewhat unusual and too large to package or containerize. Cooper and Fairbanks-Morse chose to quote a 13.8kV generator, Jenbacher chose their standard containerized system which generates at 480V. Jenbacher provides three smaller capacity units to use the majority of the BFG available. Cooper accommodated the packaging request by packaging their engine generator set as much as practical and providing a pre-engineered building that required minimum field erection.

4.1.2.2 Supplemental Fuel Requirements

All three engine manufacturers initially thought some supplemental fuel would be required and, ultimately, supplemental fuel may be required to cover all potential BFG conditions. Each manufacturer had a different level of supplemental fuel they required. Cooper requested a one percent (1%) pilot of light fuel oil, natural or LP gas. Fairbanks-Morse required a six percent (6%) heat input basis, light fuel oil supplement and Jenbacher initially stated that if supplemental fuel were required, a twenty percent (20%) volume basis supplement of LP gas or a thirty to forty percent (30-40%) supplement of natural gas would be used. Jenbacher strongly suggested reviewing CO_2 removal and ultimately stated they felt they could run their engine without supplemental fuel on the average gas composition provided. They felt confident they could run their engine on BFG alone if the hydrogen content (H_2) was above 5.5%. Testing is recommended by Jenbacher to confirm their design can run continuously on the average gas composition.

4.1.2.3 Engine Generator Package

Jenbacher proposed a four-stroke, air/gas mixture, turbocharged, spark ignited gas engine. Fairbanks-Morse proposed a four-stroke in-line, six cylinder dual fuel (Low Btu Gas and light oil) turbocharged engine generator. Cooper also proposed a four-stroke dual fuel engine generator. There were no technical concerns identified with the engine generators proposed. The Jenbacher containerized engine generator set was selected to base the feasibility assessment on because it best meets the feasibility study objectives.

4.2 System Description

The system is best described by reference to Figure 4-1, the process flow diagram of the system and Table 4-1, the heat and mass balance of the system. The numbered streams on Figure 4-1 correspond with the stream data given in Table 4-1.

BFG discharges from the top of the blast furnace and is passed through existing dry cyclones to remove particulate matter (PM) to the level of 100 mg/Nm^3 required by environmental regulations. The clean BFG (stream 1) is divided into two major flows: 60 percent (stream 2) is sent to the glendon to preheat blast furnace air and the bulk of the remainder (stream 3) is sent to the power generation system. A small amount of BFG (stream 4) is continuously sent to the flare stack where it is combusted and discharged to the atmosphere. If either the glendon or the power generation system can not accept the flow of BFG, that flow is diverted to the flare.

The BFG flow to the power generation system is controlled by a butterfly damper. After the gas stream passes the butterfly damper it flows into a venturi scrubber where it passes at a high velocity through the venturi. Scrubbing water is introduced at relatively low pressure at the venturi throat where the liquid is sheared and droplets are formed. Particulate matter in the gas stream is impacted by the water droplets and removed from the gas. The scrubber operates at around 35 millimeters H_2O pressure drop to remove particles smaller than 3 microns. The scrubbing liquid is collected in the bottom of the scrubber and recirculated with a pump. Clean water (stream 10), controlled by the liquid level in the bottom of the scrubber, is fed to compensate for evaporation and purge losses. A small purge stream (stream 11) is used to control the concentration of solid material contained in the scrubbing water. In the scrubber the gas is cooled to its adiabatic saturation temperature of about 36 °C.

Figure 4-1 Process Flow Diagram

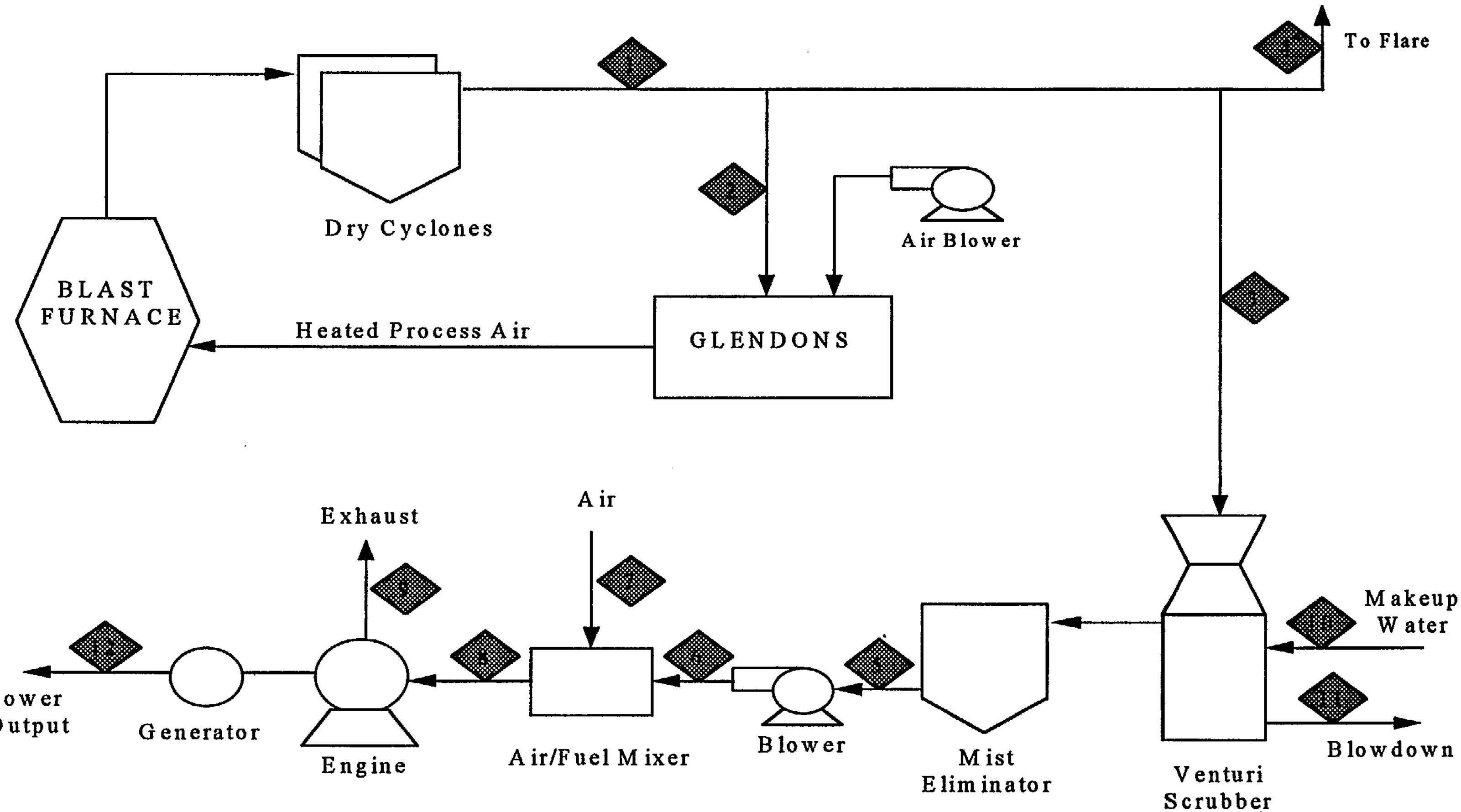

Table 4-1

Heat and Mass Balance

SI UNITS

STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
STREAM DESCRIPTION	BFG from Blast Furnace	BFG to Glendon	BFG to Scrubber	BFG to Flare	BFG from Scrubber	BFG from Blower	Air to IC Engine	Air/Fuel Mix to IC Engine	Engine Exhaust to Stack	Water to Scrubber	Bleed from Scrubber	Electrical Output
GASES: kg-mol/h												
H_2	27	16	9	2	9	9	0	9	0	0	0	
CO	131	79	45	7	45	45	0	45	0	0	0	
CO_2	87	52	30	5	30	30	0	30	77	0	0	
CH_4	5	3	2	0	2	2	0	2	0	0	0	
N_2	295	177	101	17	101	101	146	247	247	0	0	
H_2O	0	0	0	0	13	13	0	13	26	0	0	
O_2	0	0	0	0	0	0	39	39	8	0	0	
TOTAL: kg-mol/h	547	328	188	31	201	201	185	385	358	0	0	
LIQUIDS: kg/h												
H_2O	0	0	0	0	0	0	0	0	0	241	13	
SOLIDS: kg/h												
ASH	1.2	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	
TOTAL FLOW: kg/h	15,937	9,562	5,480	895	5,707	5,707	5,328	11,035	11,035	241	14	
TEMPERATURE °C	150	130	130	130	36	40	21	31	150	20	36	
Duct Press, mm H_2O	1,500	300	300	300	-210	212	212	212	25			
Total Press, bar	1.07	0.95	0.95	0.95	0.90	0.94	0.94	0.94	0.92	1.92	1.92	
ENTHALPY, GJ/h	2.3	1.2	0.7	0.1	0.7	0.7	0.0	0.7	2.7	3.2	0.2	
LHV, GJ/h	48.0	28.8	16.5	2.7	16.5	16.5	0.0	16.5	0.0	0.0	0.0	
TOTAL HEAT, GJ/h	50.3	30.0	17.2	2.8	17.2	17.2	0.0	17.2	2.7	3.2	0.2	
FLOW RATE, Nm^3/h	12,253	7,352	4,213	688	4,496	4,496	4,140	8,636	8,025			
FLOW RATE, Act m^3/h	18,010	11,570	6,630	1,083	5,720	5,539	4,798	10,335	13,642			
FLOW RATE, m^3/h										0.241	0.01363	
GROSS POWER OUTPUT, kW												1,413

ENTHALPY BASIS: 15.5 °C LIQUID WATER

The gas stream, containing some entrained water droplets, then flows to a mist eliminator where the water droplets are removed. The cleaned gas discharges horizontally to a blower. The blower increases the pressure of the gas to account for some of the pressure drop required in the venturi and the gas supply pressure required by the engine. The heat of compression from the blower reheats the gas approximately 4 °C and lowers the relative humidity to a value below saturation.

The BFG from the blower (stream 6) is sent through a safety filter to an air/fuel mixer where it is mixed with air (stream 7) and the mixture is compressed. High pressure turbocharging is used to compress the mixture. Compression increases the air/fuel mixture density and permits more fuel to be burned thereby increasing power from a given cylinder size. Air is taken from the atmosphere through a remote mounted filter with replaceable filter cartridges and ducted to the turbocharger through a flexible connection. A two-stage cooling system is used to control the temperature of the mixture delivered to the engine.

The engine is a four-stroke design with an electronic high-performance spark ignition system and equipped with a low NOx combustion system. A motorized carburetor is used to provide automatic adjustment according to changes in fuel gas quantity or characteristics. The system provides an accurately controlled air/fuel ratio, resulting in efficient fuel utilization at varying loads and ambient air conditions.

The exhaust gas (stream 9) from the exhaust side of the turbocharger outlet is piped to atmosphere through a silencer and stack. Expansion bellows are located in the piping to absorb forces created due to thermal growth and to compensate for vibrations.

