NREL
NATIONAL RENEWABLE ENERGY LABORATORY






Biomass Gasification Technology Assessment

Consolidated Report

M. Worley and J. Yale
Harris Group Inc.
Atlanta, Georgia

NREL Technical Monitor: Abhijit Dutta

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November 2012

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SECTION 1
EXECUTIVE SUMMARY

Harris Group Inc. (HGI) was commissioned by the National Renewable Energy Laboratory (NREL) in Golden, Colorado to assess gasification and tar reforming technologies. The technology assessments assist NREL in understanding the economic, technical, and global impacts of renewable technologies. They also provide direction, focus, and support for the development and commercialization of various biomass conversion technologies. The economic feasibility of the biomass technologies, as revealed by these assessments, provide important information for governments, regulators, and private sector entities in developing projects.

The goal of the technology assessments has been to solicit and review the technical and performance data of gasifier systems and develop preliminary capital cost estimates for the core equipment. Specifically, the assessments focused on gasification and tar reforming technologies that are capable of producing a syngas suitable for further treatment and conversion to liquid fuels. In order to improve confidence in the predicted economics of these technologies, a thorough understanding of the basic capital cost and engineering requirements for gasification and tar reforming technologies was necessary. These assessments can be used by NREL to guide and supplement their research and development efforts.

As expected, it was very difficult to obtain detailed information from gasification and tar reforming technology vendors. Most vendors were not interested in sharing confidential cost or engineering information for a study of this nature. However, HGI managed to gather sufficient information to analyze three gasification and tar reforming systems as follows.

- **Technology #1**
  - Gasifier – feed rate of 1,000 oven dry metric tons/day of wood residue composed of wood chips and bark, using oxygen blown autothermal (partial oxidation) bubbling fluidized bed design.

- Tar Reformer – reactor vessel filled with solid catalyst blocks designed to crack tars. Oxygen blown for partial combustion of syngas to provide heat.

- Total Project Investment Cost - $ 70,590,000 (2011 dollars).

- **Technology #2**

  - Gasifier - feed rate of 1,000 oven dry metric tons/day of wood residue composed of wood chips and bark, using allothermal (indirect heating) circulating fluidized bed design. Heating of bed media occurs in a separate combustor by combustion of char with air.

  - Tar Reformer – allothermal bubbling fluidized bed design.

  - Total Project Investment Cost - $ 59,700,000 (2011 dollars).

- **Technology #3**

  - Gasifier - feed rate of 1,000 oven dry metric tons/day of wood residue composed of wood chips and bark, using oxygen blown autothermal (partial oxidation) bubbling fluidized bed design.

  - Tar Reformer - unknown technology.

  - Total Project Investment Cost - $ 70,720,000 (2011 dollars).

This report summarizes the equipment, general arrangement of the equipment, operating characteristics and operating severity for each technology. The order of magnitude capital cost estimates are supported by a basis-of-estimate write-up, which is also included in this report.

This report also includes Microsoft Excel workbook models, which can be used to design and price the following systems:

- CFB gasifier and tar reforming system with an allothermal circulating fluid bed gasification system and an allothermal circulating fluid bed syngas reforming system

- BFB gasifier and cyclone system

- High pressure biomass feed system

- Low pressure biomass feed system

The models can be used to analyze various operating capacities and pressures. Each model produces a material balance, equipment list, capital cost estimate, equipment drawings and preliminary general arrangement drawings. Example outputs of each model are included in the Appendices.

A Capital Cost Comparison Table is included in Appendix I, which compares the order of magnitude cost estimates from the three gasification technologies with detailed cost estimates from combinations of the Microsoft Excel models.

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SECTION 2
INTRODUCTION

1. GENERAL

The National Bioenergy Center (NBC) supports the science and technology goals of the U.S. Department of Energy (DOE) Biomass Program. NBC advances technology for producing liquid fuels from biomass. Integrated systems analyses, techno economic analyses, and life cycle assessments (LCAs) are essential to the Center's research and development efforts. Analysis activities provide an understanding of the economic, technical, and global impacts of renewable technologies. These analyses also provide direction, focus, and support for the development and commercialization of various biomass conversion technologies. The economic feasibility and environmental benefits of biomass technologies revealed by these analyses are useful for the government, regulators, and the private sector.

The National Renewable Energy Laboratory (NREL) recently published several studies on thermochemical conversion of biomass for the production of ethanol via gasification. These studies include:

- "Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass" (NREL/TP-510-41168) detailing the production of ethanol via indirect gasification of biomass based on a Battelle Columbus Laboratory (BCL) gasifier design.

- "Thermochemical Ethanol via Direct Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass" (NREL/TP-510-45913) describing the production of ethanol via direct gasification of biomass using an Institute of Gas Technology (IGT) gasifier design.

- "Techno-economics of the Production of Mixed Alcohols from Lignocellulosic Biomass via High Temperature Gasification", (Environmental Progress and Sustainable Energy. Vol. 29(2), July 2010; pp. 163-174.) describing the production of ethanol via entrained flow slagging gasification of biomass.

These reports demonstrate that there are great opportunities to apply various gasifier technologies in the conversion of biomass to syngas for the production of renewable fuels. Each of these reports shows that a substantial portion of a project's capital cost is attributable to the gasifier and that the overall project cost increases with gasifier design and operational complexity. The cost values used in these reports for the gasifier economics are based on the small amount of data available in the literature and are often cited as being out of date relative to current technology. In order to improve confidence in the predicted economics of these technologies, a thorough understanding of the basic capital cost and engineering requirements for gasifiers is necessary.

In addition to studying gasification technologies, four Microsoft Excel models were also created to help NREL with the development of detailed capital cost estimates for gasification systems of various capacities and operating conditions.

2. TECHNOLOGIES STUDIED

As expected, it was very difficult to obtain detailed information from gasification and tar reforming technology vendors. Most vendors were not interested in sharing confidential cost or engineering information for a study of this nature. However, sufficient information was gathered to analyze three gasification and tar reforming systems listed below.

2.1. Technology #1

- Gasifier - direct or autothermal bubbling fluidized bed design.
- Tar Reformer - solid (blocks) catalyst filled reactor design.

2.2. Technology #2

- Gasifier - indirect or allothermal circulating fluidized bed design.
- Tar Reformer - bubbling fluidized bed design.

2.3. Technology #3

- Gasifier - direct or autothermal bubbling fluidized bed design.
- Tar Reformer – design not revealed by vendor.

3. STUDY BASIS

3.1. Feedstock Basis

Each of the reviewed technologies was adjusted to the same feedstock tonnage basis so that practical comparisons could be made. This common basis is also considered to be the "nth plant" design. The typical definition and understanding of the "nth plant" is a plant utilizing technology that is considered to be mature in nature and is both operationally and economically optimized. In the case of cellulosic ethanol, HGI projects construction of such a plant to be 10+ years in the future, assuming that a feasible and viable economic market is developed.

The common basis was determined to be a gasifier feed rate of 1,000 metric tons/day of dry cellulosic biomass. The feedstock was further limited to only wood residue composed of wood chips and bark. The basis was limited to wood because vendors are most experienced with woody feedstocks, and a great amount of research data is available for those feedstocks. There are, however, many other cellulosic biomass feedstocks that are viable with the reviewed technologies. Feedstock flexibility is discussed further in Section 4 of this report. A biomass moisture content range of 10-20% was also assumed as part of the basis.

A major objective in choosing the production basis was to select a feedstock capacity that could be processed in a single train consisting of separate gasifier and tar reformer reactors/vessels. Such a configuration allows the design to take advantage of economies of scale and lends itself to more economical methods of fabrication and construction. In addition, the stated basis is within the generally agreed upon range for suitable feedstock handling systems and lends itself to many different types of cellulosic feedstocks. A design where only virgin wood and/or pelletized or briquetted cellulosic material is consumed would allow a slightly larger single reactor system to be feasible. Flexibility in feedstock type and density are essential in accommodating unknown future markets. A feed rate of 1,000 dry metric tons/day is also considered to be more manageable with current mature designs of available feedstock handling equipment. A 1,000 dry metric tons/day system is also considered to be near the maximum size that could be modularized and/or shop fabricated. Modularized systems lend themselves to potential cost savings over stick built systems erected in the field.

Moisture content of the feedstock is also important for many reasons when considering liquid fuels production in a GTL plant. Typically, drying biomass to 10-20% moisture content is considered the optimum for minimizing the size and cost of the entire GTL plant. Moisture in the biomass has several negative impacts on the process. First, consumption of energy for drying (vaporization of the moisture) lowers the reactor temperature and results in the production of lower energy syngas and lower yields of syngas. Second, moisture in the syngas increases the volumetric flow of syngas, requiring larger downstream equipment such as; piping, cyclones, vessels, HRSG's, baghouses, synthesis reactors, etc., and increasing the gasifier system capital cost. Third, water vapor reduces the volumetric heat content of syngas and causes the gas to become progressively harder to burn as the moisture content is increased. Note that the third, moisture impact, only applies to a gas being produced for direct combustion in equipment or engines. Also note that the biomass drying and associated air emissions equipment that is required upstream of the gasification equipment also greatly impacts the capital cost of the complete plant. A cost benefit study is recommended to determine the optimum target biomass moisture content and answer the many questions about process factors and capital cost implications.

The feedstock particle size on the other hand is not strictly limited to a common basis, as different technologies require and/or operate more efficiently at various particle size distributions. Generally, the speed at which fuel particles heat up (i.e. heat transfer rate) decreases as particle size increases, resulting in the production of more char and less tar. Bed utilization and uniformity, for instance, is important for efficient and consistent operation in a bubbling fluid bed reactor. In many cases, bubbling fluid bed vendors target a biomass size of approximately 2.0 to 2.5" minus, with a limit on the amount of smaller material and fines content. On the other hand, circulating fluid bed reactors typically need to maintain a minimum transport velocity, which is a function of the size and density of the feedstock particles with a similar target biomass size of approximately 2.0 to 2.5" minus. A smaller biomass size can benefit some technologies; however, capital and operating costs increase with reduced material size. Generally, the design of the feedstock handling and feeding equipment has a large, if not overriding impact on the target size of the biomass feedstock.

3.2. Air Verses Oxygen Blown Gasifier Operation

This study was designed to investigate biomass gasification and tar reforming technologies that are capable of producing synthesis gas (syngas) suitable for biological or catalytic conversion to transportation fuels in a gas to liquids plant (GTL). Syngas is defined as a gas mixture that contains varying amounts of carbon monoxide and hydrogen, and very often some carbon dioxide, water, light hydrocarbons (methane, ethane, etc.) and tars. Producing syngas that will ultimately be converted to liquid fuels typically requires a gasifier that utilizes oxygen and/or steam as the oxidant. Air can also be used as the oxidant and means of fluidization; however, in order to supply the required amount of oxygen from air, a large volume of nitrogen will be introduced, which dilutes the syngas and reduces the concentration of hydrogen (H_2) and carbon monoxide (CO), thereby reducing the syngas heat value. In addition, processing a dilute syngas stream requires much larger and more expensive downstream equipment. Typically, a low heat value, dilute syngas is referred to as a producer gas (pgas) and is only used as a fuel gas for repowering natural gas fired unit operations or engines. Syngas, on the other hand, is better suited for conversion to liquid fuels and chemicals.

The higher heating value (HHV) of syngas depends on the biomass type, biomass moisture, combustion air/oxygen temperature and the reactor configuration/type. Typical data is as follows:

- Air blown autothermal or direct gasifiers produce a pgas with an HHV of 140-160 Btu/scf, with a possible range of 120-210 Btu/scf.

- O_2 /steam blown autothermal or direct gasifiers produce a syngas with an HHV of 350-400 Btu/scf, with a possible range of 320-560 Btu/scf.

- Allothermal or indirect gasifiers produce a syngas with a heat value typically around the higher range of the O_2 /steam blown autothermal configuration.

Conversion of H_2 and CO to liquid hydrocarbons requires either a catalyst (Fischer–Tropsch process) or a biological process (INEOS, Coskata, Inc., etc.). The H_2 to CO ratio of the syngas is also of particular importance to the syngas conversion process, although a variety of syngas compositions can be used.

3.3. Reactor Type

Only bubbling fluid bed and circulating fluid bed designs were reviewed for this report. Fixed bed and high temperature slagging gasifiers were not reviewed at this time.

Product gases from fixed-bed versus fluidized bed gasifier configurations vary significantly. Fixed-bed gasifiers are relatively easy to design and operate and are best suited for small to medium-scale applications with thermal requirements of up to a few mega watts thermal (MWt). For large scale applications, fixed bed gasifiers may encounter problems with bridging of the biomass feedstock and non-uniform bed temperatures. Bridging leads to uneven gas flow, while non-uniform bed temperature may lead to hot spots and ash deformation and slagging. Large scale applications are also susceptible to temperature variations throughout the gasifier as a result of poor mixing in the reaction zone. Most fixed-bed gasifiers are air-blown and produce low-energy pgas, although oxygen-blown designs have been tested. HGI's assessment indicates that fixed-bed gasifiers are not ideal for producing a syngas of sufficient quality for conversion to liquid hydrocarbons, and such gasifier technology was not included in the study.

Similarly, high temperature slagging gasifier technologies were not included in the study due to the cost prohibitive nature and the limited availability of information and resources for processing biomass with those technologies.

Pressurized gasification systems lend themselves to economical syngas production and can also be more flexible in production turndown depending on the reactor design. Typically this is the case for both a pressurized bubbling and circulating fluidized bed reactor, while the flexibility of an atmospheric fluidized bed reactor is typically limited to narrower pressure and production ranges. In summary, both designs are well suited for pressurized syngas production. Pressurized designs require more costly reactors, but the downstream equipment (gas cleanup equipment, heat exchangers, synthesis reactors, etc.) will consist of fewer and less expensive components.