The engine cooling water system employs fresh water in a closed circuit with a radiator type heat exchanger. The main pump circulates the cooling water into the engine jackets

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through lower water headers located at each side of the engine. Cooling water is also supplied to the turbochargers. After engine cooling, water flows through the upper return headers to the external piping and heat exchanger.

The engine lubricating system employs a gear type lube oil pump. The pump draws oil from the sump tank via a suction strainer/foot valve and discharges it through a cooler, pressure control valve, and final strainer to the inlet of the engine's lube oil header. An automatic lube oil replenishing system is provided to maintain the oil level at the prescribed level.

A self-excited, self-regulated, three phase generator with automatic power factor control is directly coupled to the engine gear box to generate electricity (stream 12). The generator consists of the main generator, the exciter, and the voltage regulator.

The control panel for the power module is furnished with automatic control to initiate a starting or stopping sequence from a remote point. The control for each module starts the engine, synchronizes it to the grid, closes the generator circuit breaker, increases the load to the prescribed setting and monitors the operation of the engine and generator. When given a shutdown signal, the engine control automatically removes load, opens the generator circuit breaker and stops the engine after a short cool down period.

4.3 Performance Data

A summary of the overall system performance is presented in Table 4-2 for both the base case (export electricity and BFG facility consumption) and the alternative case (BFG facility consumption only).

Table 4-2

Performance Data

Item	Units	Base Case	Alternative
BFG to Treatment			
Volumetric Flow Rate	Nm^3/h	4212	1404
Mass Flow Rate	Kg/h	5480	1827
Temperature	°C	130	130
LHV	$Kcal/Nm^3$	932	932
Particulate Loading	mg/Nm^3	100	100
Pressure	bar	0.95	0.95
BFG to Engine			
Flow Rate	Nm^3/h	4480	1493
Temperature	°C	43	43
Particulate Loading	mg/Nm^3	3	3
Pressure	bar	0.94	0.94
Relative Humidity	%	80	80
Engine			
BFG LHV	10^6Kcal/h	4.18	1.39
Auxiliary Fuel LHV	Kcal/h	0	0
Total Fuel Input LHV	10^6Kcal/h	4.18	1.39
Air Flow Rate	Nm^3/h	4140	1380
Power System			
Gross Power	kW	1413	471
In-Plant Power	kW	70	23
Net Power Output	kW	1343	448
Net Plant Heat Rate	Kcal/kWh	2926	2926
Net Plant Efficiency	%	29.4	29.4

Note: The values reflect full load operation at design conditions

The base case system uses three (3) engine/generator sets to produce the electricity required for both consumption in the pig iron facility and export to the grid. At the full load condition, the total BFG firing rate is 4212 Nm^3/h which is approximately 86% of that available. No supplemental or pilot fuel is assumed. The BFG at a temperature of 130 °C and containing 100 mg/Nm^3 of particulate matter is sent to a venturi scrubber gas cleaning system where it is cooled to 43°C, the particulate loading is reduced to 3 mg/Nm^3, and moisture is added. The gross and net power outputs are 1,413 and 1,343 kW respectively, with an auxiliary power consumption of 70kW. The net output is achieved with a net heat rate of 2,926 Kcal/kWh and a net efficiency of 29.4% based on the lower heating value (LHV) of the BFG.

The alternative case uses one (1) engine/generator set and produces electricity only for consumption in the pig iron facility. This system is essentially one-third the size of the base case. The BFG firing rate is 1404 Nm^3/h which is approximately 29% of that available. The net power output is 448 kW. The net heat rate and efficiency are the same as the base case.

4.4 Electrical Single Line Diagram

The facility will be connected to the CEMIG transmission system through the existing electric power feed line to the facility as shown on the Main Single Line Diagram. Refer to Figure 4-2 (Drawing number E3-00-01). CEMIG confirmed that this line would be capable of handling the power generated by the new equipment. This drawing shows two options:

- Option 1 - the base case where excess power is sold to CEMIG
- Option 2 - the alternative case where power is generated only to meet the pig iron facility internal power needs

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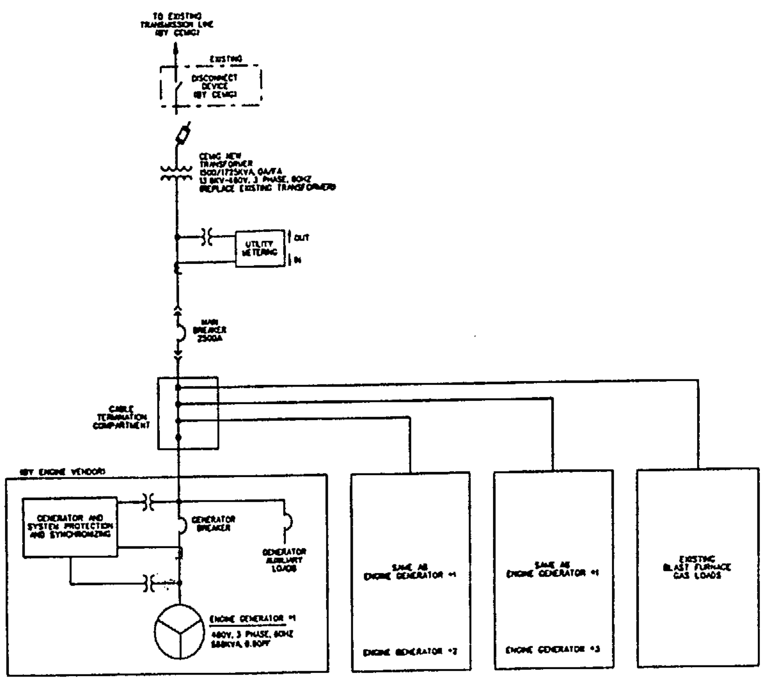
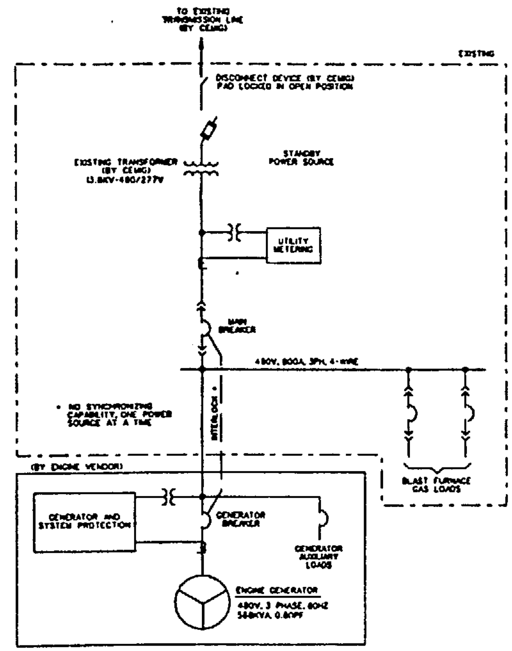
FIGURE 4-2 MAIN SINGLE LINE DIAGRAM



OPTION 1 - EXCESS POWER SALES TO CEMIG



OPTION 2 - BLAST FURNACE IN-HOUSE LOAD ONLY

ISSUED FOR STUDY

BECHTEL
GAITHERSBURG, MARYLAND

USAID
BLAST FURNACE GAS ENGINE GENERATOR FEASIBILITY STUDY

MAIN SINGLE LINE DIAGRAM

JOB NO.	DRAWING NO.	REV.
21614-002	E3-00-01	A

In the base case (Option 1) it has been assumed that CEMIG will supply the utility metering equipment, a new transformer (if required) and the disconnect device (existing). The facility constructor will provide the main breaker, cable termination compartment, and complete all electrical cabling and connections to have a facility capable of transmitting power to the grid. This option will require synchronizing equipment to synchronize the units with the CEMIG transmission system.

Option 2 shows the same arrangement and scope split except this option requires only one engine generator set. The utility equipment required for the interconnect exists. This option assumes no synchronization with the CEMIG system (CEMIG will only provide power in the case of a unit shutdown).

4.5 Major Equipment List

A listing of the major equipment required for the base case design is provided in Table 4-3. The equipment consists of the blast furnace gas supply system, the particulate removal system, the internal combustion engines and the generators.

For the base case, three identical engine generator sets are required to process the quantity of BFG available. However, only one BFG supply system and one particulate removal system is needed; the clean BFG is then distributed to the three engine generator sets.

The alternative case uses only one engine-generator set. The BFG supply system and the particulate removal system are scaled down for the smaller capacity.

Table 4-3

Major Equipment List

BLAST FURNACE GAS SUPPLY SYSTEM:

Inlet Ductwork to Scrubber

Service:	Blast Furnace Gas
Material:	10 gage Carbon Steel
Major Pieces:	16 in Diameter Tee
	16 in Diameter x 30 ft Long Straight Horizontal Duct
	16 in Diameter 90° Elbow
	16 in Diameter x 10 ft Long Straight Vertical Duct

Blast Furnace Gas Flow Control Damper

Type:	Butterfly
Service:	Blast Furnace Gas
Material:	Carbon Steel with Stainless Trim
Duct Size:	16 in
Operator:	0.25 hp

Outlet Ductwork to Blower

Service:	Scrubbed Blast Furnace Gas
Material:	10 gage Carbon Steel
Major Pieces:	20 in Diameter to 14 in Diameter Transition

Blower Discharge to Engine Intake

Service:	Pressurized Scrubbed Blast Furnace Gas
Material:	10 gage Carbon Steel
Major Pieces:	12 inch Diameter x 10 ft Long Straight Vertical Duct

PARTICULATE REMOVAL SYSTEM:

Wet Scrubber

Type:	Top Entry Venturi, with Integral Recycle Tank
Service:	Hot Blast Furnace Gas
Material:	Carbon Steel
Dimensions:	42 in Diameter x 11 ft high
Recycle Pump:	Carbon Steel with 5 HP Motor

Table 4-3

Major Equipment List (Continued)

<u>Mist Eliminator</u>

Type:	Chevron
Service:	Scrubbed Blast Furnace Gas
Material:	Carbon Steel
Dimensions:	30 in Diameter x 8 ft high
Discharge:	Horizontal

<u>BFG Pressure Booster Blower</u>

Type:	Centrifugal
Capacity:	3600 acfm at 100°F and 13.4 psia
Pressure:	1 psi
Motor:	7.5 hp

INTERNAL COMBUSTION ENGINE:

Type:	Jenbacher Energie Systeme J320 GS-B54
Service:	Low Btu Blast Furnace Gas
Cylinders:	20
Rating:	487 kW (gross)

GENERATOR:

Type:	Stamford HC 634 H
Capacity:	910 kVA, 487 kW, 0.8 PF, 3/60/480 volts

4.5.1 Engine and Generator Detailed Scope

The engine and generator sets are provided as containerized units (Jenbacher model JGC 320 GS-X.L). Three (3) gen-sets are required for the base case and one (1) for the alternative case. Each gen set is equipped with the following accessories:

- Engine management system including control panel and safety shut down
- Generator power factor control and winding temperature monitoring
- Flexible coupling, bell housing, and base frame
- Automatic lube oil replenishing system
- Fuel gas train
- Starting battery and charging system for automatic and manual operation
- Electric jacket water pre-heating system

Each gen-set has the following peripheral equipment:

- Automatic synchronizing with voltage balance
- Resynchronizing equipment
- Grid monitoring device (protection system for automatic disconnection of the generator from the grid in case of low/high voltage and frequency interruptions)
- Smoke detection alarm device
- Lube oil system with 2 x 300 liter oil tanks (for fresh and waste oil) and electric pumps for lube oil filling and draining
- Exhaust gas system
- Air intake and outlet (ventilation) system with sound attenuation and air filter
- Radiator cooling system
- Silencing for steel container

All the above mentioned components are installed and mounted in or on the top of the steel container.