3.4. Tar Reformer

In addition to the expense of the gasifier, another key contribution to the capital cost for biomass GTL projects is the need for a tar reformer. The three technologies that were reviewed in this study each included a different tar reformer technology, thus three options were analyzed and are discussed as part of the integrated gasification systems. Because Fischer-Tropsch catalysts and biological matter are sensitive to poisoning by sulfur-containing compounds as well as other contaminants, further syngas cleanup beyond tar reforming is required prior to conversion to liquid hydrocarbons. Note that while this assessment investigates tar reforming as an initial gas cleanup step, it does not include an investigation of further gas cleanup or polishing technologies.

Tar reforming technologies are utilized to breakdown or decompose tars and heavy hydrocarbons into H_2 and CO. This reaction increases the H_2/CO ratio of the syngas and reduces or eliminates tar condensation in downstream process equipment. Tar reforming can be thermally and/or catalytically driven. Thermal biomass tar reformer designs are typically fluid bed or fixed bed type. Catalytic tar reformers are filled with heated loose catalyst material or catalyst block material and can be fixed or fluid bed designs.

4. STUDY OBJECTIVES

The objectives of this study were twofold. The first objective was to review technical and performance data, determine the engineering requirements of applicable gasifier systems and summarize those findings. The second goal was to prepare preliminary capital cost estimates for the core gasification system equipment (Technologies #1, #2 & #3). The core equipment includes but is not limited to the following items:

- Biomass feed system associated with the gasifier (the feedstock receiving, handling and pre-processing equipment is not included)
- Gasifier reactor(s)
- Tar reforming system reactor(s)
- Auxiliary equipment as follows:
    - Cyclones
    - Ash handling equipment
    - Bed and/or sorbent media makeup equipment
    - Startup equipment
    - Blowers/compressors
    - Air heaters
    - Combustion equipment
    - Air separation equipment (oxygen and nitrogen production)

Secondary equipment (e.g. control systems) and all contractor and owner supplied materials (e.g. process instrumentation, cabling, concrete, structural steel, buildings, piping etc.) are included in the capital costs estimates. For further information and details on the cost estimates, see Section 5.

Note that this technology assessment not only estimates the current capital costs for the gasification and tar reforming technologies, but it also includes a brief discussion of the capital cost implications concerning “nth plant” designs.

5. MODELING AND DETAILED CAPITAL COST ESTIMATES

5.1. Model Design

NREL's need for a technology model to analyze the impact of gasification system design on capital costs for various design parameters (e.g. system capacity, reactor pressures, design temperatures, etc.) led to the development of four Microsoft Excel models.

5.1.1. CFB Gasifier Model

This model is based on a circulating fluid bed design with an allothermal circulating fluid bed gasification system and an allothermal circulating fluid bed syngas reforming system. This particular gasification process includes four fluid bed reactors: a gasifier reactor and a char combustion reactor in the gasifying loop and a syngas reformer reactor and syngas reformer bed media heating reactor in the reforming loop. The model does not include biomass feed equipment.

5.1.2. BFB Gasifier Model

This model is based on a bubbling fluid bed design with an autothermal bubbling fluid bed gasification system. This particular gasification process includes a single fluid bed reactor and a single syngas cyclone separator for removing particulates from syngas. The model does not include a syngas reforming system or biomass feed equipment.

5.1.3. High Pressure Biomass Feed Model

This model is based on a two bin design with a lock hopper as the first bin and a metering bin as the second bin.

5.1.4. Low Pressure Biomass Feed Model

This model is based on a single metering bin design with a rotary valve providing the pressure lock between the metering bin and the gasifier.

5.2. Model Outputs

From a set of input parameters entered into Design Criteria Input Tables (Excel), the models produce the following output documents:

- Material Balance (Excel)
- Material Balance Flow Diagrams (Excel)

- Equipment List (Excel)
- Equipment Drawings (Excel)
- Drawing List (Excel)
- Detailed Capital Cost Estimate (Excel)

The following documents are also produced, but they do not automatically change when changes are made to the Excel model.

- Process Flow Diagram (AutoCAD)
- General Arrangement Drawing (AutoCAD)
- Gasification/Syngas Reforming Building Isometric Drawing (AutoCAD)
- Gasification/Syngas Reforming Building Elevation Drawings (AutoCAD)

6. CAPITAL COST COMPARISONS

A Capital Cost Comparison Table is included in Appendix I, which compares the order of magnitude cost estimates from the three gasification technologies with detailed cost estimates from combinations of the Microsoft Excel models.

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SECTION 3
TECHNOLOGY DESCRIPTIONS

1. GASIFIER ISLAND – TECHNOLOGY #1

1.1. General

The Technology #1 gasifier island consists of a pressurized, directly heated biomass gasification system capable of producing a synthesis gas (syngas) that can be converted to liquid fuels via catalytic or biological processes. This particular gasification process employs a single, bubbling fluid bed reactor for gasifying biomass with oxygen to produce syngas. A catalyst filled, fixed bed reactor is used for tar reformation. The island includes a biomass handling and feed system, a gasifier, a tar reformer, a bed media handling and feed system, an oxygen handling and injection system, and an ash removal system.

The gasifier system is a direct or autothermal operation, meaning the energy used for heating and maintaining the gasification reaction temperature is supplied by the combustion of a portion of the biomass material processed.

The gasifier is designed to handle a variety of biomass feedstocks of varying size and moisture contents. The gasifier feed rate is 1,000 oven dry metric tons/day of biomass (wood residue composed of wood chips and bark) with a 20% moisture content and a higher heat value (HHV) of approximately 8,458 Btu/dry lb.

Oxygen is added to the gasifier to gasify the biomass feedstock and form hydrogen and carbon monoxide. Dolomite bed material, medium pressure steam, and recycled syngas are also added with the biomass to form and stabilize the bubbling fluid bed.

The gasifier is operated at a temperature of approximately 1,560 °F and a pressure of 130 PSIG to produce 172,000 lbs/hr of wet syngas. Note that the syngas production from the island (tar reformer outlet) is actually greater than 172,000 lbs/hr due to the additional oxygen and steam added to the tar reformer.

A flow diagram depicting the system is located in Appendix A.

1.2. Biomass Storage and Metering System

The gasifier island begins with a biomass handling system. Dried biomass is first deposited on an owner-supplied distribution conveyor, which transfers the biomass to three parallel lines for pressurization and metering to the gasifier. Each line is composed of atmospheric weigh bin storage silos, lock hoppers, storage bins and screw conveyors. Each storage silo is equipped with a live bottom screw to convey biomass to the center of the silo for discharge to a reversing conveyor beneath the silo. The three reversing conveyors each feed a pair of lock hopper bins (a total of 6 bins) to permit pressurization of the biomass to the pressure of the gasifier. Nitrogen gas is used to pressurize the lock hoppers, prior to exposing them to the gasifier pressure, and prevent hot gases from entering the lock hoppers.

Each pair of lock hoppers is staged to allow the filling of one while the second one is being discharged to a metering bin. To facilitate an automated operation, the lock hoppers are equipped with pneumatic inlet and outlet slide gates. Although lock hopper staging is a batch operation, the staging frequency can be increased or decreased to keep an operating level in the much larger downstream surge hoppers. The three surge hoppers are equipped with bottom discharge screw conveyors for separately metering biomass to each of the three gasifier in-feed screws.

The lock hoppers, surge hoppers, discharge metering screws and gasifier in-feed screws are designed for a maximum allowable working pressure (MAWP) of 130 PSIG, the operating pressure of the gasifier.

All other biomass unloading, handling and storage equipment is owner-supplied. These items include but are not limited to truck unloading, screening/sizing, as received storage, drying, dryer air emissions abatement equipment, dry storage, and all conveyance and transport equipment prior to the weigh bin storage silos.

1.3. Bed Media Storage and Metering System

Dolomite is used to form and stabilize the gasifier's bubbling fluid bed. Dolomite is delivered by truck or railcar to the plant site where it is pneumatically conveyed to a bed material storage silo. Bed material is transferred by gravity from the storage silo to a weigh hopper and from there to a lock hopper for pressurization to the gasifier pressure. Nitrogen gas is used to pressurize the lock hopper to prevent hot gases from entering the lock hopper from the gasifier. The lock hopper is equipped with a bottom discharge screw conveyor for metering bed material to one of the gasifier in-feed screws.

1.4. Air Separation Plant

Equipment for the supply of oxygen and nitrogen are not part of the vendor's scope of supply. An oxygen rich gas stream can be supplied by either an air separation plant (Vacuum-Pressure Swing Adsorption (VPSA) or cryogenic) or a liquid oxygen system using purchased liquid oxygen. For the purposes of this report, it was assumed that a VPSA air separation plant is used to produce both oxygen and nitrogen. The air separation plant, oxygen receiver, oxygen booster compressor and nitrogen receiver are included in the owner's scope of supply.

1.4.1. Oxygen Gas Supply System

An oxygen rich gas stream, containing 90-92% oxygen by weight, is needed to combust biomass in the gasifier. Oxygen rich gas from the oxygen receiver at the air separation plant is pressurized by the oxygen booster compressor to about 180 PSIG and is stored in a vendor-supplied surge tank. Oxygen from the surge tank is routed through a vendor-supplied heat exchanger, where medium pressure steam is used to indirectly pre-heat the oxygen gas stream to approximately 390 °F for introduction to the gasifier.

1.4.2. Inert Gas (Nitrogen) Supply System

Nitrogen gas is used throughout the gasifier island for the following purposes:

Biomass storage and metering system pressurization.

Dolomite bed material storage and metering system pressurization.

Ash handling systems pressurization.

Fire suppression and emergency shutdown systems.

Instrument gas.

A nitrogen booster compressor and two nitrogen storage tanks are included as part of the vendor's scope of supply. An emergency booster compressor and high pressure nitrogen storage tank are also included for the safety systems.

1.5. Steam Supply System

Medium pressure saturated steam is supplied by the owner at a pressure of approximately 200 PSIG for oxygen heating, startup heating and gasifier operation.

1.6. Cooling Water Supply System

A closed loop high pressure cooling water system is included as part of the gasifier package. Owner-supplied cooling water is required to indirectly cool the high pressure cooling water system. The system includes two high pressure circulation pumps, an expansion tank, and a heat exchanger.

1.7. Gasifier

The gasifier partially combusts biomass feedstock with oxygen to form hydrogen and carbon monoxide. The gasifier operates at a temperature of approximately 1,560 °F and a pressure of 130 PSIG. Due to the high combustion temperature, the gasifier vessel is constructed with a refractory lining to protect the integrity of the steel shell. Dolomite, medium pressure steam and a recycled portion of syngas and ash are also introduced into the bottom of the gasifier to form and stabilize the bubbling fluid bed. The upper portion of the gasifier vessel allows the bed material and syngas to separate, reducing the amount of solids carryover with the syngas.

As described above, three in-feed screw conveyors are used to feed dried biomass and dolomite bed material to the bottom of the gasifier. Since the pressurized in-feed screw conveyors are exposed to hot gases from the gasifier, they are designed with water cooling coils for protection.

Syngas is discharged at the top of the gasifier vessel and routed to the gasifier cyclone for particulate (char, bed material, un-reacted biomass, etc.) recovery.

1.8. Ash/Char Discharge System

A portion of the dolomite bed material and ash from fuel combustion are periodically removed from the bottom of the gasifier and discharged to an ash removal screw conveyor. The water cooled screw conveyor is exposed to the gasifier pressure and discharges dolomite and ash to a lock hopper where the material is depressurized. The dolomite and ash then discharge to a conveyor hopper for pneumatic transfer to an ash storage silo where material is accumulated for disposal.

1.9. Gasifier and Tar Reformer Startup Burners

The gasifier is equipped with a light fuel oil (LFO) burner for pre-heating the gasifier pressure vessel's refractory lining and other downstream systems prior to introduction of the biomass. The tar reformer is also equipped with a light fuel oil burner at the top of the vessel for pre-heating purposes as well. Note that natural gas can be substituted for LFO with a modification in burner design. The LFO system also includes a booster pump and piping.

An air system, including an air compressor and an air receiver tank, is also included for supplying combustion air to the startup burners.

1.10. Dust Collection Cyclone

Syngas exits the gasifier and is routed through a refractory lined cyclone separator vessel where ash and entrained bed material are removed. The bulk of the entrained particulate is removed from the syngas in the cyclone. The cyclone is efficient enough to keep particulate concentrations below a level acceptable for the tar reformer. The particulate dust is returned through the cyclone dropleg to the fluidized bed of the gasifier for further carbon conversion.

1.11. Tar Reformer

The tar reformer utilizes a catalyst to decompose tars and heavy hydrocarbons into hydrogen and carbon monoxide. Without this decomposition the tars and heavy hydrocarbons in the syngas will condense as the syngas is cooled in the down-stream process equipment. In addition, the tar reformer increases the hydrogen/carbon monoxide ratio for optimal conversion.

The tar reformer is a refractory lined steel vessel equipped with catalyst blocks. The catalyst is a noble metal or a nickel enhanced material. Syngas is routed to the top of the vessel and flows down through the catalyst blocks. Oxygen and steam are added to the tar reformer at several locations along the flow path to enhance the syngas composition and achieve optimum performance in the reformer.

Medium pressure steam is also piped to nozzles on the tar reformer vessel to provide pulsing steam for removal of ash dust from channels in the catalyst blocks.

Syngas is routed from the tar reformer to downstream heat recovery and gas cleanup unit operations. The tar reformer outlet is the boundary of the vendor's scope of supply.

1.12. Gasifier Control System

The gasifier system includes a digital distributed control system (DCS), which integrates main logic, human interface, field bus, and distributed I/O devices. All critical systems are double protected. The control system equipment and I/O cabinets are located in an electrical room. A data collection and reporting system is also included with the control system.

All field instruments for measuring pressure, temperature, flow, etc. are included. In addition, special instruments such as various gas analysis devices and special reactor bed level control devices are also included.

An instrument air supply system is not included in the vendor's scope of supply. However, since excess nitrogen is available from the air separation plant (nitrogen receiver), nitrogen is used in place of instrument air. An instrument air tank included in the vendor's scope of supply is converted to a nitrogen tank for surge capacity.

1.13. Miscellaneous Systems

1.13.1. Seal Water System

The seal water system includes both low pressure and high pressure sub-systems. The high pressure seal water sub-system includes a seal water tank, two seal water pumps, a seal water cooling heat exchanger and associated piping. Process water is used for makeup to the seal water system to account for any losses or blowdown.

1.13.2. Process Air System

A compressed air system for general process needs is not included in the vendor's scope of supply. However, an owner-supplied system is included and is comprised of an air compressor, an air dryer and a receiver. The process air receiver supplies pressurized air for general plant needs and is also used to supply compressed air to the air separation plant for O_2 and N_2 generation.

1.13.3. Flare Stack

During start-ups, shutdowns and emergency stop events, syngas is routed to an owner-supplied flare stack for incineration and exhaust to the atmosphere.

1.13.4. Piping and Valves

Various gas piping is included in the vendor's scope of supply, consisting of items such as the gasifier to cyclone line, the cyclone to tar reformer line, and the cyclone dropleg return line to the gasifier. All gas piping is refractory lined.

Most of the process piping is included in the vendor's scope of supply, consisting of services such as inert gas, LFO, instrument air, oxygen, recycle gas, HP cooling water, HP seal water, HP feed water, and dolomite pneumatic conveying. Note that distribution manifolds and control valves are also included. All hot process piping is insulated.

All process valves are included.

1.13.5. Electrical

All electrical systems are included in the vendor's scope of supply, consisting of items such as a distribution transformer, low voltage switch-gear, power cabling, control cabling, cable ways, frequency converters, grounding systems, UPS, motors and AC-drives, and wiring to furnish power to automation and process protection systems.

An electrical room to house the switch gear and automation equipment is part of the owner's scope of supply. The electrical room will be equipped with ventilation, air conditioning and filtering.

1.13.6. Building/Structural

The main process equipment is located in an owner-supplied steel building that includes all structural components as well as access to all equipment. The building sits on a reinforced concrete floor with all other elevated floors constructed from steel. The building also includes an elevator, two staircases, three 10-ton cranes, and a hoist shaft. Pipe bridges, platforms and steel structure as related to equipment support are vendor supplied.

1.13.7. Gasifier Safety Systems

All critical gasifier system components, valves and equipment are protected by a safety logic system that is separate from the process control system.

1.13.8. Burner Safety Systems

The startup burners on the gasifier and tar reformer are equipped with flame safety systems which are separate from the process control system.

1.14. Utility Requirements

The utilities required for operation are as follows:

Oxygen at 90-92% purity, 68 °F and 210 PSIG.

Nitrogen at 98% purity, 68 °F and 210 PSIG.

Instrument air at 68 °F and 130 PSIG, assume nitrogen.

Light fuel oil at 75 PSIG (note that natural gas can be substituted with a modification in burner design).

Medium pressure steam at approximatley 200 PSIG, saturated.

Cooling water at 115 °F and approximatley 45 PSIG.

Process water for makeup to high pressure seal water system, hose stations and other users (temperature and pressure is unknown).

Potable water for emergency eye wash and showers.

Ambient air.

2. GASIFIER ISLAND – TECHNOLOGY #2

2.1. General

The Technology #2 gasifier island consists of an atmospheric, indirectly heated biomass gasifier system capable of producing a syngas that can be converted to liquid fuels via catalytic or biological processes. This particular gasification process uses three fluid bed reactors: a gasification reactor, a gas conditioning reactor (tar reformer) and a combustion reactor (heat source). The gasification and combustion reactors employ circulating fluid beds, while the gas conditioning reactor uses a bubbling fluid bed. The island includes a biomass handling and feed system, a gasifier, a combustion reactor, a tar reformer, a bed media handling and feed system, a combustion air system, an oxygen handling and injection system, and an ash removal system.

The gasifier system is an indirect or allothermal operation, meaning the energy used for heating and maintaining the gasification reaction temperature is applied indirectly by heating the bed material from the combustion of the char in the combustion reactor.

The gasifier is designed to handle a variety of biomass feedstocks of varying size and moisture content. The gasifier feed rate is 1,000 metric tons/day of dry biomass (wood residue composed of wood chips and bark) with a 10% moisture content. The chip size is specified as 2.0 inch minus with no fines specification.

Saturated low to medium pressure steam at a pressure of approximately 20 to 150 PSIG is required and added to the gasifier for bed fluidization. A natural mineral bed material (the exact composition has not been disclosed) is also added with the biomass to form the fluidized bed. Note that oxygen is not added to the gasifier reactor because the gasification reactions are driven by indirect heating. Oxygen via air is however added to the combustion reactor to produce the necessary heat which is transferred to the bed material.

The gasifier system is operated at a temperature of 1,560 °F and a pressure of 1.0 PSIG to produce approximately 1,580,000 standard cubic feet per hour of dry syngas.

A flow diagram depicting the system is located in Appendix A.

2.2. Biomass Storage and Metering System

The gasifier island begins with a biomass handling system. Dried biomass is metered to the gasifier through four parallel lines of storage bins and screw conveyors. The low operating pressure of the gasifier system produces syngas with a pressure of approximately 1.0 PSIG. This low pressure operation allows for a simpler biomass feed system.

Dried biomass is first deposited on an owner-supplied delivery conveyor, which transfers the biomass to the inlet of a weigh bin. The weigh bin feeds a lock hopper via a twin screw discharger and rotary discharge device. The lock hopper then feeds a pressurized metering bin that conveys the biomass to the gasifier via a screw conveyor. The lock hoppers, metering bins and in-feed screws are all designed for pressurized operation.

All other biomass unloading, handling and storage equipment is owner-supplied. These items include but are not limited to truck unloading, screening/sizing, as-received storage, drying, dryer air emissions abatement equipment, dry storage, and all conveyance and transport equipment prior to the weigh bin storage silos.

2.3. Bed Media Storage and Metering System

The bed media makeup system meters bed material to the gasifier to make up for any bed material lost as a result of carryover in the syngas and/or combustor flue gas. The bed media is a natural mineral, although, the exact composition has not been disclosed. The media is delivered by truck or railcar to the plant site where it is pneumatically conveyed to a bed material storage silo by owner-supplied equipment. The media is discharged from the bed media storage silo to another pneumatic conveyance system which feeds directly into the bed material surge vessel. Bed media is systematically purged from the bed material surge vessel to a water-cooled discharge screw conveyor which moves purged material to an owner-supplied disposal system.

2.4. Air Separation Plant

Equipment for the supply of nitrogen is part of the vendor's scope of supply. The nitrogen gas stream is supplied by a VPSA air separation plant. An inert gas generator could be substituted for the VPSA air separation plant if a cost analysis showed it to be more economical.

2.4.1. Oxygen Gas

Elemental oxygen is not required for the Technology #2 process. Therefore, the air separation plant's oxygen rich gas stream is vented to the atmosphere.

2.4.2. Inert Gas (Nitrogen) Supply System

Nitrogen gas at 98% purity is used throughout the gasifier island for the following purposes:

Biomass storage and metering system pressurization.

Bed media storage and metering system pressurization.

Fire suppression and emergency shutdown systems.

Instrument gas.

A nitrogen booster compressor and two nitrogen storage tanks are included as part of the vendor's scope of supply.

2.5. Steam Supply System

Saturated, low to medium pressure steam is required and supplied by the owner at a pressure of approximately 20 to 150 PSIG for startup heating and gasifier bed fluidization.

2.6. Cooling Water Supply System

Owner-provided cooling water is supplied to the bed material disposal screw conveyor.

2.7. Gasifier

The gasifier utilizes medium pressure steam and heat from the bed media to gasify the biomass feedstock and form hydrogen and carbon monoxide. Saturated 20 to 150 PSIG steam is injected at the bottom of the circulating fluid bed reactor vessel, where it passes through a distributor to evenly distribute the steam and facilitate fluidization. No air or oxygen is added to the gasifier. Due to the high combustion temperature, the gasifier vessel is constructed with a refractory lining to protect the integrity of the steel shell. Reheated bed material is introduced into the bottom portion of the gasifier to provide heat and help form the fluidized bed. The circulating fluid bed gasification reactor is a non-coded vessel operating at atmospheric pressure.

Due to the fast fluidization and the high gas velocities, the biomass material becomes thoroughly mixed with the bed material to enhance the heat and mass transfer. The biomass is rapidly converted into syngas at a temperature of approximately 1,560 °F.

As described above, two in-feed screw conveyors are used to feed dried biomass and bed material to the bottom of the gasifier. The in-feed screw conveyors are not designed with any cooling systems.

No bed material is removed or purged from the gasifier, rather a portion of the bed media is carried out with the syngas to the gasifier cyclones.

Syngas is discharged at the top of the gasifier vessel and is routed to the cyclone for char and particulate removal.

2.8. Gasifier Cyclone

Any unconverted biomass, along with the cooled bed material, is carried out of the gasification reactor to two cyclones in series, where char and bed material are separated from the syngas. The bed material and char exit from the bottom of both gasifier cyclones and enter the ash surge bin. The bed material and char are then fed to the bottom of the combustion reactor for combustion of the char and reheating of the bed media.

Syngas exits the top of the second gasifier cyclone and enters the bottom of the gas conditioning reactor for tar reforming.

2.9. Combustion Reactor and Combustion Air System

The circulating fluid bed combustion reactor is a non-coded vessel operating at atmospheric pressure. The fluid bed reactor is a refractory lined pressure vessel with a distributor located at the bottom of the vessel to facilitate fluidization. A centrifugal fan blows ambient air through a combustion air heater, where the air is indirectly heated to approximately 1,000 °F with the flue gas produced by the combustion reactor. The heated combustion air is then injected beneath the distributor to achieve fluidization. The combustion process consumes the char and reheats the bed material to approximately 1,000 °C or 1,830 °F. The remaining carbon is consumed in the combustion reactor, resulting in a carbon-free ash.

2.10. Combustion Cyclone

The reheated bed material is separated from the char combustion reactor flue gas in a cyclone and is returned to the gas conditioning reactor for tar reforming of the syngas. The flue gas then exits the top of the combustion cyclone and is routed to the ash cyclone for further solids/dust removal.

2.11. Combustion Reactor Startup Burner

The combustion reactor is equipped with a natural gas burner for pre-heating the reactor's refractory lining and to provide heat to the rest of the vessels in the system to bring them up to operating temperature prior to introduction of the biomass.

2.12. Ash Cyclone and Char Discharge System

The flue gas stream from the combustion reactor is cleaned of any remaining ash and particulate matter by the ash cyclone before exiting the system. After cleaning, the hot flue gas at approximately 1,000 °C or 1,830 °F is then used to heat combustion air for the combustion reactor. The cooled flue gas exits the air heater and is pulled through an exhaust fan to a vent stack, where it is vented to the atmosphere. Note that there is sufficient heat remaining in the flue gas that it could be used for further heat recovery prior to venting.

Ash removed by the cyclone is discharged through a rotary valve to the ash transfer screw conveyor. This screw conveyor is water-cooled. The ash transfer screw conveyor discharges cooled ash to the ash bin for accumulation prior to disposal. Ash is discharged from the ash bin to the ash discharge screw conveyor where a small amount of process water is mixed with the ash to form a damp mixture with a reduced tendency to create dust during subsequent handling.

2.13. Gas Conditioning Reactor (Tar Reformer)

Tar reforming is accomplished via an integral thermal conditioning reactor that utilizes the heated bed material from the combustion reactor to provide heat for the reactor. Heated bed material from the combustion reactor cyclone is routed to the top of the gas conditioning reactor, and syngas from the second gasifier cyclone is routed to the bottom of the gas conditioning reactor. The upward flowing syngas passes through a distributor, which is located near the bottom of the vessel, to fluidize the bed material and form a bubbling fluid bed. Tar reformed syngas is discharged from the top of the gas conditioning reactor.

Tar reforming occurs when water vapor in the incoming syngas is heated to a sufficient temperature to cause steam reforming in the gas conditioning reactor, converting condensable hydrocarbons (tars) to non-condensable lower molecular weight molecules. The residence time in the conditioning reactor is sufficient to also allow a water gas shift reaction to occur and generate increased amounts of hydrogen in the syngas.

The steam reforming reactions and the water gas shift reaction are balanced thermally so that no cooling of the circulating solids takes place. The temperature of the bed material entering and exiting the gas conditioning reactor is approximately 1,000 °C or 1,830 °F.

The gas conditioning reactor is a refractory lined, non-coded vessel operating at atmospheric pressure. No air or oxygen is added to the gas conditioning reactor. As the level of the bed material in the reactor increases, it reaches a level where it continuously overflows into the bed material surge vessel from which it is fed into the gasification reactor.