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4.6 Engineering/Procurement/Construction Schedule

A preliminary milestone summary schedule was developed which shows the approximate duration and interrelationship of the engineering, procurement and construction activities. This schedule incorporates a two month pre-notice-to-proceed period to allow preparation of a purchase order for the engine generator and other preliminary engineering activities. This schedule shows a twelve month duration from full release to commercial operation and is based on a five month equipment delivery time provided by the engine generator manufacturers. The schedule is relatively conservative because it is based on constructing the demonstration facility. This schedule assumes that all engine manufacturer testing for commercial guarantees and project developmental activities are completed ahead of full Notice to Proceed. Once the manufacturers develop a standard product and the first full-scale demonstration project is built the overall schedule could likely be reduced significantly.

4.7 Product Packaging and Construction Issues

As noted previously, for a standardized system in this type of market (small industrial power), maximizing product packaging thereby minimizing field construction, is critical to the product success. This was one of the primary reasons for the selection of a containerized engine generator set as the basis for the conceptual product design. In addition to the containerized engine generator set, the gas cleaning system is skid mounted to reduce field installation.

Other than the two major components, the only additional equipment is as follows:

- BFG blower
- Transformer (if required)
- Main breaker
- Cable termination compartment

- Piping and valves
- Electrical and control cabling

In Phase II, inclusion of these items in the two major packages (engine generator and gas cleaning system) will be reviewed to further reduce field construction. The overall field construction work is kept to a minimum as evidenced by the small number of components and electrical/ piping interfaces. The construction activities are shown on the Milestone Summary Schedule (Figure 4-3), taking place over a four to five month period. The construction period could potentially be reduced to two to three months if a shortened construction period enhanced the project.

Assumptions on the scope, site and construction related issues are provided in Section 5 for the EPC capital cost estimate. The key construction issues that will require further review are:

- Tie-in to the operating flare stack
- Tie-in to the existing electrical system
- Space and location for the new equipment
- Site specific issues (i.e. Metalsider construction restrictions/ requirements, laydown, fencing, soil conditions, etc.)

These issues will be resolved in Phase II of this study with Metalsider.

4.8 Environmental Considerations

This section presents estimates of the conceptual power facility emissions for particulate, NO_x, CO, SO_2, non-methane hydrocarbons (NMHC), and scrubber effluent. These are shown in Table 4-4 along with the source standards given by existing regulations.

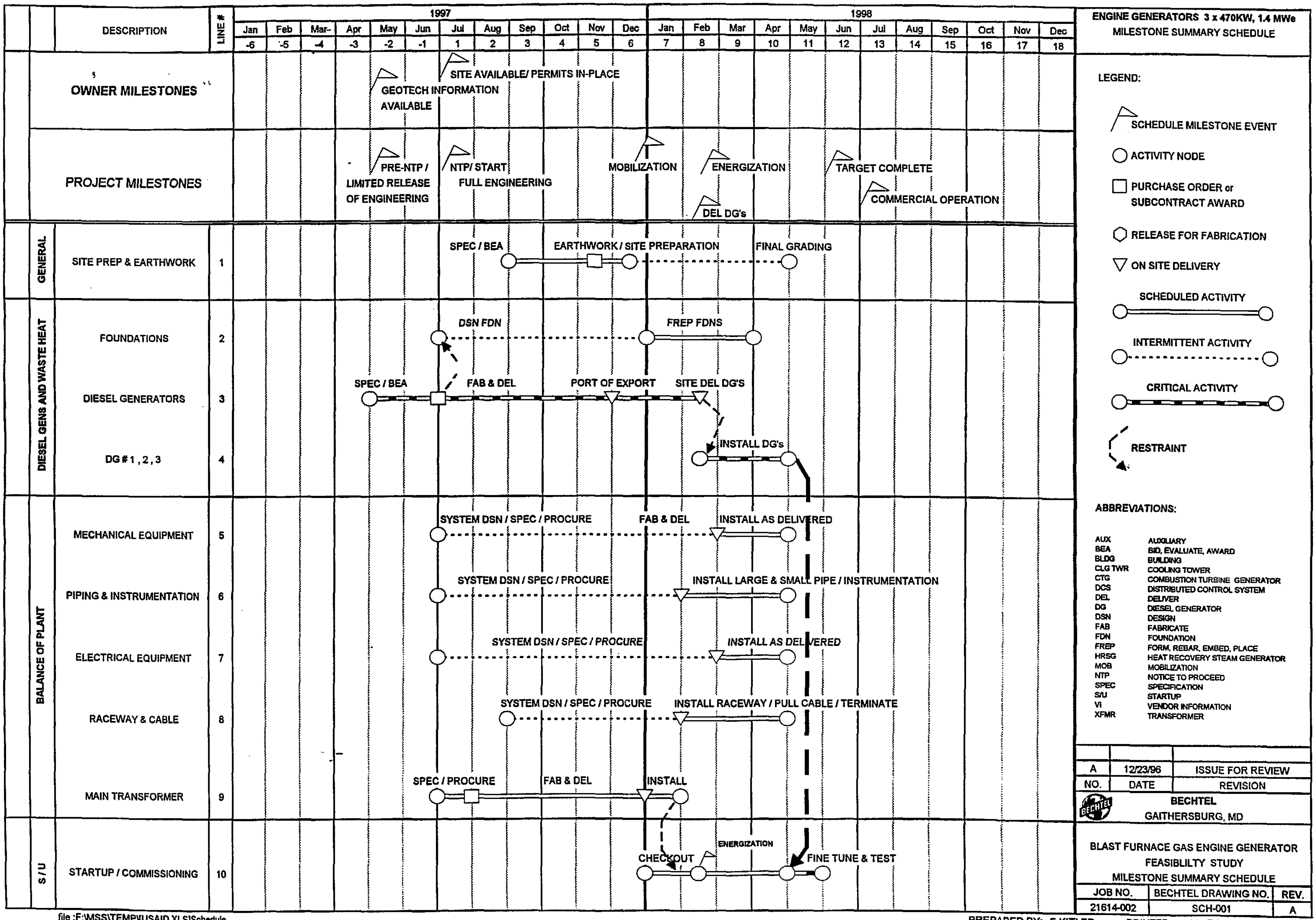

FIGURE 4-3 MILESTONE SUMMARY SCHEDULE

The discharges are at or below the regulatory limits. It is assumed that the scrubber effluent would be combined with the effluent from the existing dry cyclones for treatment or disposal. The amount of solids in the scrubber effluent will be less than one percent of that in the dry cyclone effluent and have negligible effect on the existing treatment or disposal systems. It should be noted that combustion of this waste gas, not only reduces the overall emission levels from the BFG facility of CO, H_2, CH_4 and particulate matter (via gas cleaning), but also displaces the emissions from new fossil power sources that will be required to meet Brazils growing electrical demand.

Table 4-4

Environmental Discharge Rates

Discharge	Units	Base	Alternative	Regulations
Particulate	mg/Nm^3	50	50	150(1)
NO_x (as NO_2)	g/MMBtu Input	90	90	90(2)
CO	g/MMBtu Input	280	280	NS(3)
SO_2	mg/Nm^3	NS	NS	2500(1)
NMHC	g/MMBtu Input	45	45	NS(3)
Scrubber Effluent	m^3/d	0.33	0.11	NS(3)

Notes:

(1) Brazilian Source Regulations
(2) World Bank Source Regulations
(3) No Specified Regulation or Discharges

4.9 CO_2 Removal Evaluation

The BFG has a very low heating value which is marginal for combustion in internal combustion engines. The design basis BFG contains 16% CO_2 and has an LHV of 932

Kcal/Nm^3. By removal of all CO_2, the LHV could theoretically be increased to 1109 Kcal/Nm^3, an increase of 19%. CO_2 removal would also increase the H_2 content of the gas by 1% to a level of 6%, which would be an important consideration for some engine designs.

4.9.1 Recovery of Food Grade CO_2

The merchant CO_2 market includes uses such as refrigeration and beverage carbonation. All of the CO_2 removal processes examined will remove portions of the other components in the BFG stream resulting in a contaminated CO_2 stream. Additional processing and subsequent cost would be required to produce food grade CO_2. It is technically feasible to do this but, in this size range it is unlikely to be economically viable to do so.

4.9.2 Non-Recovery Removal Systems

It is possible to remove CO_2 from the BFG by reacting it with an alkali, such as lime or caustic. This would tie up the CO_2 as a solid waste product which would have to be thrown away. The reaction could be accomplished in a gas-liquid contacting device, such as a scrubber, under favorable conditions. The reaction of CO_2 with caustic proceeds quite rapidly whereas its reaction with lime proceeds very slowly. However, caustic is much more expensive than lime, and the reaction product formed from caustic is difficult to dispose of because it is soluble.

A quick evaluation of the feasibility of this approach can be made by comparing the reagent cost for CO_2 removal with the value of the electricity generated.

The reaction of lime with CO_2 is equimolar, i. e., it takes one mole of lime to react with one mole of CO_2. The waste BFG stream that would be supplied to the engine/generator set contains 30 kg-moles per hour of CO_2. Therefore, 30 kg-moles of lime per hour would be required to remove all the CO_2.

CEMIG provided the following costs for lime:

- CaO $64/t
- $Ca(OH)_2$ $66.5/t

On a molar basis these costs equate to:

- CaO $3.59/kg-mole
- $Ca(OH)_2$ $4.93/kg-mole

The $Ca(OH)_2$ (hydrated lime) is more expensive than the CaO(quicklime) which is expected. However, the quicklime would have to be slaked (reacted with water) before it could be used, which would narrow the price differential somewhat. The cost for the raw quicklime required to remove all the CO_2 would be:

$3.59/kg-mole x 30 kg-mol/h=$108/h

The potential electricity generation is approximately 1,400 kW (base case). Even if this electricity were sold for $0.07/kWh, the revenue stream would be $98/h. This revenue stream is less than the cost of raw quicklime needed to remove the CO_2. Therefore, it can be concluded that removal of the CO_2 with reagents is not a viable option.