Syngas exits the top of the gas conditioning reactor and is routed to additional owner-supplied equipment for further processing. The temperature of the syngas at this point is approximately 1,000 °C or 1,830 °F. Typically, syngas is routed through heat exchange equipment to cool the syngas and transfer heat to a steam generator or water heating system. Additional cleanup of the cooled syngas usually follows the heat exchange operation. Because of the significant reduction in condensable material that occurred in the gas conditioning reactor, the syngas can be cooled to low temperatures to increases the heat recovery potential without the fear of buildup or fouling of the heat exchange surfaces.

2.14. Gasifier Control System

The gasifier system includes a programmable logic controller (PLC) based control system with a human-machine interface (HMI) and the necessary computer systems to operate the software.

All field instruments for measuring pressure, temperature, flow, etc. are included. In addition, special instruments such as various gas analysis devices and special reactor bed level control devices are also included.

An instrument air supply system is not included in the vendor's scope of supply. However, since nitrogen is available from the air separation plant (N_2 receiver), nitrogen is used in place of instrument air. An instrument air tank included in the vendor's scope of supply is converted to a nitrogen tank for surge capacity.

2.15. Miscellaneous Systems

2.15.1. Seal Water System

Seal water is not required for Technology #2.

2.15.2. Process Air System

A compressed air system for general process needs is not included in the vendor's scope of supply. However, an owner-supplied system is included and is comprised of an air compressor, an air dryer and a receiver. The process air receiver supplies pressurized air for general plant needs and is also used to supply compressed air to the air separation plant for nitrogen generation.

2.15.3. Flare Stack

During start-ups, shutdowns and emergency stop events, syngas is routed to an owner-supplied flare stack for incineration and exhaust to the atmosphere.

2.15.4. Piping and Valves

All syngas piping and process piping is included in the vendor's scope of supply. All high temperature gas piping is refractory lined. All other hot process piping will be externally insulated.

All process valves are included.

2.15.5. Electrical

All electrical systems are included in the vendor's scope of supply, consisting of items such as motor control centers (MCCs), power cabling, control cabling, cable ways, UPS, motors, and wiring to furnish power to automation and process protection systems.

An electrical room to house the switch gear and automation equipment is part of the owner's scope of supply. The electrical room will be equipped with ventilation, air conditioning and filtering.

2.15.6. Building/Structural

The main process equipment is located in a vendor-supplied steel structure that includes all structural components as well as access to all equipment. The building sits on an owner furnished reinforced concrete floor. The structure does not include a roof or siding.

2.15.7. Gasifier Safety Systems

All critical components, valves and equipment are protected by a safety logic system separate from the process control system.

2.15.8. Burner Safety Systems

The startup burner on the combustion reactor is equipped with flame safety systems which are separate from the process control system.

2.16. Utility Requirements

The utilities required for operation are as follows:

Nitrogen at 98% purity, temperature and pressure is unknown.

Instrument air, temperature and pressure is unknown, assume nitrogen.

Natural gas, pressure is unknown.

Low to medium pressure steam at 20 to 150 PSIG, saturated.

Cooling water, temperature and pressure is unknown.

Process water for hose stations and other, temperature and pressure is unknown.

Potable water for emergency eye wash and showers.

Ambient air.

3. GASIFIER ISLAND – TECHNOLOGY #3

3.1. General

The Technology #3 gasifier island consists of a pressurized, directly heated biomass gasification system capable of producing a syngas that can be converted to liquid fuels via catalytic or biological processes. This particular gasification process employs a single, bubbling fluid bed reactor for gasifying biomass with oxygen and steam to produce syngas. The process utilizes a tar reformer; however, the design was not revealed by the vendor. The island includes a biomass handling and feed system, a gasifier, a tar reformer, a bed media handling and feed system, an oxygen handling and injection system, and an ash removal system.

The gasifier system is a direct or autothermal operation, meaning the energy used for heating and maintaining the gasification reaction temperature is supplied by the combustion of a portion of the biomass material processed.

The gasifier is designed to handle a variety of biomass feedstocks of varying size and moisture contents. The gasifier feed rate is 1,000 metric tons/day of dry biomass (wood residue composed of wood chips and bark) with a 15% moisture content. The chip size is specified as 2.5″ minus and approximately ¼″ to ½″ thick. At least 25% of the chips by weight are 1″ plus and ¼″ to ½″ thick. The acceptable percentage of fines is undefined at this point.

Oxygen and superheated medium pressure steam are mixed and added to the gasifier to fluidize the bed and gasify the biomass feedstock to form hydrogen and carbon monoxide. Silica sand or olivine bed material is also added with the biomass to form and stabilize the bubbling fluid bed.

The gasifier is operated at a temperature of approximately 1,475 °F and a pressure of 38 PSIG to produce 153,000 lbs/hr of wet syngas with a higher heat value of 4,216 Btu/wet lb. Note that the syngas production from the island (tar reformer outlet) is actually greater than 153,000 lbs/hr due to the additional oxygen and steam added to the tar reformer.

A flow diagram depicting the system is located in Appendix A.

3.2. Biomass Storage and Metering System

The gasifier island begins with a biomass handling system. Dried biomass is first deposited on an owner-supplied distribution conveyor, which transfers the biomass to six parallel feed lines for pressurization and metering to the gasifier. Each line is composed of lock hoppers, metering bins and screw conveyors. Nitrogen gas is used to pressurize the lock hoppers and metering bins, prior to exposing them to the gasifier pressure, and prevent hot gases from entering the metering screws and bins.

Each lock hopper and metering bin is equipped with a set of parallel screw augers that turn simultaneously to create a live bottom that prevents bridging and moves feedstock to a perpendicularly mounted, external screw conveyor. The screw speed in each metering bin is adjusted using variable frequency drives. The six air-lock metering bins are equipped with inlet and outlet pneumatic slide gates. During operation, each metering vessel can be isolated from the gasifier with double block and bleed valves to enable repairs, while maintaining high gasifier availability. During the metering vessel fill and discharge cycle, the following sequence is used:

3.2.1. Low level signal, control system timer, or operator initiates fill cycle for a metering vessel.

3.2.2. Feedstock outlet slide gate is closed.

3.2.3. Metering vessel is depressurized.

3.2.4. Feedstock inlet slide gate is opened to allow metering vessel to be filled with biomass material that falls through drag chain conveyor.

3.2.5. Feedstock inlet slide gate is closed to seal the metering vessel.

3.2.6. Metering vessel is pressurized to process pressure.

3.2.7. Feedstock outlet slide gate is opened to permit material to be conveyed to the gasifier vessel.

3.2.8. Repeat starting at (1).

The lock hoppers, metering bins, metering screw conveyors and gasifier in-feed screws are designed for a maximum allowable working pressure (MAWP) of 50 PSIG.

All other biomass unloading, handling and storage equipment is owner-supplied. These items include but are not limited to truck unloading, screening/sizing, as-received storage, drying, dryer air emissions abatement equipment, dry storage, and all conveyance and transport equipment prior to the six metering bins.

3.3. Bed and Sorbent Media Storage and Metering System

Silica sand or olivine mineral is used to form and stabilize the gasifier's bubbling fluid bed. The bed media is delivered by truck or railcar to the plant site where it is pneumatically conveyed to a bed material storage silo. Bed material is transferred by screw conveyor from the storage silo to a mix tank surge vessel where it is mixed with recycled screened bed and sorbent media. From the mix tank, bed media is transferred by gravity to a lock hopper and from there to the gasifier via a pneumatic conveyor pressurized with nitrogen. Nitrogen gas is used to pressurize the lock hopper to prevent hot gases from back flowing into the hopper from the gasifier.

New sorbent media (limestone or dolomite) is separately injected into the gasifier by using a screw conveyor to transfer sorbent media from a storage silo to a lock hopper for pneumatic injection into the gasifier.

3.4. Air Separation Plant

Equipment for the supply of oxygen and nitrogen are not part of the vendor's scope of supply. An oxygen-rich gas stream can be supplied by either an air separation plant (Vacuum-Pressure Swing Adsorption (VPSA) or cryogenic) or a liquid oxygen system using purchased liquid oxygen. For the purposes of this report, it was assumed that a VPSA air separation plant is used to produce both oxygen and nitrogen. The air separation plant, oxygen receiver, oxygen booster compressor and nitrogen receiver are included in the owner's scope of supply.

3.4.1. Oxygen Gas Supply System

An oxygen-rich gas stream, containing 90-92% oxygen by weight, is needed to combust biomass in the gasifier. Oxygen-rich gas from the oxygen receiver at the air separation plant is pressurized by the oxygen booster compressor to about 180 PSIG and is stored in a vendor supplied surge tank. Oxygen from the surge tank is mixed with medium pressure superheated steam prior to introduction to the gasifier. The oxygen surge tank is part of the owner's scope of supply.

3.4.2. Inert Gas (Nitrogen) Supply System

Nitrogen gas is used throughout the gasifier island for the following purposes:

Biomass storage and metering system pressurization.

Bed and sorbent material storage and metering system pressurization.

Fire suppression and emergency shutdown systems.

Instrument gas.

A nitrogen booster compressor and a nitrogen storage tank are part of the owner's scope of supply.

3.5. Steam Supply System

Medium pressure saturated steam is supplied by the owner at a pressure of approximately 125 PSIG for oxygen heating, startup heating and gasifier operation. Prior to entering the gasifier, the saturated steam is indirectly superheated with syngas from the tar reformer.

3.6. Cooling Water Supply System

Owner-supplied cooling water is required for the gasifier in-feed screws and bed media cooling system.

3.7. Gasifier

The gasifier partially combusts biomass feedstock with oxygen to form hydrogen and carbon monoxide. The gasifier operates at a temperature of approximately 1,475 °F and a pressure of 38 PSIG. Due to the high combustion temperature, the gasifier vessel is constructed with a refractory lining to protect the integrity of the steel shell. Bed media and medium pressure superheated steam are also introduced into the bottom of the gasifier to form and stabilize the bubbling fluid bed.

As described above, six in-feed screw conveyors are used to feed dried biomass to the bottom of the gasifier. Since the pressurized in-feed screw conveyors are exposed to hot gases from the gasifier, they are designed with water cooling coils for protection.

Syngas is discharged at the top of the gasifier vessel and routed to the gasifier cyclone for particulate (char, bed material, un-reacted biomass, etc.) recovery.

Fluidizing bed media is periodically withdrawn from the gasifier for cleaning, purging, and/or replenishment. The material being withdrawn consists of primary bed media, sorbent media, and entrained tramp material (e.g., rocks, metals and other non-combustibles). As material is withdrawn from the gasifier it is cooled by a flow of fluidization steam. The partially cooled, withdrawn material is discharged from the cone bottom of the gasifier into a water-cooled, pressurized screw conveyor where its temperature is reduced to < 400 °F. The screw conveyor discharges the cooled material into a pressurized surge vessel/lock hopper system to bring the material to atmospheric pressure. The bed material is then conveyed to a screen where tramp material is separated from the recyclable bed and sorbent media. Tramp material and purged bed media are conveyed to a bunker for subsequent disposal.

3.8. Dust Collection Cyclone

Syngas exits the gasifier and is routed through a refractory lined cyclone separator vessel where ash and entrained bed material are removed. The bulk of the entrained particulate is removed from the syngas in the cyclone. It is assumed that the cyclone is efficient enough to keep particulate concentrations below a level acceptable for the tar reformer; however, the design of the tar reformer is unknown. The particulate dust is returned to the fluidized bed of the gasifier for further carbon conversion.

3.9. Ash/Char Discharge System

Technology #3 depicts the recovered particulate material (ash and char) from the gasifier cyclone being recycled back to the gasifier, with an option for sending the ash to a conditioning and disposal system. Exercising this option would involve the addition of a gas filtration step, typically following the tar reformer reactor, for further particulate removal from the syngas. Ash conditioning equipment associated with the gas filtration step would then be sized to handle the particulate carryover from the cyclone. This system would include a water-cooled ash removal screw conveyor, a lock hopper for depressurization, and a conveyor hopper for pneumatic discharge to an ash storage silo for accumulation of material prior to disposal. Note that this ash conditioning and disposal equipment is outside the scope of this study and is not included in the cost estimate.

3.10. Gasifier and Tar Reformer Startup Burners

The gasifier is equipped with a natural gas burner for pre-heating the gasifier pressure vessel's refractory lining and other downstream systems prior to introduction of the biomass. The tar reformer is also equipped with a natural gas burner for pre-heating purposes as well.

An air system, including an air compressor and an air receiver tank, is also included for supplying combustion air to the startup burners.

3.11. Tar Reformer

The design of the tar reformer was not revealed by the vendor; however, it is assumed to be a fixed bed design. Such a tar reformer utilizes a catalyst and heat to assist in decomposing tars and heavy hydrocarbons into hydrogen, carbon monoxide and other combustible gases. The use and type of catalyst is unknown. Without this decomposition the tars and heavy hydrocarbons in the syngas will condense as the syngas is cooled in the down-stream process equipment. In addition, the tar reformer increases the hydrogen/carbon monoxide ratio for optimal conversion.

The tar reformer is most likely a refractory lined steel vessel filled with a catalyst material. The catalyst material type and structure is unknown. The method of loading and or feeding the catalyst material to the tar reformer reactor is also unknown. Syngas flows through the tar reformer vessel, although the direction is unknown. Steam is added to the tar reformer to adjust the syngas composition as needed to achieve optimum performance.

Syngas is routed from the tar reformer to downstream heat recovery and gas cleanup unit operations. The tar reformer outlet is the boundary of the vendor's scope of supply.

3.12. Gasifier Control System

The gasifier system includes Allen-Bradley ControlLogix Programmable Automation Controllers (PAC) hardware, an engineering work station and one operator work station, including human-machine interface (HMI) software. The PAC modules are mounted in control panels, prewired and delivered to the job-site with field wiring connections ready for installation. A controls program for monitoring and controlling the process is also included.