4.9.3 CO_2 Recovery Systems

Conventional CO_2 recovery systems fall into the following categories:

- Chemical solvents which chemically react with CO_2 to remove it and then release the CO_2 by reversing the reaction with heat and/or pressure reduction
- Physical solvent systems in which the CO_2 is absorbed by physical means and released with heat and/or pressure reduction

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- Molecular sieve systems in which the CO_2 is absorbed by physical means and released with heat and/or pressure reduction
- Membranes or permeable films that permit some gases to transfer through them more rapidly than other, thereby permitting components to be separated
- Cryogenic separation in which very low temperatures are used to condense the gases which are then separated by distillation

As discussed in Section 2, vendors for these systems (except for cryogenic) were asked for budgetary information. All but one, Union Carbide, declined to provide information indicating that the separation was too difficult or that their equipment was not suitable. Union Carbide indicated that they could do the separation with their UCARSOL® solvent. They would require the gas to be compressed to 17 bar and treated in a 20 tray absorber with 310 lpm of solvent with regeneration in a 20 tray stripping tower to remove 91% of the CO_2.

Union Carbide primarily provides gas treating solvents and does not provide equipment, therefore, they declined to provide a budgetary cost for the system. However, considering the complex nature of the system (compression, absorption, stripping, steam generation, multiple heat exchangers, etc.) a judgment can be made that the capital cost will be too high for consideration.

As another check on the economic viability of CO_2 recovery, a previous cost estimate was examined for a 1,000 tpd CO_2 recovery facility using a low-pressure amine system. This facility, although, larger in size had comparable gas characteristics that would make it reasonable for a first order economic comparison. After making adjustments (for the size difference, escalation, etc.) it was concluded that CO_2 removal would not be economically viable because the cost would be greater than the potential revenue from the electricity produced.

5. Economic Evaluation

This Section provides an estimate of the installed cost of the product defined in Section 4 at the site recommended in Section 2. Additionally, based upon the installed product cost estimate, the results of an analysis performed to determine the cost of electricity are provided.

5.1 Major Equipment Quotes

To support and consequently minimize the cost estimating effort, a decision was made early in the study to prepare relatively detailed budgetary specifications (Appendices A, B, and C). This effort was performed to solicit detailed budgetary quotations and support from the major equipment manufacturers. It was to demonstrate our serious intent to the manufacturers and thereby obtain as much information and support from them as possible. This effort was successful in obtaining detailed budgetary quotes from two manufacturers, and an abbreviated budgetary quote from a third manufacturer. All six manufacturers requested to quote, provided full details on their experience and knowledge as reported in Section 2.

5.2 Engineering/Procurement/Construction and Operation and Maintenance Cost Estimate

The budgetary quotes from the major equipment vendors and in-house data for other equipment was used in the cost estimate. Bechtel's in-house cost data base and previous Brazilian project and proposal experience were used for bulk materials and labor costs required to arrive at a installed facility cost estimate with due consideration for local conditions.

The following are the major assumptions for the Engineering, Procurement, and Construction (EPC) capital cost estimate:

- Engine generator will be located as close to the gas supply and the electric power interfaces as possible.
- Soil conditions are assumed to support the equipment pad without piles or spread footings.
- Engine generators will be packaged/self contained units with minimal interfaces (i.e., gas supply, electrical output, makeup water, etc.)
- Minimal site preparation is required (i.e., no clearing and grubbing, no underground obstructions, no utilities to be moved, no hazardous wastes, etc.).
- Gas cleaning and other minor equipment will be located outdoors.
- Electrical equipment scope split between the constructor and CEMIG is as described in Section 4.0 and as noted on the Main Single Line Diagram (Figure 4-2).
- Engineering and field construction costs are kept to a minimum based on containerized engine generator set design and skid mounted gas cleaning equipment.
- No escalation is included in EPC estimate.
- Site access by existing roadway and parking are adequate "as is".
- Makeup water is available from the existing facility and requires no further treatment.
- Waste water will be discharged without treatment to the existing facility waste water system.

The manufacturers were consulted on the expected operating and maintenance costs for their engine generator sets. The following information was provided:

O&M without labor:	4 - 4.5 mils/kWh (0.4-0.45 cents/kWh)
O&M with labor:	10 - 12 mils/kWh (1 -1.2 cents/kWh)
Overhaul every 5 years:	$125,000/unit

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Based on these assumptions, the EPC estimate was performed resulting in a US$3.4 million total installed capital cost.

5.3 Financial Analysis

Using the performance data shown in Section 4, operations and maintenance costs from manufacturers and the EPC cost estimate, an economic evaluation was performed based on the following major assumptions:

- The power generation equipment will be owned and operated by a third party that sells electricity to the pig iron producer and CEMIG.
- The levelized cost of electricity is based on the assumption that no supplemental fuel is needed.
- Financial evaluation factors (i.e., interest rates, taxes, escalation, property insurance, depreciation, cost of debt, return on equity, minimum debt coverage, etc.) are based on assumptions supplied by CEMIG or typical factors for this type and size project in Brazil. For a complete set of assumptions used, refer to Simplified Financial Proforma (Appendix F).
- Blast furnace waste gas is assumed to be supplied at no cost.
- Annual Capacity Factor based on engine quotes is assumed to be 92.5%.
- O & M costs were provided by manufacturers as stated above.

The calculated levelized cost of electricity is 7.85 cents/kWh with a ROE of 15.7% for the base case (See Appendix F). An implicit assumption was made that a prospective investor would accept a minimum ROE of around 15%.

This analysis is considered conservative for several reasons:

- No government incentives of any kind were assumed. In the U.S. and other countries similar projects often enjoy tax and/or other incentives.

- The potential advantage of the Imposto Sobre Circulacao de Mercadorias e Servicios (ICMS) tax has not been taken into account since it was not known how it would affect the depreciation schedule. ICMS is basically a value-added tax.
- Given the experimental nature of this project, there is a strong conviction that EPC costs and schedule can and will be reduced for replicated projects.
- The overhaul costs which are incurred after five years have been uniformly allocated over this period.

A sensitivity analysis (see Appendix F) was carried out to determine the sensitivity of the project viability to changes in values of loan interest rate, term, and depreciation period. As expected, by reducing the depreciation period to 10 years a higher ROE of 20% resulted, and an increase in loan term to 12 years further increased ROE to 24.2%. With these preliminary ranges for LEC and ROE a further investigation is warranted.

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6. Product Development Plan

This Section provides a preliminary plan for the development of the standard product (this plan covers Phase II) conceptualized in Section 4. Phase II will continue the pilot work performed by CEMIG and Metalsider and the work performed in this study by taking steps required to bring the project to the point of authorizing the start of design and construction of the full scale demonstration facility (Phase III).

6.1 Plan Outline

The following are the key steps to the product development plan:

- Confirm results and justify continuation (with all parties)
- Secure funding for Phase II (all parties)
- Continue pilot testing with Mercedes engine (CEMIG and Metalsider)
- Confirm engine and gas cleaning manufacturer selection (engineering company selected for Phase II)
- Confirm the demonstration project host will be Metalsider (all parties)
- Prepare a detailed budget and schedule for Phase II (all parties)
- Determine potential funding source(s) for Phase III (developer)
- Coordinate with the engine manufacturer(s) to complete testing requirements for performance guarantees (engineering company)
- Complete the preliminary design for the demonstration plant (engineering company)
- Conclude Phase II by determining organizational structure between parties involved for Phase III

Phase III will involve building the full-scale demonstration plant at Metalsider facilities and during initial operation provide feedback for corrective actions to the equipment manufacturers.

6.2 Plan Step Descriptions

The following are descriptions for each step associated with completing the commercial development process.

6.2.1 Confirm results and justify continuation with all parties

Review results with CEMIG and Metalsider to confirm the results of the analysis warrant continuation with Phase II. CEMIG and Metalsider need to confirm at what price they will purchase electricity from the facility and their ability to make a long term power purchase agreement, if a third party is to build own and operate the facility.

6.2.2 Secure Funding for Phase II

Determine division of responsibility between Phase II participants and determine sources of funding for key activities.

6.2.3 Continue Pilot Testing with Mercedes Engine at Metalsider Facilities

CEMIG and Metalsider should continue to work through operational issues with the pilot scale test arrangement they have in place. This effort should be coordinated with the selected engine and gas cleaning equipment manufacturers to allow test result feedback to be incorporated in the equipment manufacturer's design. These tests should include the BFG data collection required by the engine manufacturers including; composition, flow rate, pressure and temperature variations over time. This should also include detailed data on any transient conditions.

6.2.4 Confirm Engine and Gas Cleaning Manufacturer Selection

Confirm with all project participants the selection of the engine and gas cleaning manufacturers for Phase III.

6.2.5 Confirm that the Demonstration Project Host will be Metalsider

Review to confirm that the Metalsider site is appropriate for a demonstration project. Select a specific blast furnace from the multiple furnaces available and select a site location to build the demonstration facility. Confirm with all project participants the selection of the site.

6.2.6 Prepare a Detailed Budget and Schedule for Phase II

Develop a detailed product development plan with the manufacturer, CEMIG, Metalsider and developer (if applicable). This plan will include detailed activities, schedule and budget for the process. The plan should be updated as the development process is defined.

6.2.7 Determine Potential Funding Source(s) for Phase III

Determine potential funding source(s) for the demonstration project (Phase III).

6.2.8 Coordinate with the Engine Manufacturer(s) to Complete Testing Requirements for Performance Guarantees

Work with CEMIG and Metalsider to provide the engine manufacturer with the full range of BFG conditions expected at the demonstration facility. This will allow the engine manufacturer to complete testing requirements for commercial guarantees and warrantees.

6.2.9 Complete the Preliminary Design for the Demonstration Plant

Complete preliminary design for the demonstration plant. This includes preparation of the following preliminary drawings:

- Site/ equipment layout
- BFG P&ID
- Single line diagram

It also includes detailed specifications for the engine generator and the gas cleaning equipment. Other preliminary design activities will be included as required and defined.

6.2.10 Conclude Phase II by Determining Organizational Structure Between Parties Involved for Phase III

Prepare conceptual arrangements between parties involved (CEMIG, Metalsider, developer/owner/operator and EPC contractor) for full scale demonstration at Metalsider facilities.

7. Conclusions and Recommendations

7.1 Conclusions

The feasibility of using BFG from pig iron industries in Minas Gerais, Brazil to fuel internal combustion engine generators for electricity production has been evaluated. The past research and development efforts, discussions with equipment suppliers, and a technical and economic evaluation of the concept indicate the following conclusions:

- Tests conducted by CEMIG and Metalsider confirmed that it is possible to combust BFG in an internal combustion engine and generate electricity without supplemental fuel.
- CEMIG, Metalsider and other pig iron producers in Minas Gerais support the development of the concept and their cooperation is expected.
- The internal combustion engine is the best technology over alternatives such as combustion turbines and boiler/steam turbine for this size and type of application.
- The concept is technically viable:
  - Gas cleaning system suppliers are confident that their equipment can clean the BFG to the levels required by the engine manufacturers.
  - Internal combustion engine suppliers, specifically Jenbacher, have experience with combusting low-energy-content gases and are reasonably confident of firing the BFG without supplemental fuel.
- Implementation of the concept would provide environmental benefits by reducing emissions to the atmosphere. With the potential net generating capacity of about 103,000 kW, this would result in approximately 400,000 tons/year reductions of CO_2 emissions (assuming a 50-50 oil-gas power generation split.) Any environmental discharges from the engine-generator system would be at or below regulatory limits.