This system controls most aspects of normal startup, continuous operation, normal shutdown, soft shutdown, emergency shutdown and emergency stop via proven and tested automated sequence controls. Such a control system greatly reduces human error and provides a safer, more uniform operation of the unit.

The gasifier control system modulates the gasifier air supply to achieve a gasifier freeboard pressure appropriate for the required syngas capacity. The gasifier freeboard pressure set-point is allowed to float as needed to achieve the optimum gas velocity (or range) in the dense phase of the fluid bed reactor. Gasifier temperatures are held to a set point value using feedback-control-modulation of the biomass feed rate.

All field instruments for measuring pressure, temperature, flow, etc. are included. In addition, special instruments such as various gas analysis devices and special reactor bed level control devices are also included.

An instrument air supply system is not included in the vendor's scope of supply. However, since nitrogen is available from the air separation plant (N_2 receiver), nitrogen is used in place of instrument air. An instrument nitrogen tank for surge capacity is part of the owner's scope of supply tank.

3.13. Miscellaneous Systems

3.13.1. Seal Water System

Seal water is not required for Technology #3.

3.13.2. Process Air System

A compressed air system for general process needs is not included in the vendor's scope of supply. However, an owner-supplied system is included and is comprised of an air compressor, an air dryer and a receiver. The process air receiver supplies pressurized air for general plant needs and is also used to supply compressed air to the air separation plant for oxygen and nitrogen generation.

3.13.3. Flare Stack

During start-ups, shutdowns and emergency stop events, syngas is routed to a vendor-supplied flare stack for incineration and exhaust to the atmosphere.

3.13.4. Piping and Valves

All syngas piping and process piping is included in the vendor's scope of supply. All high temperature gas piping is refractory lined. All other hot process piping will be externally insulated.

All process valves are included.

3.13.5. Electrical

All electrical systems are included in the vendor's scope of supply, consisting of items such as motor control centers (MCCs), power cabling, control cabling, cable ways, UPS, motors, and wiring to furnish power to automation and process protection systems.

An electrical room to house the switch gear and automation equipment is part of the owner's scope of supply. The electrical room will be equipped with ventilation, air conditioning and filtering.

3.13.6. Building/Structural

The main process equipment is located in a vendor supplied steel structure that includes all structural components as well as access to all equipment. The building sits on an owner furnished reinforced concrete floor. The structure does not include a roof or siding.

3.13.7. Gasifier Safety Systems

All critical components, valves and equipment are protected by a safety logic system separate from the process control system. Items in the safety system include but are not limited to the following:

Pneumatically operated process control valves with appropriate open/closed/last fail positioning.

Hard-wired e-stop circuit for critical process instrumentation. Hard-wired components include code vessel rupture disks, strategically located emergency stop pushbuttons, and high temperature limit switches for gasifier exit temperature.

Appropriate overpressure protection of ASME code stamped vessels.

Redundant instrumentation for critical process conditions.

Robust control system with appropriate operator limits.

Uninterruptable power supply for gasifier control system to provide ongoing operator access to equipment and process conditions.

3.13.8. Burner Safety Systems

The startup burners on the gasifier and the tar reformer are equipped with flame safety systems which are separate from the process control system.

3.14. Utility Requirements

The utilities required for operation are as follows:

Oxygen at 90-92% purity, temperature and pressure is unknown.

Nitrogen at 98% purity, temperature and pressure is unknown.

Instrument air, temperature and pressure is unknown, assume nitrogen.

Natural gas, pressure is unknown.

Medium pressure steam at 125 PSIG, saturated.

Cooling water, temperature and pressure is unknown.

Process water for hose stations and other, temperature and pressure is unknown.

Potable water for emergency eye wash and showers.

Ambient air.

August 3, 2012

REPORT 30300/01
GASIFIER TECHNOLOGY ASSESSMENT – CONSOLIDATED REPORT

SECTION 4
GASIFIER OPERATION AND PERFORMANCE

1. FEEDSTOCK TYPE

Bubbling fluid bed (BFB) and circulating fluid bed (CFB) gasifiers are both capable of gasifying a wide range of biomass materials.

Generally anything with organic content can be gasified to produce a usable syngas. Disregarding logistics and biomass availability, the ability of the feedstock handling system to convey and feed biomass material will generally determine the range of feedstock types that a gasifier can efficiently process. Depending on the feedstock type and as-delivered characteristics, the feedstock processing system could potentially require equipment to screen-out over sized material, reduce particle size, remove fines, remove metals, remove dense contaminants, increase bulk density, etc., to optimize the gasification process. Although a broad range of feedstock types can be gasified, the efficiency and production rates for each type of gasifier can vary greatly with feedstock type and characteristics.

Biomass types with potential for gasification are listed below:

- Wood chips - sawmill residuals, whole log chips, etc.
- Waste wood - bark, sawdust, other sawmill waste, etc.
- Agricultural waste.
- Crop residues - corn stover, wheat straw, etc.
- Municipal Solid Waste (MSW) or Refuse Derived Fuel (RDF).
- Construction and demolition waste.
- Switchgrass.
- Sorghum, bagasse, energy canes, miscanthus etc.

Ultimately, flexibility must be designed into the feedstock handling system to take advantage of a variety of feedstocks that might be available over time. The reliability of the feedstock handling system is often taken for granted; however, it is usually the weak link within a gasification system. A thorough economic analysis must be performed to determine the optimal gasifier and feedstock handling system design for the type and amount of feedstock being processed. For example, gasifying a high bulk density biomass pellet at 10% moisture content can improve a gasifier production rate, efficiency, reliability, syngas quality and capital cost, while a lower grade residue or refuse type feedstock will be less expensive but increase the capital cost of the feedstock handling system.

2. FEEDSTOCK SIZE

BFB and CFB gasifiers are similar in their ability to efficiently process a variety of feedstock particle sizes; however, a CFB design is a bit more flexible. Industry experts would typically agree that a feedstock size of 2.0-2.5" minus is ideal for either technology.

Uniform bed formation in a fluid bed reactor is very important for efficient bed utilization and consistent operation during gasification of the biomass material. In order to enhance the mixing and uniformity of a bubbling fluid bed, the biomass is fed to the bed at multiple feed points around the circumference of the reactor vessel. In addition, the fluidization medium, whether air, oxygen, steam, or some combination of these substances, should be uniform in composition and should be introduced in multiple locations.

A BFB design is generally more sensitive to bed utilization. The size of biomass particles greatly affects the rate of gasification and the ability of the biomass to migrate to the center of the bed in a BFB design. With small particles, the gasification is very quick, and unburned material might not make it to the center of the bed, resulting in oxygen slip and a void center in the BFB reactor. If all or a majority of the biomass material quickly gasifies, there will be insufficient char to maintain a uniform bed. For this reason, more detail is required in designing the in-feed system with the proper number of in-feed points and controlling and/or monitoring the size particle distribution of the feedstock material. A BFB will generally require additional feed points that must be balanced for larger particle sizes. A CFB design, on the other hand, operates at a higher velocity and incorporates recycling of the char and bed material, resulting in complete mixing regardless of feedstock size. Note that CFB designs are more flexible but are still limited by the amount of very fine material that they can process.

The design of the feedstock handling and gasifier feed equipment has a large, if not overriding impact on the acceptable size of the biomass feedstock. Typically what you can reliably feed and distribute uniformly into a BFB or CFB bed is considered acceptable by most gasifier technology providers. Acceptable feedstock size targets are listed below.

The target feedstock size for both a BFB and CFB gasifier is approximately 2.0-2.5″ minus with a thickness of ¼″ to ½″. Larger sizes are acceptable if the thickness remains near ¼″ to ½″; however, the thickness will typically increase as length increases with less expensive size reduction devices such as tub grinders. Also, 2.0-2.5″ minus material reduces the bridging potential in bins and silos when compared to larger material, which tends to contain more stringy material depending on the feedstock type.

A feedstock handling system designed to accept residues must be capable of handling a feedstock containing 4.0-6.0″ minus material. Forest, urban and agricultural residues typically contain 4.0-6.0″ minus material. A rule of thumb for design purposes is to assume that approximately 30% of residue material will be 3.0″ plus. The 3.0″ plus material can be removed with a scalping screen. The over sized material is then hogged to 2.0-2.5″ minus and reintroduced into the biomass feed stream.

Directly gasifying large amounts of lightweight, low density material reduces gasifier production and must be weighed against the cost of densifying the material prior to gasification. In order to maintain bed uniformity when gasifying large amounts of ¼″ minus material, a properly designed gasifier in-feed system is required. Modifications to the gasifier operation (fluidization steam flow, etc.) might also be necessary in order to process large amounts smaller material. Fixed bed gasifiers, on the other hand, will usually have a strict limitation of approximately 10-15% for ¼″ minus material to prevent air flow restriction through the bed.

Most gasifier technology providers, regardless of the reactor design, prefer to densify (pelletize or briquette) very lightweight, fine material when it is the majority of the feedstock. RDF feedstocks and feedstocks containing 100% sawdust fall into this category.

Feedstocks containing large amounts of ¼″ minus material should gasify without any problems in either a BFB or CFB, depending on the percentage of small, very fine particles. Due to high velocities in the gasifier reactor, small, lightweight biomass particles such as sawdust and fines are quickly carried up the gasifier without spending sufficient time in the fluidization zone to form a cohesive bed. While this is more of a problem in a BFB than a CFB, very large amounts of fine material will also cause operational issues in a CFB design. The reason a CFB more easily handles fine, lightweight material is its ability to recirculate the char, unreacted biomass and bed media. Recirculation enables the unreacted material to finish reacting on its second or third pass through the gasifier vessel. However, this flexibility is only applicable for a single vessel CFB design, where the recirculated material is reintroduced back to the gasifier. In a dual vessel indirect design, the recovered char and unreacted biomass are combusted in a separate combustion reactor. In the dual vessel indirect design, heavy fines loading is typically not acceptable for optimal operation, because much of the fines can carry over to the combustion reactor and greatly reduce carbon conversion in the gasifier.

Many gasifier technology providers suggest an additional feedstock size specification to limit the amount of small material in the feedstock. Specifying that 20-25% of the feedstock by weight should contain 1″ plus material to optimize bed uniformity and bed utilization and limit the amount of fines is typical.

The advantage of a fluid bed is its uniform and efficient heat transfer capability and fast reaction kinetics. Biomass must be uniformly introduced into the reactor to fully utilize the bed, maximize fluid bed capabilities and maintain efficient conversion. Uniform distribution of the feedstock is more important than actual feedstock particle size characteristics.

Syngas quality is expected to be similar whether using small or large feedstock material, as long as the design of the gasifier and particle size distribution contribute to uniform feed and uniform bed formation.

3. FEEDSTOCK DENSITY

Feedstock density considerations are similar for both BFB and CFB gasifiers. Dense feedstocks benefit both technologies in similar ways.

Equipment is available to compress small biomass particles into very dense briquettes or pellets (40 lb/ft^3 for instance) to improve material handling characteristics as well as energy density.

A gasifier system benefits from dense feedstock material. As feedstock density increases, the following benefits are experienced:

- The size and capital cost of the feedstock handling equipment decreases.
- The size and capital cost of the gasifier reactor decreases and/or the production increases as a result of:
  - Increased residence time within the gasifier.
  - More predicable operation resulting from improved biomass distribution and a more uniform bed.
  - Reduction in the required reactor volume

- The reliability of the feedstock handling and in-feed systems increases, resulting in improved operating uptime.

Feedstock density is dependent on the type of biomass being used and the extent of pretreatment. Densifying a biomass feedstock is typically beneficial to the gasification process; however, it is rarely cost effective unless the gasification process is pressurized, which is still not always cost effective. The savings with a pressurized system are realized by the reduction in feedstock and gasifier equipment size and capital cost. Also, more reliable operating conditions and better equipment uptime reduces operating costs and offsets some of the higher feedstock cost.

Overcoming the pressure of a pressurized gasifier requires pressurization of the biomass feed equipment with an inert gas (N_2, CO_2, etc.), including the void space among the biomass particles. Since a dense feedstock has less void space, it requires the addition of less inert gas for pressurization. This reduces the amount of syngas dilution resulting from the inert gas.

A typical biomass densification plant that produces packaged wood pellets at 10% moisture identifies their costs as follows.

- Raw material cost of approximately $40-$60/short ton produced.

- Packaging cost of approximately $20/short ton produced.

- Drying and densification cost of approximately $70/short ton produced, which consists mostly of labor, electricity, and die wear costs.

- Total operating cost on the order of $150-$160/short ton produced.

If a pellet plant produces briquettes for gasification rather than pellets for a packaged product, the wood only needs to be dried to 15% moisture rather than 10% moisture, and the drying and densification cost is reduced from $70/short ton of pellets to approximately $50-$60/short ton of briquettes. This incremental cost of $50-$60/short ton can easily double the raw material cost for gasification. Note that the drier, densified biomass will require less heat for drying in the gasifier, which will mitigate some of the added cost and benefit the operation of both BFB and CFB gasifiers.

The cost of densification should decline over time as the technologies mature and become optimized for certain raw material characteristics. The cost reduction for feedstock densification in the "nth plant" is estimated to be the same or very similar to that for the gasification system at 10-15%. Further discussion about "nth plant" costs can be found in Section 5.

The particle size and bulk density of the feedstock can impact the minimum fluidization velocity and the optimal operation of either the BFB or CFB gasifier. A

CFB reactor is generally the most flexible type of gasifier with regard to feedstock solids size and density. The size and density of feedstock particles determines the required minimum transport velocity, although the operating velocity of a properly designed circulating fluid bed reactor is generally far enough above the minimum transport velocity to ensure proper operation. High velocities may, however, result in accelerated equipment erosion. Similarly, a properly designed BFB gasifier should be designed to permit adjustment of the bed velocity to accommodate various feedstock sizes and densities.