- The total installed costs, including development and financing, for the system evaluated were estimated at $3.4 million US for a net electricity production of 1,343 kW. This equates to approximately $2,500/kW.
- The estimated levelized cost of electricity is 7.85 cents/kW/hr (base case). This cost, while higher than the cost of hydroelectric power generation in Brazil, is not unreasonable when compared to other methods of waste fuel power generation, particularly in this size range.

7.2 Recommendations

Based on the evaluation results being sufficiently positive and three of the potential key project participants (CEMIG, Metalsider, and Jenbacher) being highly motivated to move the concept forward, our recommendation is to proceed with Phase II. The steps recommended in Section 6 provide the framework for the continuation with Phase II (product development) which will resolve the issues identified in Section 2 of this report and move the concept to the stage of being able to proceed with Phase III (demonstration project).

APPENDIX A

Specification 21614-3PS-MG-001

SPECIFICATION

FOR

BLAST FURNACE GAS (BFG) FIRED ENGINE GENERATOR & AUXILIARIES

BECHTEL CORPORATION
GAITHERSBURG, MARYLAND

NO.	DATE	REVISIONS	BY	CHK'D	APPROVALS	
0	11/19/96	Issued for Quote	CLW	JN		
1	11/22/96	Revised and Reissued	CLW	JN		

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APPENDICES

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PART 1 - GENERAL

PLEASE NOTE: Items in bold print are specific requests for the Seller to respond to or of particular importance.

PROJECT BACKGROUND

Bechtel is performing a study assessing the economic and technical feasibility of using pig-iron blast furnace gas to fuel internal combustion engine generators for electricity production. **The basis for this study is experimental work that has been performed on a pilot scale system that has been operational on the BFG with no enrichment, pilot or starting fuel.**

STUDY AND SPECIFICATION OBJECTIVE

The objective of the study is to assess the potential of using this resource in a standard power generation system design that could be replicated at multiple installations (over 100 potential host blast furnaces). The objective of this specification is to obtain budgetary information from the most qualified Manufacturers (based on similar experience) to support the study. Additionally, the completeness of the response to this request will weigh heavily on the decision of which manufacturer to work with in developing a standard design and ultimately to provide a product for multiple installations.

1.1 WORK INCLUDED

1.1.1 This specification covers design, fabrication, testing, and delivery of a complete containerized or trailer mounted 60 Hz, 3-phase, 0.8 p.f., engine generator set, associated control panels, and accessories. **The voltage level of the generator shall be selected by the Seller based on Sellers economics to deliver 13.8 kV power through the existing interconnection to the grid. Seller to include a separate price for the equipment (transformer, etc.) necessary to tie the engine generator to the grid.**

1.1.2 This specification also requests the **Seller to provide an option price for design, fabrication, testing, and delivery of any gas cleaning, compressing, or enriching equipment (as required by the Sellers equipment offered) to prepare the blast furnace gas to be fired in the engine generator.**

1.1.3 The engine generator set shall be a single completely self-contained, trailer mounted or containerized package suitable for minimum field installation, containing the manufacturers standard equipment and systems including the following:

a. Engine and Generator

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b. Combustion air system, including intake air filter

c. **Electric starting system using power backfed from the grid through the existing host blast furnace facility electrical system**

d. **Starting or enriching fuel system including day tank (preferred not to have enriching system unless technically or economically required)**

e. Lubricating oil system

f. Cooling system

g. Exhaust system including silencer, flex connections, and rain caps

h. Speed control system

i. Excitation and voltage control system

j. Engine and generator protection system

k. Control, protection, and surveillance systems associated with the engine generator unit

l. Generator grounding system including neutral grounding resistor

m. All interconnecting piping and wiring for engine generator and auxiliary systems required for manufacturers proposed layout (sketch included with proposal)

n. Local control panel(s) furnished with equipment for controls, indications, and alarms. Startup and Shutdown to be performed manually from these panel(s).

o. Engine generator enclosure including engine cooling fan intake and exhaust louvers, etc.

p. Engine block heater with thermostatic control

q. Generator protective relaying

r. Special tools required to install, test, operate, and maintain the Seller's equipment.

s. Typical interconnection devices required for an Independent Power Production facility tied to a utility grid. Detailed requirements for the utility tie in are not available yet.

1.2 RELATED WORK NOT INCLUDED

1.2.1 Unloading and storage at jobsite **(provide option quote for unloading and installation)**

1.2.2 Installation labor **(provide option quote for unloading and installation)**

1.2.3 Foundations and standard anchor bolts

1.3 TERMINAL POINTS

The engine generator set with all auxiliaries and gas cleaning, compressing, enriching equipment shall be containerized or mounted on trailers to the maximum extent practical. The Buyer's interfaces shall be limited to the following terminal points:

a. Fuel supplies - Single inlet to fuel supply connections (for BFG, NG or oil)

b. Drains - Single outlets for cooling system, lube oil system and fuel systems

c. Relief valves - Coolant pressure cap shall be vented outside the enclosure.

d. Remote control and monitoring (if used by Buyer)- Interfaces shall be at the terminal blocks within the control panel and Seller-supplied terminal boxes.

e. Power connection - Interfaces shall be within the Seller-supplied terminal boxes. The Buyer will supply power to generator space heaters, engine block heater, etc.

1.4 SUBMITTALS

Submit the following documents with budgetary proposal (typical drawings with hand mark-ups for project specifics or hand sketches are acceptable if equipment specific drawings and information are not available):

a. Outline / arrangement drawings for supplied equipment showing overall dimensions, basic foundation requirements, and weights

b. System flow diagrams for engine, auxiliary systems, BFG cleaning, enriching and compressing systems (if required).

c. Electrical 1-line diagram for proposed interconnection to the 13.8 kV grid connection

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d. **Major Equipment list**

e. **Brief System description**

f. **Performance data**

g. **Approximate Delivery and Installation Schedule**

h. **Completed data sheets (only information bolded and marked with asterisks).**

PART 2 - PRODUCTS

2.1 SERVICE REQUIREMENTS

2.1.1 Plant Location and Environmental Conditions

a. Location — Belo Horizonte, Brazil

b. Elevation — 800 meters, msl

c. Ambient Air Temperature (average) — 20.6 °C

d. Ambient Air Temperature (extremes) — 0 °C to 37 °C (min and max)

2.1.2 Blast Furnace Gas Conditions

a. Blast Furnace Gas Low Calorific Value: 930 kcal/Nm^3

b. BFG Flow Rate available for engine generator : 4,900 Nm^3/hour

c. BFG Pressure (average) @ inlet to gas cleaning equipment: 0.03 kg/cm^2

d. Temperature @ inlet to gas cleaning equipment: 130°C (average)

e. Dust @ inlet to gas cleaning equipment: 100 mg/Nm^3

f. Blast Furnace Gas Composition. Average Percent Volume values can vary up to +/- 5%.

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Constituent	Average Percent Volume	Minimum
O_2	0	
CO_2	16	
CO	24	18
H_2	5	1.5
CH_4	1	0.08
N_2	54	

Contaminants	Average (mg/Nm^3)
Na_2O	42.4
K_2O	105.6
Cl	0.9

2.1.3 Operating Data

a. Engine Generator Operation:

Planned: continuous full load operation 24 hours/day, 365 days/year

Seller to provide expected system capacity factor

b. Number of units required: one standard design to be replicated at up to 104 different operating blast furnace sites

c. **Unit rating: continuous rating to be calculated by Seller**

d. **Generating voltage selected by Seller** @ 460 V or 13.8 kV, 0.8 p.f. (if other than 13.8 kV selected Seller to provide all equipment for transmission at 13.8 kV)

e. **Enrichment fuel (if required): LPG or natural gas (if LPG selected please provide option cost for LPG receiving, storage and supply systems)**

The engine generator will supply continuous power to the host facility (approximately one third of the power generated) with the remainder of the power generated sold to the grid.

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MAKE AND MODEL OF ENGINE	*
TWO OR FOUR CYCLE	
TYPE OF AIR INTAKE SYSTEM (CARBERATOR, TURBOCHARGER, ETC.)	* INCLUDE BRIEF DESCRIPTION OF HOW/WHY MODIFIED
MEANS OF PROVIDING SCAVENGING AIR IF TWO CYCLE	
BRAKE MEAN EFFECTIVE PRESSURE, BAR (G)	
PISTONS: SINGLE ACTING/DOUBLE/OPPOSED	
NUMBER OF CYLINDERS/ARRANGEMENT	*
BORE AND STROKE, MM	
RATED SPEED, RPM	
PISTON COOLING MEDIUM/MAX. PISTON SPEED, M/MIN	
STANDARD RATING, BHP/RATING @ SITE, BHP	*
RATING AT 110%, KW	
CONTINUOUS/ MAX/ MIN RATING, KW	*
FUEL CONSUMPTION @ SITE, DEMA STD. PRACTICE	
• 4/4 LOAD, KG/KW-HR	
• 3/4 LOAD, KG/KW-HR	
• 1/2 LOAD, KG/KW-HR	
FLOOR TO CRANKSHAFT, M	
OVERALL LENGTH W/GENERATOR, M	
L/R RATION, M/M	
TYPE OF BARRING DEVICE	
TYPE OF LUBRICATION OF MAIN PARTS	
CYLINDER LUBRICATION (SPLASH OR FORCE FEED)	
LUBE OIL FLOW REQUIRED, M^3/HR	
MAX. LUBE OIL TEMP. @ FULL LOAD, °C	
MAX. LOADINGS, SQ. MM/BAR	
• MAIN BEARINGS	
• CRANK PIN BEARINGS	
• WRIST PIN BEARINGS	
D/B RATIO (CRANKSHAFT DIA./CYLINDER BORE)	
JACKET COOLING WATER REQUIRED, M^3/HR	*
MAX. JACKET COOLING WATER TEMP., °C	
MAX. JACKET COOLING WATER PRESSURE, BAR	
DIMENSIONS: WIDTH W/O PLATFORM, M	* LAYOUT SKETCH PREFERED
HEIGHT FROM FLOOR, M	
FLOOR TO CRANE HOOK, M	
AUXILIARIES: SIZE, MODEL NUMBER, RATING:	* LAYOUT SKETCH PREFERED COVERING MAJOR COMPONENTS
• INTAKE SILENCER	
• LUBE OIL PUMPS	
• JACKET WATER PUMPS	
• JACKET WATER HEAT EXCHANGER	
• EXHAUST SILENCER	
• FUEL OIL PUMPS	
• AIR COOLED RADIATOR (IF USED)	
BUYER'S EQUIPMENT IDENTIFICATION NO.	
CU. YDS. FOUNDATION REQ'D (ENG. AND GEN.)	*
SHIPPING WEIGHT ENGINE LESS FLYWHEEL, KG	
SHIPPING WEIGHT FLYWHEEL, KG	
SHIPPING WEIGHT OF ALL EQUIP., KG	*
SHIPPING WEIGHT OF HEAVIEST PIECE, KG	
HEAVIEST PIECE HANDLED IN MAINTENANCE, KG	

BECHTEL	**ENGINE DATA SHEET** ENGINE GENERATOR	Job No. 21614	
		Specification 3PS-MG-001	REV
		Appendix A	0
		Sheet A-1 of 2	

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MANUFACTURER	
SIZE & TYPE	*
FRAME DESIGNATION	
RATING: KVA/POWER FACTOR	*
LINE CURRENT/FIELD WL & FL CURRENTS	
LINE VOLTAGE/FIELD	
TEMPERATURE, °C	
AMBIENT(MIN,MAX)/MTH AVE (MIN,MAX)/ STATOR RISE/ROTOR RISE	0 to 37/ 9 & 30/
INSULATION CLASS	
RPM/FREQUENCY	* /60
STEADY STATE FREQUENCY VARIATION	
MOMENTARY FREQUENCY VARIATION	
REACTANCES	
DIRECT AXIS SYNCHRONOUS, Xd	
QUADRATURE AXIS SYNCHRONOUS, Xq	
DIRECT AXIS TRANSIENT, X'd	
DIRECT SUBTRANSIENT, X"d	
NEGATIVE SEQUENCE, X'2	
ZERO SEQUENCE, X'O	
TIME CONSTANTS, SECONDS AT 75 °C	
DIRECT AXIS TRANSIENT OPEN CIRCUIT, T'do	
DIRECT AXIS TRANSIENT SHORT CIRCUIT, T'd	
DIRECT AXIS SUBTRANSIENT SHORT CIRCUIT, T"d	
ASYM. COMP. OF ARMATURE CURRENT, T'a	
WINDING CAPACITANCE TO GROUND	
SHORT CIRCUIT RATIO	
BALANCED TIF	
VOLTAGE REGULATOR	
MODEL & TYPE	
RATING	
CHARACTERISTICS	
VOLTAGE REGULATION	
GEN. INHERENT REG. NL & FL W. VOLT. REG., %	
NO LOAD TO FULL LOAD @ 0.8 P.F., RATED SPEED (STEADY STATE)	
NO LOAD TO FULL LOAD @ 0.8 P.F. (TRANS. CONDITION)	
MAXIMUM EXCITATION REQ. UNDER TWO ABOVE CONDITIONS	
SYNCHR. COEFF., KW/RADIAN - FULL LOAD/NO LOAD	
EXCITER	
MODEL & TYPE	
RATING & VOLTAGE	
CURRENT & RESPONSE RATE	
FIELD RESISTANCE AT 75 °C	
EXCITATION AT RATED VOLTAGE	
NO LOAD, AMP, DC	
FULL LOAD, 0.8 P.F., AMP, DC	
EFFICIENCY	
AT FULL LOAD, 0.9 P.F. AND 0.8 P.F.	*
AT 3/4 LOAD / AT HALF LOAD	
ENCLOSURE	*
VENTILATION	
TORQUE (WK2)	
WEIGHTS: STATOR/ROTOR/TOTAL	//*

BECHTEL	GENERATOR DATA SHEET	Job No. 21614	
		Specification 3PS-MG-001	REV
		Appendix A	
		Sheet A-2 of 2	

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APPENDIX B

SPECIFICATION

FOR

BLAST FURNACE GAS (BFG)

PARTICULATE REMOVAL SYSTEM

BECHTEL CORPORATION

GAITHERSBURG, MARYLAND

NO.	DATE	REVISIONS	BY	CHK'D	APPROVALS	
0	11/19/96	Issued for Quote	JN	CLW		

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APPENDIX B

FORM OF PROPOSAL FOR BFG ENGINE GENERATOR

Bidder:____________________________

Provide the following information with the proposal for base bid and alternates/options. Please respond to all items, if answered elsewhere in the proposal please indicate specific location of information.

1.0 <u>COMPLETED DATA SHEETS </u>(Appendix A)

a. Engine (Sheet A-1) ________________________

b. Generator (Sheet A-2) ________________________

2.0 <u>PROPOSAL SUBMITTALS</u>

2.1 Arrangement/ process drawings

a. General arrangement drawing showing arrangement of package(s) ________________________

b. Outline drawings showing dimensions of major components ________________________

c. System flow diagram showing Seller's complete scope of supply ________________________

2.2 Preliminary electrical single line diagram for proposed 13.8 kV interconnect

____

2.3 Major equipment list ________________________

2.4 System description ________________________

2.5 Performance data (@ 22.5 C, 800 above msl & continuous full load)

- Unit load rating, continuous, 8760 hr/yr. (kW) ________________________
- Auxiliary load (kW) ________________________
- Heat Rate / Efficiency (Btu/kW-hr/ %) LHV ________________________
- System capacity factor (% of year available)
- Noise level at 3 m from engine generator skid, dBA ________________________

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2.6 Delivery and installation schedule ____________________

2.7 Experience list of similar applications of engine generators ____________________

3.0 PRICING

Please provide budgetary pricing for the engine generator base scope. ____________________

4.0 OPTION PRICING

Please provide optional pricing for the following items.

a. Tie-in equipment (transformer etc.) if generating at other than 13.8 kV ____________________

b. Gas cleaning equipment ____________________

c. Gas compressing equipment ____________________

d. Gas enriching equipment ____________________

e. Total Freight estimate ____________________

f. Unloading and installation estimate ____________________

g. If proposed, estimated LPG system price ____________________

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PART 1 - GENERAL

PROJECT BACKGROUND

Bechtel is performing a USAID study assessing the economic and technical feasibility of using pig-iron blast furnace gas to fuel internal combustion engine generators for electricity production. The pig iron industries under consideration are located in the state of Minas Gerais, Brazil where there are 104 blast furnaces primarily using charcoal as ore reductor and source of heat. In these industries, approximately 50% of the blast furnace gas (BFG) is used in the process, and the remaining 50% is released into the atmosphere directly or burned in flares.

The objective of the study is to assess the potential of using the excess BFG in a standard internal combustion power generation system design that could be replicated at multiple installations. The objective of this specification is to obtain budgetary information from the most qualified manufacturers (based on similar experience) to support the study. Additionally, the completeness of the response to this request will weigh heavily on the decision of which manufacturer to work with in developing a standard design and ultimately to provide a product for multiple installations.

The BFG at the blast furnace installation is cleaned using dry cyclones and, sometimes spray washers, to meet environmental regulations and to prepare it for use in air heaters. Additional treatment of the BFG is required to remove the remaining particulate matter before the gas can be sent to the internal combustion engine.

1.1 WORK INCLUDED

This specification covers design, fabrication, testing, and delivery of a complete particulate matter removal system including accessories. The equipment shall be a single, completely self-contained, containerized package suitable for minimum field installation, containing the manufacturers standard equipment and systems including the following:

a. All interconnecting ductwork, piping and wiring required for manufacturers proposed layout (sketch included with proposal)

b. Control, protection, and surveillance systems associated with the equipment

c. Local control panel furnished with equipment for controls, indications, and alarms. Startup and shutdown to be performed manually from this panel.

d. Special tools required to install, test, operate, and maintain the equipment.

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1.2 RELATED WORK NOT INCLUDED

a. Unloading and storage at jobsite (provide option quote or estimated requirements for unloading)

b. Installation labor (provide option quote or estimated requirements for installation)

c. Foundations and standard anchor bolts

1.3 TERMINAL POINTS

The equipment shall be containerized to the maximum extent practical. The Buyer's interfaces shall be limited to the following terminal points:

a. Inlet flange for raw BFG and discharge flange for treated BFG.

b. Solids discharge point (if applicable).

c. Process water connection point (if applicable).

d. Process water discharge point (if applicable).

e. Remote control and monitoring (if used by Buyer)- Interfaces shall be at the terminal blocks within the control panel and Seller-supplied terminal boxes.

f. Power connection - Interfaces shall be within the Seller-supplied terminal boxes. The Buyer will supply power to the terminal boxes.

1.4 SUBMITTALS

Submit the following documents with budgetary proposal (typical drawings with hand mark-ups for project specifics or hand sketches are acceptable if equipment specific drawings and information are not available):

a. Outline / arrangement drawings for supplied equipment showing overall dimensions, basic foundation requirements, and weights.

b. System flow diagrams for BFG, process water, etc.

c. Major equipment list.

d. Brief system description.

e. Performance data.

f. Approximate delivery and installation schedule.

PART 2 - DESIGN BASIS

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2.1 Plant Location and Environmental Conditions

a.	Location	Belo Horizonte, Brazil
b.	Elevation	800 meters, msl
c.	Ambient air temperature (average)	21°C
d.	Ambient air temperature (extremes)	0 °C to 37 °C (min and max)

2.2 Blast Furnace Gas Average Conditions

a.	Flow rate:	4,900 Nm^3/hour
b.	Pressure at inlet to gas cleaning equipment:	300 mm H_2O
c.	Temperature at inlet to gas cleaning equipment:	130 °C (max 180 °C)
d.	Dust loading at inlet to gas cleaning equipment:	100 mg/Nm^3
e.	Particle size distribution:	Unknown

f. Average blast furnace dry gas composition (may also contain 3% H_2O).

Component	Volume %
O_2	0
CO_2	16
CO	24
H_2	5
CH_4	1
N_2	54

2.3 Performance

Particulate removal: Minimum 95%. Vendor to state expected performance using available pressure drop, or state pressure drop required.

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APPENDIX C

Specification 21614-

SPECIFICATION

FOR

BLAST FURNACE GAS (BFG)

CARBON DIOXIDE REMOVAL SYSTEM

BECHTEL CORPORATION

GAITHERSBURG, MARYLAND

NO.	DATE	REVISIONS	BY	CHK'D	APPROVALS	
0	11/23/96	Issued for Quote	JN	CLW		

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PROJECT BACKGROUND

Bechtel is performing a USAID study assessing the economic and technical feasibility of using pig-iron blast furnace gas to fuel internal combustion engine generators for electricity production. The pig iron industries under consideration are located in the state of Minas Gerais, Brazil where there are 104 blast furnaces primarily using charcoal as ore reductor and source of heat. In these industries, approximately 50% of the blast furnace gas (BFG) is used in the process, and the remaining 50% is released into the atmosphere directly or burned in flares.

The objective of the study is to assess the potential of using the excess BFG in a standard internal combustion power generation system design that could be replicated at multiple installations. If the process appears viable, it is expected that a prototype system would be installed to confirm the viability.

Currently, the BFG at the blast furnace installation is cleaned using dry cyclones and, sometimes spray washers, to meet environmental regulations and to prepare it for use in air heaters. We are investigating additional treatment of the BFG (filtration or venturi scrubbing) to remove the bulk of the remaining particulate matter before the gas is sent to the internal combustion engine.

CO_2 REMOVAL

The BFG has a very low heating value which is marginal for combustion in an internal combustion engine. We would like to increase its heating value by removal of the bulk of the CO_2. The attached design basis provides the current condition of the BFG. The properties would change somewhat if it is further treated in a filter or venturi.