Syngas quality is expected to be similar whether using raw or densified feedstock material, provided the gasifier and feed system design includes equipment for uniform feed and uniform bed formation.

4. FEEDSTOCK MOISTURE

BFB and CFB gasifiers each have similar responses to variations in feedstock moisture content. Gasifier operation is a function of the moisture content of the biomass material being used. The biomass conversion efficiency and production rate typically decrease with increasing moisture content, because the process consumes more carbon (directly heated gasifier) or uses more of the available heat (indirectly heated gasifier) to heat and vaporize the water to the syngas temperature. Indirect gasification systems experience a drop in temperature due to the consumption of additional heat, producing more char and subsequently increasing the amount of char combustion gases, which would ultimately increase the hot gas flow to the gasifier in a self-correcting type of action. It would, however, result in a lower carbon conversion in the gasifier and negatively affect the syngas composition and quality. An increase in biomass moisture may also have an impact on syngas composition and/or quality by producing more CO_2 and diluting the syngas. In addition, a higher moisture biomass increases the syngas volume and lowers the H_2 and CO concentration of the syngas, while requiring larger downstream processing equipment for the same biomass consumption rate.

Most gasifier technology providers require feedstock with a target range moisture content of 10-20%. A 20% moisture content is typically the fiber saturation point, with the remaining water being chemically bound. It is typically cost effective and beneficial for syngas quality to remove free water in an external dryer prior to gasification; however, studies have even been conducted to analyze the cost benefit of bypassing drying and gasifying raw biomass at 45-50% moisture content. These studies imply that having the gasifier accept the moisture and the associated lower efficiency, is still a better choice economically than drying, as long as there is a use for waste heat in the plant, be it in distillation, heating, chilled water, or other beneficial use, and, the air emissions limits are similar to the U.S., making the dryer expensive due to the necessary equipment (WESP and RTO) for air emission abatement. Note that this assumes use of a direct fired rotary wood dryer. A thorough cost benefit analysis is always recommended to determine the economical extent of feedstock drying.

Water in the feedstock is also necessary to drive the water gas shift reaction; however, with a moisture content in the 15-20% range there is substantially more water than is needed for the water gas shift reaction to reach equilibrium.

High moisture content in the feedstock, which translates into high moisture content in the syngas, also puts a condensing load on downstream cooling and filtering equipment.

The impact of feedstock moisture on heat value and energy density is typically only a concern when combusting the syngas in an engine for power production because an oxygen blown system has a higher tolerance, both economically and technically, for moisture in the reactor. This study of course is focused on producing a syngas for conversion to liquid hydrocarbons, which benefits from the highest H_2 and CO concentrations that are economically achievable.

5. FEEDSTOCK ASH CONTENT

The amount of ash in different types of feedstock varies widely (0.1% for wood and up to 15% for some agricultural products) and influences the design of the ash removal and handling system.

6. FEEDSTOCK CONTAMINANTS

BFB and CFB gasifiers are not overly sensitive to contaminants in the feedstock; however, contaminant removal is typically beneficial depending on the contaminant type.

Macro contaminants such as dirt and rocks are more of a nuisance and can be removed from the feedstock with certain preprocessing equipment or in a bed media recycle and screening system. Similarly, intermittent purging and disposal of the bed material will remove the dirt and rocks as well.

Metals, on the other hand can be more of an issue. Metal in the form of wire or stringy pieces can form balls that defluidize the bed if the size and number of balls are large enough. Removal of ferrous metals is fairly easily accomplished with magnetic preprocessing equipment and is always recommended if the feedstock has any chance of containing metal material.

Micro contaminants such as alkalis, chlorine, and sulfur compounds are not beneficial to the gasification environment because they can generate corrosive compounds, agglomerate and form buildup that can attack the gasifier refractory. A sorbent material such as limestone, magnesium oxide and/or dolomite is typically used as the bed media or to supplement the bed media to help capture and remove the alkali, chlorine, and sulfur compounds. Not all of the alkali, chlorine, and sulfur compounds are easily or economically removed; therefore, buildup is inevitable if these compounds are present in the feedstock. The sticky buildup will coat the refractory surfaces and attract bed media. Buildup will also occur on the bed media itself, causing agglomeration and the formation of balls known as sand babies. These sand babies must then be screened-out in a fashion similar to rocks or dirt before they can defluidize the bed. Excessive coating of the bed media can also reduce its heat transfer characteristics and interfere with the carbon conversion efficiency. Typically, the use of a sorbent material will reduce the agglomeration potential for sufficient worry-free operation.

Cooling of the syngas, combined with sorbent addition, allows much of the micro contaminants to condense and be filtered out in solid form. This filtration step is typically included all gasification processes; however, the filtration step is not always in the same location. Usually, the filtration step is after tar reformation. Cooling of the syngas via heat recovery is also typical prior to filtration to promote the condensation of the contaminants in solid form, and to fall below the maximum feasible filter media temperature which is currently approximately 850 °F. Another option to reduce build up and volatilization of the alkali, chlorine, and sulfur compounds is to maintain a lower gasification temperature; however, this is not applicable in a BFB or CFB gasifier because the operating temperatures are already above this point. Fixed bed gasifier temperatures are typically kept below 1,200 °F to reduce the potential for volatilization.

Understanding feedstock composition is critical to determining and estimating the cost of a contaminant abatement strategy. The bottom line is that feedstocks containing macro and micro contaminants can be gasified in either a BFB or CFB, as long as efforts are made to control, minimize or remove and dispose of those contaminants.

7. ABILITY TO HANDLE CORROSIVE MATERIALS

Similar to solid contaminants, corrosive alkali, chlorine and sulfur compounds can also be present in feedstocks. Corrosive materials affect both BFB and CFB gasifiers in a similar manner and must be accounted for in the gasifier and refractory design. Proper metallurgy and refractory design typically mitigates any excessive corrosion problems, however, some feedstocks can contain large amounts of potentially corrosive materials and may require blending with cleaner feedstocks to extend refractory life.

8. CARBON CONVERSION

Carbon conversion efficiency is defined as the amount of carbon in the fuel, minus the amount of solid carbon leaving the gasifier, divided by the amount of carbon in the fuel. In other words carbon conversion is the amount of carbon converted to usable syngas. Carbon conversion is influenced by biomass particle size, biomass type, temperature, and residence time in the gasifier.

In the indirect dual CFB reactor design, the unconverted biomass (char) is sent to the combustor where it is completely combusted to produce the heat for the gasification reactor. As a result, the fuel conversion in an indirect gasifier system, similar to Technology #2, is essentially 100%; however, the carbon conversion in the gasification reactor section typically varies between 70% and 90%. Carbon conversion generally increases with increasing temperature. For the indirect dual CFB reactor design this makes the process self-regulating; if the temperature in the reactor drops, the amount of char produced increases, combustion of the additional char produces more heat in the combustor, and the recirculation rate of bed material from the combustor to the gasifier carries the additional heat to the gasifier reactor.

Carbon conversion for BFB and CFB gasifiers is generally very similar, however a CFB can have a higher conversion because the char is recycled back to the reactor and theoretically has more total residence time in the reactor. Note that some BFB designs can also recycle the char carryover back to the gasifier bed, thus improving the carbon conversion.

Technology vendors #1 and #2 did not disclose typical carbon conversion efficiencies; however, technology vendor #3 claims a carbon conversion of 97.1% for a poplar (hardwood) feedstock and 84.4% for a densified RDF feedstock.

9. COLD GAS EFFICIENCY

The fraction of the feedstock's chemical energy or heating value, which remains in the product syngas, is termed the "cold gas efficiency." Most commercial-scale gasification processes have a cold gas efficiency of at least 65% and some exceed 80%. Note that the cold gas efficiency does not account for the sensible heat available in the syngas, only the chemical energy available.

Technology vendor #1 did not disclose their typical cold gas efficiency; however, technology vendor #2 claims a cold gas efficiency of 70-75% for RDF, while technology vendor #3 claims a cold gas efficiency of 80.9% for a poplar (hardwood) feedstock, and 73.0% for a densified RDF feedstock.

In theory, a CFB can have slightly higher cold gas efficiency due to more efficient exposure to radiant heat transfer. However, operating costs for a CFB gasifier will be higher than for a BFB gasifier because of the larger fan power requirement and the abrasion and wear that occurs due to the higher velocities and turbulence. For further comparisons see Reactor Design and Comparisons below.

10. HEAT LOSS

Note that the sensible heat losses and the thermal efficiency should be very similar for either a BFB or CFB design. The overall gasifier and tar reformer island thermal efficiency obviously depends on the extent of the heat recovery which falls outside of the scope of this study.

11. BED/SORBENT MEDIA TYPE

A mineral type bed material, resistant to the high heat environment, is typically used to assist in heat transfer and facilitate the chemical reactions inside the gasifier and tar reformer. Sorbent material is also typically added for control of alkalis, chlorine and sulfur, and to reduce the potential of ash agglomeration and subsequent choking of the bed. Some bed media such as dolomite can act as both the bed and sorbent material.

There is also a great potential for in-bed additives in terms of tar reduction. These bed additives can act as catalysts for promoting several chemical reactions in the gasifier and/or tar reformer. The presence of additives influences the gas composition and the heating value of the product gas. The use of catalytically active materials during biomass gasification can promote char gasification, change the product gas composition and reduce tar formation. Although experts agree on the potential for in-bed additives, there is not yet a consensus on the optimal material and optimal conditions. This is partly due to the fact that feedstock flexibility is very important in gasifier design, and changing feedstock characteristics and composition can affect the activity of a bed-additive/catalyst. The bottom line is that further research needs to be directed at finding a catalytically active fluidizable bed material for biomass gasification and tar reformation.

Catalysts that have been studied or trialed include nickel based catalysts, dolomites and magnesites, zeolites, olivine, silica sand, engineered clays and iron catalysts. Sorbent materials include dolomite, limestone and magnesium oxide.

11.1. Ni-based catalysts

Examples - NiO/olivine, Ni/dolomite, Ni/Dolomite+Silica binder, Ni-WO_3/Dolomite, Ni/Al_2O_3, NiCuMo/SiO_2-Al_2O_3.

Notes - Ni-based catalysts have been found to be effective, however, they tend to deactivate quickly due to carbon deposition and poisoning in the presence of

H_2S. Ni-based catalysts are also very expensive for single use without regeneration.

11.2. Dolomite - $CaMg(CO_3)_2$

Notes - Dolomite is the most popular and most studied material. Although dolomite has been proven to be an effective bed additive in terms of tar reduction and prevention of bed agglomeration, it has some critical limitations. Dolomite is softer than other minerals and thus gets eroded by silica sand particles, also some dolomite particles break during calcination and give rise to a large proportion of fines. Thus, there is a problem of carryover of solids from the bed. Dolomite is, however, more resistant to attrition than limestone.

11.3. Zeolites - microporous aluminosilicate minerals

Notes – Zeolites can be used as high-surface-area binders to support catalysts or can be used as a bed material on their own. They are similar in effectiveness to silica sand and high alumina clays.

11.4. Olivine - $(Mg,Fe)_2SiO_4$

Notes – Olivine is a mineral containing magnesium, iron and silica. It is very resistant to attrition (greater than dolomite), and its activity is comparable to dolomite.

11.5. Silica Sand

Notes - Silica sand and limestone were the first additives used in gasifiers to improve gasification. Silica is still widely used, however further development is leading some technology providers toward olivine or engineered materials such as crushed fired clay with high alumina content. Silica sand is also the cheapest media used today.

11.6. Limestone

Notes – Limestone has been used for quite some time (with silica sand as mentioned above) and is very effective as a sorbent to reduce or prevent agglomeration of the bed. It is, however, the softest sorbent material with the least resistance to attrition and can result in large particulate and dust carryover.

11.7. Magnesium Oxide

Notes – MgO is also widely used as a sorbent to minimize agglomeration.

11.8. Engineered Clays

Notes – Engineered materials such as crushed fired clay with high alumina content is a very effective heat transfer material and is very resistant to attrition.

An economic and process analysis is recommended for the selection of the best bed/sorbent material. The selection should be based on the anticipated feedstock composition, expected media life, as well as the gasifier and refractory design as gleaned from pilot scale operating data.

12. SYNGAS H_2/CO VOLUME RATIO

Typically an allothermal (indirect) gasification system will produce syngas with a higher H_2 to CO ratio than an autothermal (direct) system. In an allothermal system there is no need for the incomplete combustion or partial oxidation (volatile products and some of the char reacts with O_2 to form CO_2 and CO) step to take place because the heat required to volatilize the organic (biomass) material is added indirectly. As a result, most of the biomass reacts with CO_2 and water vapor to produce CO and H_2 in the gasification/steam reforming reactions. After the water-gas-shift reaction reaches equilibrium in the gasifier, the total resulting H_2 concentration from the allothermal gasifier is typically greater.

A higher H_2 to CO ratio is beneficial in the gas synthesis step when converting syngas to liquid hydrocarbons in a Fischer–Tropsch process. The ideal ratio depends on the catalyst being used. Cobalt and iron are well known catalysts, but each has a different optimal H_2/CO ratio. For cobalt-based catalysts, the optimal H_2/CO ratio is around 1.8-2.1. Iron-based catalysts, on the other hand, can tolerate significantly lower H_2/CO ratios than cobalt because the iron-based catalysts promote additional H_2 formation by way of a water-gas-shift reaction in the Fischer–Tropsch process. This can be important for syngas derived from biomass, which tends to have a relatively low H_2/CO ratio (<1.0). The optimal H_2/CO ratio for biological synthesis processes is unknown.