The blast furnace plant has no steam producing facilities. The BFG that is used in the process is burned in a heat exchanger to indirectly heat air to 1500 °F to be used in the blast furnace. Some of this heated air could be tempered and used to provide any required heat duty for the CO_2 removal.

There is a potential market for food grade CO_2. If it were possible to produce this, it would help offset the cost of the CO_2 removal.

DESIGN BASIS

Plant Location and Environmental Conditions

a. Location	Belo Horizonte, Brazil
b. Elevation	800 meters
c. Barometric pressure:	13.36 psia
d. Ambient air temperature (average)	21°C
e. Ambient air temperature (extremes)	0 °C to 37 °C (min and max)

Blast Furnace Gas Average Conditions

a. Flow rate:	4,900 Nm^3/hour (3050 scfm)
b. Pressure in duct:	300 mm H_2O (0.427 psi)
c. Temperature:	130 °C (max 180 °C)
d. Dust loading:	100 mg/Nm^3 (40 ppm by wt)
e. Particle size distribution:	Unknown

f. Average blast furnace dry gas composition (may also contain 3% H_2O).

Component	Volume %
O_2	0
CO_2	16
CO	24
H_2	5
CH_4	1
N_2	54

Performance

CO_2 removal: Require only bulk removal to avoid high marginal removal cost. 80 to 95% removal is a suggested target.

APPENDIX D

BTeC
BECHTEL TECHNOLOGY & CONSULTING
MEETING NOTES

BTeCMM-003

Location of Meeting: **Belo Horizonte, Brazil**
Date(s) of Meeting: **11/4/96**
Attendees:

USAID: Simkha Palant

Bechtel: C. Wagstaff
J. Newman

CEMIG: Mr. Dimas Costa (Dept Asst)
Mr. Manuel Emilio de Torres (Dept Asst)
Mr. Eduardo Costa Vasconcelos
Ms. Dulce Maria de Castro Rocha Correa de Barros
Mr. Celio Santana
Mr. Paulo Marcos Martins

Recorded by: C. Wagstaff

Purpose of Meeting:

To gain a thorough understanding of the CEMIG & METALSIDER concept to use blast furnace gas (BFG) to produce electricity using internal combustion engines. Additionally, to gather available information required to perform a feasibility assessment of the concept.

Discussion:

State of Minas Gerais:

- 15M Inhabitants
- 5000MW Installed Capacity (98% of 5000MW-Hydro)
- 2nd largest state in gross production and consumption in Brazil

CEMIG (key facts):

Primary functions: Generation, transmission, & distribution of electricity, with some gas distribution and other minor interests.

- 96% of state population served.
- 67% of energy in state consumed by industry.
- Best run and strongest company in the state.
- CEMIG's distribution system is the largest in Latin America.
- Natural gas arrived mid -1996
- 45% State owned
- 25% International
- 30% Others

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Continuously looking for new and renewable energies (wind, solar, biomass and hydro).

Renewable Activities:

PV Systems:

Being used for remote/rural distributed systems.

Wind:

- CEMIG has sixty-six (66) stations for collecting wind data around the state.
- 1000kW Wind plant installed 240 km from Belo Horizonte.

Biomass:

- Cogeneration facilities w/bagasse
- Gasifiers

Bio-digesters:

Several different types are to be used on farms to replace energy and gas requirements.

Microhydro:

Testing installed units for (12 kVA system installed) small farms.

Pig Iron Industry in Minas Gerais (1995):

- Existing companies -- 68 (total in Brazil: 82)
- Producing Companies -- 47 (total in Brazil: 55)
- Existing Blast Furnaces: 124 (total in Brazil: 147)
- All pig iron companies are privately owned.
- Blast Furnace Energy Consumption = 80 kW/t of pig iron
- Blast furnace gas exit temp. = 108-200°C
- NG price ~0.16Rs/m^3

BFG fired in Engines:

- Started w/ idea 3 years ago.
- Experiments started 4-5 months ago with a Ford engine (described as a slow engine).
- Related project underway: Shell Sigami project -- biomass gasifier linked to CTG.
- Now using a new Mercedes engine designed for NG firing w/minor adjustment to accept BFG. Mercedes donated the engine. The generator was a used one from CEMIG.
- No compressor used or required to inject gas into the test engine.
- Both CEMIG and pig iron companies hope this concept can be commercialized: CEMIG would gain distribution capacity with negligible capital outlay; the pig iron companies would produce pig iron more economically and become more competitive with the Chinese.

BTeC
BECHTEL TECHNOLOGY & CONSULTING
MEETING NOTES

BTeCMM-003A

Location of Meeting: **Betim, Brazil (METALSIDER)**
Date(s) of Meeting: **11/5/96**
Attendees:

USAID: Simkha Palant

Bechtel: C. Wagstaff
J. Newman

CEMIG:
Mr. Eduardo Costa Vasconcelos
Ms. Dulce Maria de Castro Rocha Correa de Barros
Mr. Celio Santana

Recorded by: **C. Wagstaff**

Purpose of Meeting: To tour METALSIDER and Sidersa blast furnace facilities and see the installation of the experimental engine firing Blast Furnace Gas (BFG).

Topics reviewed:

1. Design basis
2. Process conditions
3. Operation considerations
4. Enrichment possibilities.

Discussion:

BFG flow rate varies +/- 10% from the values provided.
A gas holder/ accumulator may be required.

DESIGN BASIS STANDARD IC ENGINE:

A) Blast Furnace pig iron capacity = 140 t/day
B) Total gas flow rate = 2100 Nm^3/t
C) % of gas to engine = 40%
% of BFG to process (Glendon-stoves/ air heaters) = 60%
D) Calorific value = base on gas composition below

E) Gas composition (% volume):

	Design Basis	Range on Charcoal	Charcoal/Coke Sidersa
O_2	0	0	1.2
CO_2	16	20-23	18
CO	24	22-26	21.4
H_2	5	3	1.6
CH_4	1	0.4-0.8	12.0
N_2	54	48-52	balance
H_2O		3	

If Glendon efficiency improvements are made, 60% of the BFG would be available to the engines.

Question to CEMIG: Are any sodium, potassium, chlorides or other aggressive components in the BFG that would reduce engine life.

CEMIG response: Dulce to provide us with detailed data when she can obtain it.

CETEC(a gasifier supplier in Minas Gerais)/Thermo equipment/CEMIG has distributed energy production facilities (charcoal gasifiers linked to engine/generator sets) of 180, 35 and 15 kVA, and 15 HP. Their 180 kVA facility supplies a 6000 person town.

Blast Furnace Operation:

- 4-5 years between rebuilds. 3 months to rebuild.
- Operation is continuous at 100% for 24 hr. & 365 days/yr. except rebuilds
- Therefore, average annual capacity factor = 90%
- Particulate removal from the BFG is done with dry cyclones only.

Sidersa tour:

Sidersa has blast furnace capacities of 280, 2 x 140 and 120 t/d. We toured the 280 t/d facility and the following comments apply to that facility.

- 8 years between rebuilds.
- One year to rebuild.
- 60% of BFG available for engine generator electric power production (due to improved efficiency glendons)
- Sidersa has a different blast furnace gas composition than METALSIDER probably due to the subsitution of 20 wt% of the charcoal with petroleum coke.
- They control air flow to the process to maintain the ratio of $CO/CO_2 = 1$
- They also control the ingredient mix to maintain the ratio $CO_2/(CO+CO_2) = 0.5$
- The iron ore is dried before it is fed to the furnace.
- The petroleum coke contains ~ 1% sulfur; charcoal has a very low sulfur content.
- Particulate removal is done with dry cyclones followed by a water spray washer.

BTeC
BECHTEL TECHNOLOGY & CONSULTING
MEETING NOTES

BTeCMM-003B

Location of Meeting: **Belo Horizonte, Brazil**
Date(s) of Meeting: **11/5/96**
Attendees:

USAID:	Simkha Palant
Bechtel:	C. Wagstaff
	J. Newman
CEMIG:	
	Mr. Dimas Costa (Dept Asst)
	Mr. Eduardo Costa Vasconcelos
	Ms. Dulce Maria de Castro Rocha Correa de Barros
	Mr. Celio Santana

Recorded by: **C. Wagstaff**

Purpose of Meeting: To discuss open issues from the tours, additional information required for the feasibility study, and follow-up actions by the participants.

Discussion:

CEMIG provided a process flow diagram of the METALSIDER BFG system including the test equipment with temperature and pressure profiles. Bechtel is to use this information as required to complete the design basis.

Total operating hours for the engines on BFG:

- Ford engine -- 60 hours
- Mercedes -- 10-12 hours

ELECTRICAL INTERCONNECT

Q: What power level do we need to generate at: 460V or 13.8 kV?
A: We can decide what is most cost effective generating at 460 and stepping up to 13.8 or generating at 13.8. CEMIG said we can assume that the existing power feed line at 13.8 kV to the blast furnace facilities can take the generated load backfed through the existing equipment.

CEMIG will provide equipment to meter the electricity supplied to the grid. Study capital cost estimates should cover any transformers, synchronization equipment, relays, protection equipment, etc. required.

ACTIONS:

Bechtel

1. Send requests for additional information (i.e. tariffs on imported equipment) to CEMIG.
2. Bechtel to consider CO_2 removal processes to:.
    - Recover food grade CO_2
    - Increase the calorific value of the BFG.

CEMIG

1. To provide detailed information (quantities of each constituent) on aggressive components (Sodium, Potassium, Chlorides, Fluorides, etc.) that may be in the BFG.
2. To translate and provide applicable environmental regulations.
3. To provide data on BFG flow rates and composition that constitutes a representative range of the BFG available from operating facilities in Brazil.
4. To provide results of testing performed to date on the Ford and Mercedes engines.
5. To provide any diagrams available of the test arrangement.
6. To provide cost and availability of CaO (Quicklime) and $Ca(OH)_2$ (Hydrated Lime).

USAID (Simkha Palant)

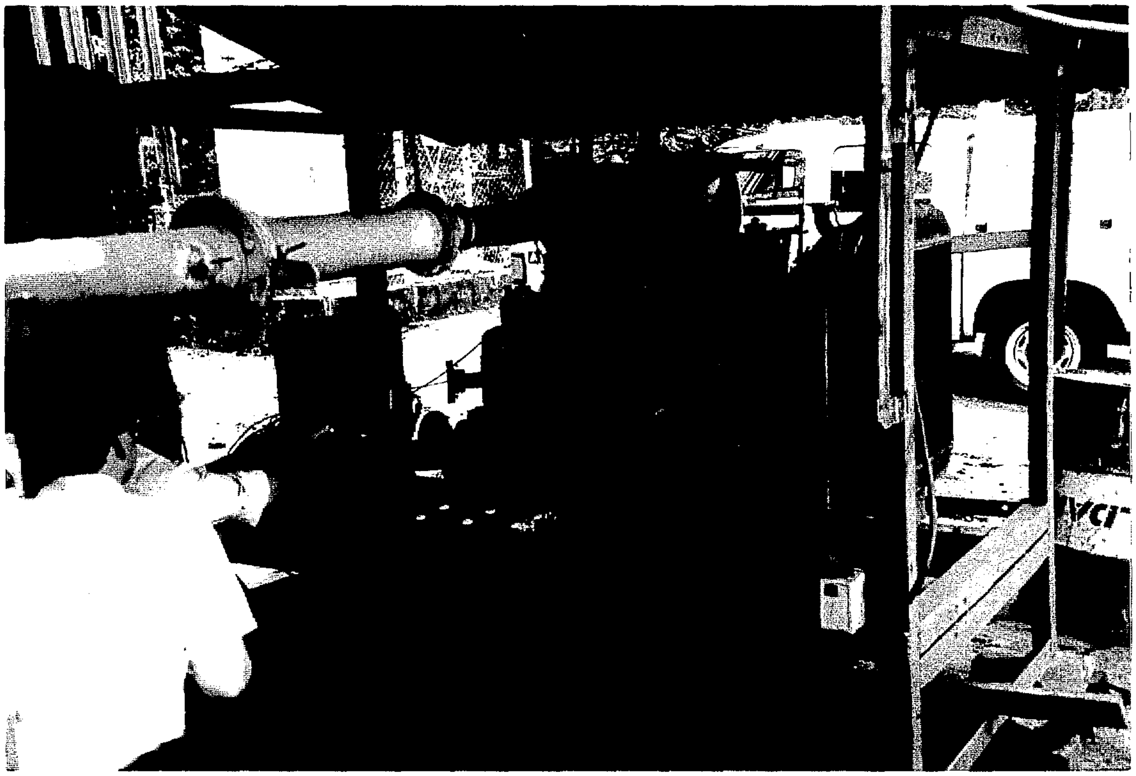
1. To provide a letter stating that we have started the project, summarizing scope, roles and schedule of our efforts to CEMIG.

APPENDIX E

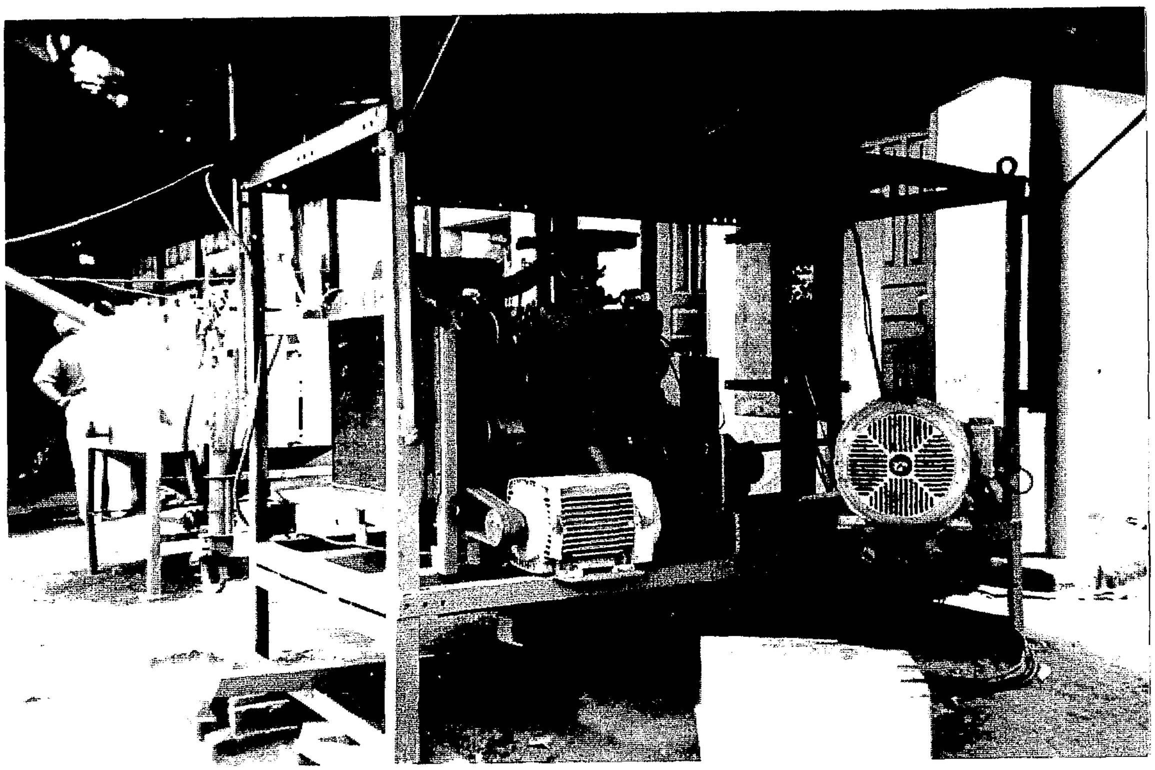
LIST OF PICTURES

1) Metalsider Blast Furnace and Test Engine Arrangement.

2) Metalsider Test Engine Arrangement.



3) Metalsider - BFG/Test Engine Interface.



4) Metalsider - Test Engine.

APPENDIX F

SENSITIVITY ANALYSIS

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Simplified Financial Proforma

Project: **Metalsider power generation, ($US):** (BASE CASE)
Site: **Brazil**

Plant Design and Performance Summary

Rated Plant Power (MWe)	1.343	busbar, mameplate capacity at site
Annual Electricity Production (GWH)	10.88	includes plant capacity factor of *92.50%*

Fuel Requirements and Cost 0

Operations & Maintenance Costs

	Operations	Maintenance	
Fixed Cost (M$/yr)	0.050	0.025	Overhaul spread over 5 years at $125K/unit
Variable Cost ($/kWH)	0.00032	0.004	

Other Operating Costs

Property Insurance	1.0%	of adj. plant cost
Property Tax	0.0%	according to CEMIG this is insignificant
Contrib to Fed	2.65%	of gross revenues

Escalations

	Annual Basis	
Operations	3.00%	labor
Maintenance	3.00%	labor & spare parts
Production Credits	0.00%	
Property Taxes	0.00%	
Property Insurance	1.00%	
Wheeling Fee	0.00%	
Capacity Credit	0.00%	
Subsidy	0.00%	

Income Tax & Incentives

State Income Tax Rate	0.0%	per CEMIG state sales tax (ICMS) is pass through to consumer
Federal Income Tax Rate	23.0%	level of federal tax, per CEMIG, for this level of revenue
Effective Income Tax Rate	23.0%	
No-Tax Holiday Period (years)	0	
Production Based Incentive ($/kWH)	0.000	NA - Production Tax Credit, or, Renewable Energy Production Incentive
Duration of Production Incentive (years)	0	NA - beginning at plant start date
Capital Qualifying for Depreciation	100%	

	Depreciation	
Investment Tax Credit	0%	
Depreciation Schedule Flag	2	(1=half yr. MACRS, 2=Straight Line, 3=User Defined)
Depreciation Period (years)	20	(select only 5, 7,15 or 20 yr for MACRS)

Financial Parameters

Book life (years) 20 from plant start date

	Long-term Debt	Project Equity	
Contribution	70.00%	30.0%	
Cost/Return (ROE)	10.00%	15.7%	
Term (years)	10	20	
Reserve Fund (years of debt service)	1/2	-	capitalized
Interest on Reserve Fund	6.00%	-	additional income to project
Discount rate	12.0%	assumed weighted cost of capital	

Cost Summary (estimated)

EPC Budget Cost (M$)	2.5	*1,862*	*$/kW, specific cost*	
Financing & Development Costs (M$)	0.9	*670*	*$/kW*	*36% of EPC*
EPC, Financing & Dev. Cost (M$)	3.4	*2,532*	*$/kW, supply side*	
Total Adjusted Installed Cost (M$)	**3.4**	***2,532***	*$/kW, investor cost*	

Energy and Power Value

First Year Electricity Cost ($/kWH)	0.0680	negotiated, power purchase
Electricity Escalation	3.000%	negotiated, power purchase
Levelized Energy Cost ($/kWH)	**0.0785**	@ busbar

Debt Coverage

Minimum Debt Coverage 154%

Depreciation 20 Years

Interest Rate (%)	Term (years)	1st Year Energy Cost (cents/Kwh)	LEC (cents/Kwh)	Min. Debt Coverage (%)	ROE (%)
12.5%	7	.068	.0785	111	11.1
		.073	.0843	121	14.9
	10	.068	.0785	138	11.9
		.071	.082	146	15.1
	12	.068	.0785	152	16.0
		.067	.0774	149	14.9
10%	7	.068	.0785	121	13.3
		.0705	.0814	126	15.2
BASE	10	.068	.0785	154	15.7
	12	.068	.0785	172	19.9
		.064	.0739	159	15.6
8.5%	7	.068	.0785	127	14.6
		.069	.0797	130	15.3
	10	.068	.0785	165	17.8
		.066	.0762	159	15.7
	12	.068	.0785	185	22.0
		.061	.0704	161	14.5
		.062	.0716	165	15.6

Depreciation 15 Years

Interest Rate (%)	Term (years)	1st Year Energy Cost (cents/Kwh)	LEC (cents/Kwh)	Min. Debt Coverage (%)	ROE (%)
12.5%	7	.068	.0785	111	12.2
		.072	.0831	119	15.2
	10	.068	.0785	138	13.4
		.07	.0808	143	15.5
		.0695	.0803	142	15.0
	12	.068	.0785	152	17.5
		.0657	.0759	145	15.0
		.066	.0762	146	15.3
10%	7	.068	.0785	121	14.4
		.069	.0797	123	15.1
	10	.068	.0785	154	17.1
		.066	.0762	148	15.0
	12	.068	.0785	172	21.3
		.062	.0716	153	14.9
		.0621	.0717	153	15.0
8.5%	7	.068	.0785	127	15.7
		.067	.0774	125	14.9
		.0672	.0776	126	15.0
	10	.068	.0785	165	19.2
		.064	.0774	153	15.0
			.0776		
	12	.068	.0785	185	23.5
		.060	.0693	158	14.9

Depreciation 10 Years

Interest Rate (%)	Term (years)	1st Year Energy Cost (cents/Kwh)	LEC (cents/Kwh)	Min. Debt Coverage (%)	ROE (%)
12.5%	7	.068	.0785	111	14.3
		.069	.0797	113	15.1
	10	.067	.0774	136	15.3
		.068	.0785	138	16.4
	12	.068	.0785	152	20.5
		.063	.0727	138	15.1
10%	7	.068	.0785	121	16.6
		.066	.0762	116	15.0
	10	.068	.0785	154	20
		.0635	.0733	141	15.3
		.063	.0727	140	14.8
	12	.068	.0785	172	24.2
		.0595	.0687	145	15.2
		.059	.0681	143	14.6
8.5%	7	.068	.0785	127	17.9
		.064	.0739	118	14.7
		.0645	.0745	119	15.1
	10	.068	.0785	165	22.1
		.061	.0704	144	14.8
		.062	.0716	147	15.9
	12	.068	.0785	185	26.2
		.0575	.0664	149	15.2