The following H_2/CO ratios were specified by the technology providers for the fuels listed.

12.1. Technology #1

Gasifier outlet H_2/CO ratio is 1.30, and tar reformer outlet H_2/CO ratio is 1.19.

The biomass feed stock is southern pine wood chip and bark mixture with the following analysis:

- Carbon 49.72 % wt. dry

- Hydrogen 5.67 % wt. dry
- Nitrogen 0.2 % wt. dry
- Sulfur 0.02 % wt. dry
- Oxygen 42.31 % wt. dry
- Chlorine 0.000122 % wt. dry
- Ash 2.08 % wt. dry

12.2. Technology #2

Gasifier outlet H_2/CO ratio is unknown, and tar reformer outlet H_2/CO ratio is 1.74.

The biomass feed stock is hybrid poplar wood chips with the following analysis:

- Carbon 50.88 % wt. dry
- Hydrogen 6.04 % wt. dry
- Nitrogen 0.17 % wt. dry
- Sulfur 0.09 % wt. dry
- Oxygen 41.9 % wt. dry
- Chlorine unknown
- Ash 0.92 % wt. dry

12.3. Technology #3

Gasifier outlet H_2/CO ratio is 0.72, and tar reformer outlet H_2/CO ratio is unknown.

The biomass feed stock is hybrid poplar wood chips with the same analysis as that shown above in technology #2.

13. REACTOR TEMPERATURE

The first step in the gasification process is the drying or driving off of the moisture contained in the feedstock. The subsequent step is a pyrolysis step where volatiles are released at temperatures up to approximately 1,300 °F. The material that remains is activated carbon or char material. In an autothermal (direct) gasification process the next step is incomplete combustion or partial oxidation of the carbon to produce heat. An allothermal (indirect) gasification process, on the other hand, skips the combustion step and moves directly to the final reduction step. In the reduction step the carbon reacts with CO_2 and water vapor to produce CO and H_2. Typically the reduction reactions occur at temperatures between 1,400 °F and 1,600 °F for gasification system that produces dry ash and 1,650 °F to 1,800 °F for a gasification system that produces a slag type ash.

Both the BFB and CFB gasification technologies operate within the dry ash temperature range and are not expected to have drastic temperature related differences.

The following gasification and tar reforming temperatures were given by the technology providers.

13.1. Technology #1

- Gasifier outlet - 1,560 °F
- Tar reformer outlet – 1,600 °F

13.2. Technology #2

- Gasifier outlet - 1,560 °F
- Tar reformer outlet – 1,830 °F

13.3. Technology #3

- Gasifier outlet - 1,475 °F
- Tar reformer outlet – unknown

Higher gasification and tar reforming temperatures would result in the following:

- Increase in carbon conversion
- Reduction in tar content
- Reduction in methane and higher hydrocarbons content
- Maximized H_2 and CO production
- Increased slagging and agglomeration potential

14. REACTOR PRESSURE

Gasifier operating pressure affects not only equipment cost and size but also the interfaces with the rest of the GTL plant, including the necessary gas cleanup systems. Since gas synthesis processes operate at elevated pressures, the syngas generated by low pressure gasifiers must be compressed. This favors low temperature gas cleaning since the syngas must be cooled prior to compression in any case. High pressure gasification favors hot, pressurized cleanup of the syngas and operation of downstream equipment at high temperature and sufficiently high pressure to accommodate flow control and equipment pressure drops.

14.1. Gasification Pressure by Technology

- Technology #1 – 130 PSIG
- Technology #2 – 1 PSIG
- Technology #3 – 38 PSIG

14.2. Pressurized System Advantages

- Lower level of internal power consumption
- Reduced air space per mass of fuel, which increases the syngas production rate for a given reactor volume.
- Reduced reactor volume and investment costs required for a given throughput. However, such a vessel requires more steel and a code stamp, which increases the investment cost. Overall, the investment cost would still decrease with increased pressure.
- Decreased sintering of the ash.

14.3. Pressurized System Disadvantages

- A more complicated pressurized feed system is required; however, with densified fuel a reduction in feed system equipment size and/or count can be realized.
- The need for high pressure syngas cleanup devices, which are still in an early stage of development.
- Higher methane content in the syngas
- A more complex installation, which will lead to high specific investment costs for low capacity installations.

15. FIXED BED, BFB, CFB REACTOR DESIGN COMPARISONS

The following is a discussion of the advantages of fluid bed (BFB and CFB) versus fixed bed (down and updraft) gasifier designs. Note that the discussion does not compare or contrast entrained flow designs due to their inherent difficulty in gasifying biomass and their relatively high investment costs.

15.1. Advantages - Fluidized Bed versus Fixed Bed

- Relatively smaller volumes required due to high heat exchange and reaction rates resulting from the intense mixing of the bed.
- Wider range of acceptable feedstock particle sizes, density, moisture and ash content.
- More scalable and applicable for large installations.
- More uniform and narrow temperature profile without hot spots.
- Higher conversion rates possible resulting in less unconverted carbon.

15.2. Disadvantages - Fluidized Bed versus Fixed Bed

- More complicated design.
- Higher specific investment cost.
- Possibly higher tar and dust content (except fixed bed updraft design can contain 10-20% tars).
- Higher gas temperature vaporizes alkali metals, which leads to the need for sorbent material.
- Incomplete carbon burn out.
- More complex operation. Must control the supply of biomass, oxygen and steam as well as the reactor pressure.
- Higher power consumption due to compression of gas stream if pressurized.

15.3. Advantages of CFB Design versus BFB Design

- The fluidized bed in a BFB reactor acts similarly to the bed in a continuous stirred reactor, which enables some of the biomass and tar to escape/slip from the bed. This problem is much less likely to occur in a CFB design.

Uniform feedstock introduction and proper bed utilization minimizes the escape of any biomass and tar.

- CFB designs have a bit more fuel flexibility to process larger amounts of lightweight, fine material.

- A CFB reactor requires the bed material and char to leave the reactor and be circulated back to the gasifier via cyclone(s), thus a swedged (a continuous stacked cylinder vessel with a smaller diameter lower section and a larger diameter upper section) gasifier is not necessary for disengagement of the solids. The resulting reactor cross-sectional area will be smaller for a CFB at the same throughput, but since residence time is an important process variable to guarantee complete pyrolysis, then either optimal feedstock particle sizes must be fed to the gasifier, or the CFB must be taller so that there is sufficient volume to achieve the desired residence time. While a sweged BFB reactor can be more complicated to fabricate, a CFB reactor may have to be taller. Considering all factors and depending on the reactor design, a CFB reactor (alone) will typically only be slightly less expensive than a BFB reactor at the same throughput.

- A CFB reactor can be scaled-up to a much larger capacity than a BFB; however, pressurized BFB's can be very large scale. For biomass gasification, HGI's opinion is that a single, pressurized BFB reactor can be designed to handle all the woodchip feedstock that can be economically procured from the land surrounding a greenfield installation. Thus both designs are well suited for operation at the proposed feedstock rate of 1,000 oven dry metric tons per day. Note that a CFB has a much broader window of acceptable gas velocity and that the whole reactor volume is usable, which gives a CFB a scale-up advantage.

- A CFB reactor generally has a better turn down capability than a low or atmospheric pressure BFB because bed utilization is not as big an issue as it is for a BFB design. Assuming atmospheric pressure operation, a BFB may be able to accomplish a 3:1 turndown, and a CFB may be able to achieve a 5:1 turndown. However, assuming a pressurized BFB design, reducing the reactor pressure makes a 10:1 turndown possible, while maintaining the gas velocity within an operating window acceptable for optimal BFB operation. Note that the turndown for a pressurized CFB reactor should be similar to that of the BFB design.

- A consensus seems to be that char conversion is slightly higher for CFB designs due to the recycling of the char; however, based on published data for biomass gasification, there seems to be no statistical difference in the carbon conversion between the two designs. Although a CFB has the ability to manage zoning of oxidation/pyrolysis, it is handicapped by the limited particle collection efficiency of a cyclone. Since biomass is typically highly friable, it quickly turns to fine particles that blow through the cyclone and don't get another opportunity to pass through the gasifier. A BFB with underbed feedstock introduction has a similar advantage of zoning the oxidation/pyrolysis. With an underbed feedstock design, carbon conversions greater than 96% have been demonstrated using woody feedstocks. The bottom line is that the design of the BFB reactor really determines if there is any advantage or disadvantage in char conversion between the two designs.

- Carbon burn-out is sometimes considered higher in a CFB; however, the same argument that was offered in the char conversion discussion above applies.

15.4. Disadvantages of CFB Design versus BFB Design

- The balance of plant or auxiliary equipment for CFB designs is generally more costly due to the higher costs associated with larger fans/compressors and the associated larger horsepower drives for the same throughput. This is especially true when comparing a CFB to a low or atmospheric pressure BFB; however, pressurized BFB designs will have compressors that are similar in size to those used on CFB designs.

- Heat exchange within the fluidized bed can be more efficient in a BFB design, assuming optimal bed utilization and uniformity.

- A BFB may yield a slightly more uniform syngas, especially when operating with variable feedstocks; however, this depends on the characteristics of the feedstock and how frequently the feedstock type is changed. Ultimately, proper design determines how well each reactor responds to changes in feedstock.

- A BFB design exhibits a nearly uniform temperature distribution throughout the reactor, while a CFB reactor develops a temperature gradient in the direction of solid flow. When temperature control is important (managing ash chemistry and promoting the most efficient gasification reactions), the BFB is generally preferred. Note, however, that an indirect or allothermal CFB design, rather than a direct or autothermal CFB design will exhibit much less in the way of temperature gradients.

- A CFB design generally exhibits higher abrasion and wear due to the higher velocities within the reactor and cyclone. Therefore, care must be taken when designing the refractory and metallurgy of the reactor and cyclone.

This challenge also typically results in higher refractory maintenance costs for CFB designs.

- Because of the overall design, a CFB is a bit more complex to operate than a BFB. The main control parameters in a BFB are gas velocity, temperature and pressure. In a CFB, the media recirculation rate, which establishes the axial temperature profile, adds another level of operational complexity.

- BFB reactors are generally of swedged design (a continuous stacked cylinder vessel with a smaller diameter lower section and a larger diameter upper section). Gas rising from the lower section to the larger diameter upper section decreases in velocity below the fluidization velocity and disengages from the bed. This large diameter diengagment zone also improves residence time and thus improves syngas composition. Biomass reacts so fast that many BFB vendors do not employ this design, and it has been abandoned to some degree based on the added cost of the swedged design.

- In general there are fewer, proven CFB gasifiers in operation, and less data is available than for BFB designs.

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SECTION 5
ORDER OF MAGNITUDE CAPITAL COST ESTIMATES

1. GENERAL

The cost estimates for the three gasifier technologies are order of magnitude or feasibility capital grade estimates. According to The Association for the Advancement of Cost Engineering (AACE), these are considered Class 4 capital cost estimates.

The cost estimates are based on the written project descriptions in Section 3 of this report. Overall process flow diagrams and preliminary equipment lists were developed to help define the scope for each technology. Quotes were obtained for the major equipment components and scaling factors were used to put the prices for all three technologies on a common capacity basis. The remaining cost inputs were factored from the major equipment pricing and did not include material takeoffs.

According to AACE, the expected level of accuracy for a Class 4 estimate is as follows:

- Low: -15% to -30%
- High: +20% to +50%

The estimates are also considered to be in current 2011 dollars. A discussion of the "nth" plant costs follows in this section.

2. CAPITAL COST ESTIMATES

Order of magnitude capital cost estimates in 2011 dollars for installation of 1,000 oven dry metric tons per day biomass gasification and tar reformer systems are shown below.

- Total Installed Cost - Technology #1 - $71,497,300
- Total Installed Cost - Technology #2 - $60,529,800
- Total Installed Cost - Technology #3 - $71,622,900

Additional details of the order of magnitude estimates are shown in Appendix D.

3. NTH PLANT COST CONSIDERATIONS

Operating in competitive markets makes individuals, enterprises and industries improve, innovate and become more efficient. This fact is at the heart of the experience curve or learning curve phenomenon. This phenomenon holds true for industrial process industries, including energy technologies. History tells us that experience accumulates with time and that unit costs decrease with experience, therefore unit costs for a given technology are expected to decrease with time. In addition, total installed costs also follow this phenomenon to a point. Emerging technologies are also subject to these capital cost reductions over time; however, costs generally level out once the technology and industry matures.

Biomass conversion to liquid fuels is an immature industry with only a handful of commercial installations operating or near the construction phase. As the basis for this discussion, it is assumed that cellulosic conversion to liquid fuels will become a viable industry and produce a marketable product over the next 10 to 15 years. This implies that the industry will become mature by the end of this 10 to 15 year period, and we refer to this mature industry as the "nth" plant. Over this time period, based on the learning curve phenomenon, it is also expected that the technology providers, fabricators and engineering firms will innovate and become more efficient and that capital costs and installation costs will decrease.

It is our estimate that the capital costs for gasification and tar reformation equipment will decrease 10-15% over the next 10 to 15 years. It is also noted that the 10 to 15% reduction is based on constant dollars.

The following list summarizes our reasoning for the potential decrease in the capital costs for gasification and tar reformation equipment over the next 10 to 15 years.

- Technology provider engineering costs will come down for an "nth" plant due to the repetition and reuse of previous designs.

- Engineering consultant costs will decrease because technology providers will begin to engineer and design more complete installation packages.

- Future competition will generally lead to more competitive bidding and a reduction in vendor profit margin, thus reducing equipment capital costs.

- A reduction in technology provider margins used to cover initial R&D costs will decrease, thus reducing equipment capital costs.

- Process contingency and engineering contingency will decrease because designs will be more compete and optimized for the “nth” plant.

- Inovation and improvements in design will lead to reliability and uptime improvements for the same cost. This will not factor directly into capital costs, unless the improvements allow for a downsizing of the original design that leads to a reduction in equipment size and/or removal of backup/spare equipment. As an example, a system that was originally designed for two parallel feed lines, each with the capability to deliver 50% of the rated system capacity, might be replaced by a new, improved and more reliable single feed system sized at 100% of the rated capacity, which could reduce the “nth” plant feed system cost by 50%.

- Process intensification will lead to process changes that reduce energy, increase yields and reduce size and cost of equipment. Process intensification is a paradigm shift in process design, development and implementation. As an example, process intensification often invovles one or more of the following:

    - A move from batch to continuous processing.

    - Use of intensive reactor technologies with high mixing and heat transfer rates (e.g. FlexReactor, HEX Reactors) in place of conventional stirred tanks.

    - Implementation of a multidisciplinary methodology which considers opportunities to improve the process technology and underlying chemistry at the same time.

    - Use of 'Plug and Play' process technology to provide flexibility in a multiproduct environment.

- Possible examples of process intensification related to gasification and tar reformation are:

    - Improvements in reforming catalysts that eliminate the need for regeneration.

    - Implementation of catalytic gasification to eliminate the need for a tar reformer.

- Development of higher pressure systems that permit the use of smaller volume reactors.

- Use of modular design techniques will lead to improvments in fabrication, shipping and construction costs.

- Taking advantage of economies of scale will lead to the design of larger capacity plants, typically resulting in a decrease in the marginal cost of increased production.

- Use of a conventional construction approach (owner procured equipment, engineering and construction management) as a replacement for the engineer, procure and construct (EPC) approach (reduced owner risk and easier access to capital) used by immature industries will reduce overall installation costs for "nth" plant construction.

- Changes in consumables will decrease operating costs as follows:

  - A reduction in oxygen usage will reduce the size and cost of the air separation plant.

  - More resistant or longer lasting bed and sorbent materials could decrease the storage and feeding equipment size and cost.

  - A reduction in steam usage will decrease the steam generation system size and cost.

  - Optimization/integration of cooling demand will reduce cooling water system size and cost.

4. BASIS OF ESTIMATES – DIRECT COSTS

Note that the basis of estimate for many of the direct costs is common for the three technologies. The similarities and differences are explained below.

4.1. Land

The cost of land is not included in the three capital cost estimates.

4.2. Civil/Earthwork

For each of the three technologies the project site is assumed to be a relatively flat, greenfield site, free of equipment and buildings. The site requires minimal grading, cut and backfill to prepare it for construction. An allowance is included in the estimates for general site preparation (grading, cut and backfill) for the gasifier islands as well as the air separation plants.

Allowances are included in the three estimates for excavation and backfill requirements related to the gasifier island foundation. The gasifier island structure, including the tar reformer, is expected to be approximately 50′ wide, 100′ long and 100′ tall for all three technologies. All equipment itemized in the equipment lists, with the exception of the following, is expected be included in the common gasifier island structure.

- Air separation plant (O_2 and N_2, different for all three technologies).
- Ash silo (Technology #1 and Technology #2).
- Combustion reactor stack (Technology #2 only).

Allowances are also included in the three estimates for excavation and backfill requirements related to the air separation plant foundations. Technology #1 and Technology #3 are expected to use on the order of 30,000 to 32,000 lb/hr of oxygen (92% purity). The estimated layout for a VPSA air separation plant at this production rate is approximately 70′ wide by 150′ long. Technology #2 does not use oxygen; however, it includes a small air separation plant for nitrogen production. The estimated layout for this plant is approximately 20′ wide by 40′ long.

The following civil/earthwork items are also included in the capital cost estimates:

- Storm water collection systems, ditches and containment systems (retention pond, etc.).
- Roadways around gasification and air separation plant only.
- Paving around gasification and air separation plant only.
- Civil/earthwork related to a process sewer system within the gasification and air separation plant boundaries only.
- Civil/earthwork related to a sanitary sewer system within the gasification and air separation plant boundaries only (assumed to tie into a municipal system).
- Civil/earthwork related to a natural gas supply line within the gasification and air separation plant boundaries only (assumed to tie into a municipal system).

4.3. Buildings

The three estimates each include two buildings: an electrical room and a control room.

An electrical room is included to house the secondary switch gear, MCCs and automation equipment. The room will be equipped with ventilation, air conditioning and filtering. The estimate includes a factor for the electrical room with allowances for all electrical, mechanical and plumbing typical of an industrial electrical building. The electrical room is estimated to be approximately 25′ wide, 100′ long and 17′ tall.

A control room is included to house the control stations and associated computer hardware for operation of the control systems and will also include restrooms. The control room will be equipped with ventilation, air conditioning and filtering. The estimate includes a factor for the control room with allowances for all electrical, mechanical and plumbing typical of an industrial control room building. The control room is estimated to be approximately 25′ wide, 50′ long and 17′ tall.

The following items are not included in the capital cost estimates:

- Lockers.
- Lunch rooms (cafeterias).
- Office space or meeting space.

4.4. Equipment Foundations and Supports

The main process equipment for all three technologies is located in steel structures which include all structural components, as well as access to all equipment. The structure does not include a roof or siding. The steel and erection of the structure is included in the three vendor packages.

The entire gasifier island structure will sit on foundations that are optimized for the arrangement of building columns and actual loads. The entire structure will also sit on a curbed concrete slab. The area will be sloped to a u-drain which will drain to a storm water system (piping and retention pond) that is included in the estimate. The air separation plant will include a combination of foundations and slabs depending on equipment loads. Mat type foundations are used. All mat foundations include rebar rather than mesh, and include form work, hardware (anchor bolts, iron, etc.), concrete, finishing and stripping. The estimate includes factors for all of the above items.

The loads of the gasification and tar reforming equipment are expected to necessitate piles. The number of piles depends on the site location and the soil conditions. For the purposes of these estimates, the soils are assumed to have a 3,000-4,000 psi bearing pressure for foundation design. A factor is included for piles and pile caps for these soil conditions. The air separation plant equipment is not expected to require piles.

No structures or bridges are included to support interconnecting piping between the gasifier island and the remaining process areas. Piping is assumed to terminate at the gasifier island structure boundary, with the exception of the O_2, N_2 and flue gas piping/ductwork. All piping supports within the gasifier island boundary are included in the estimate.

4.5. Piping

All syngas piping, ductwork, process piping, manual process valves, dampers and expansion joints are included in the three vendor packages. All high temperature gas piping is refractory lined. All other hot process piping is externally insulated. Refractory and insulation is also included in the vendor packages.

Installation of the above piping/ductwork and related items is included in the vendor packages.

The following additional items are also included in the estimates:

- Wash up hose stations.
- Eyewash and shower stations.
- Piping related to storm water runoff systems.
- Natural gas piping within the gasification island boundary.
- Process water piping within the gasification island boundary.
- Potable water piping within the gasification island boundary.
- Cooling water piping within the gasification island boundary.
- Steam piping within the gasification island boundary.
- Fire water systems (piping, hydrants, sprinklers etc.) for the gasifier island only.

The following items are not included in the estimates:

- Natural gas piping (including the source tie-in) outside of the gasification island boundary.
- Process water piping (including the source tie-in) outside of the gasification island boundary.
- Potable water piping (including the source tie-in) outside of the gasification island boundary.
- Cooling water piping outside of the gasification island boundary.
- Steam piping outside of the gasification island boundary.
- Fire water source tie-in.

4.6. Electrical

Most of the electrical systems and associated installation costs are included in the vendor packages. The electrical systems include: MCCs, motor cabling and control cabling, terminations, conduit, cable ways, control systems' uninterrupted power supplies (UPS), motors, lightning protection, lighting, grounding and wiring to supply power to automation and process protection systems.

The following additional electrical items are also included in the capital cost estimates:

- Unit substations (transformers/primary switch/secondary switch gear).
- The substations would normally be located outside in a curbed area. The secondary switch gear would normally be located inside the electrical building.
- Cable and conduit for the power distribution feeders between the transformers and the indoor switchgear, and between the switchgear and the MCCs.

The following electrical items are not included in the capital cost estimates:

- High voltage feeder and breaker.
- Medium voltage feeder (this feeder will feed a single substation or loop feed multiple unit substations).

4.7. Instrumentation

A programmable logic controller (PLC) based control system with a human machine interface (HMI) and the necessary computer software and hardware to operate the gasifier system is included in each of the vendor packages. The estimates also include the installation of the PLC and HMI, and the associated control system equipment (I/O racks, etc.). PLC programming and programming software is also included.

All field instruments for the measurement and control of such parameters as pressure, temperature and flow, and their installation costs, are included in the estimates. Special instruments such as various gas analysis devices and special reactor bed level control devices and their installation are also included. Field instruments and transducers are 4-20mA type with twisted shield pair wiring and discrete devices are normally 120VAC.

All actuated valves (control valves) and dampers and their installation are included in the estimate.

Technology #2 will also require a continuous emissions monitoring system (CEMS) to monitor emissions from the combustion reactor stack, which is included in the Technology #2 estimate.

4.8. Insulation and Painting

Labor as well as materials related to insulation of equipment and piping is included in the estimates.

An allowance is also included for general painting of equipment.

4.9. Equipment

Major gasification and tar reforming equipment and erection pricing was provided in vendor quotations for all three technologies. The erection pricing was adjusted by taking advantage of HGI's cost estimating experience.

Detailed equipment lists located in Appendix D show the equipment that is included in the estimates.

The following items are specifically not included in the estimates:

- Natural gas compression (if necessary).
- Process water treatment system (filters, pumps, tanks, etc.).
- Potable water system (pumps, tanks, etc.).

- Cooling water system (cooling tower, pumps, etc.).
- Steam generation system (heat recovery steam generator or fired boiler).
- Fire water system (pumps, tanks, etc.).
- Waste water treatment facility.

Note that rather than using an over the fence oxygen source, air separation plants are included as indicated in the equipment lists. For information purposes only, the costs and operating conditions for an example over the fence VPSA oxygen supply system are listed below. Note that this information is for a 243 tons per day supply system at 92% purity. This flow rate does not represent the actual demand of any of the technologies analyzed. For comparison sake, technology #1 requires a total of 473 tons per day of oxygen at 92% purity.

- O_2 capacity 243 stpd @ 92% purity & 10 psig
- Plot size approx 70′ x 150′
- Unit power 1/12 kW/thousand cubic feet
- Largest motor 2,500 HP
- Total connected load 4500 kvA
- Condensate 5 gal/day
- Cost $150,000 /month
- Liquid O_2 backup $9,000 /month

4.10. Demolition

It is assumed that the gasifier system is erected on a greenfield site, thus no demolition is included in any of the estimates.

4.11. Labor

Total direct labor costs were determined by applying hourly labor rates to work hour estimates. The estimated labor rates are based on union wage rates for the Southeastern United States. No added labor costs for overtime work were taken into account in the estimate. The labor rates are fully loaded rates, thus all contractor premium pay, indirects and markups are included in the base rate.

All equipment work hour estimates were derived using factors.

5. BASIS OF ESTIMATES – INDIRECT AND OTHER COSTS

Note that the indirect and other costs are common for the three estimates as follows:

5.1. Contractor indirect costs included in the labor rate:

- Home office job management costs.
- Statutory taxes and insurance.
- Welfare and fringes.
- Workers compensation.
- Contractor's general liability insurance.
- Small tools / consumables.
- Field office job management costs.
- Support craft - fire watch, snorkel watch, cleanup, warehousing.
- Scaffolding.
- Temporary construction – power, air, ice, water, toilets, barricades.
- Rental of construction equipment and required supplies and services.
- Field office and miscellaneous expenses.
- Supervision (above first level 'pusher' foreman).
- Casual overtime premium pay (i.e., not scheduled).
- Contractor markup.

5.2. Indirect Costs

Direct costs and contractor's indirect costs are combined in the estimates and result in the total construction cost, otherwise known as total installed cost (TIC). To this were added the following indirect costs:

5.2.1. Engineering (Consultant)

Engineering costs are included at a rate of 10.0% of the total direct cost. This rate includes both feasibility and detailed design engineering.

5.2.2. Owner Engineering

Owner engineering costs are included at a rate of 2.0% of the total direct cost. This includes the owners engineering and oversight efforts.

5.2.3. Pre-Project Cost

Pre-project costs such as those associated with surveying, soil testing, ecological studies, etc. are included at a rate of 0.5% of the total construction cost.

5.2.4. Construction Management

Construction Management costs are included at a rate of 2.0% of the total construction cost.

5.2.5. Environmental or Legislative Costs

Environmental or legislative costs such as those associated with environmental permitting are included at a rate of 1.0% of the total construction cost.

5.2.6. Capitalized Spares

The costs of recommended spare parts are included at a rate of 3.0% of the total construction cost.

5.2.7. Sales Taxes

Sales taxes are included for owner and contractor furnished materials, including equipment, consumables and rentals. Sales taxes are included at a rate of 3.5% of the total construction cost, which approximates a 7.0% sales tax on the sum of the owner and contractor furnished materials.

5.2.8. Freight

Freight costs are included at a rate of 3.0% of the owner direct cost of equipment and materials.

5.3. Contingency

This category covers unforeseen costs that are expected but not identified at the time of the estimate. Contingency costs are included at a rate of 20% of the total direct and indirect costs. The percentage is based on HGI experience and the class of the estimate. Contingency is used to cover unanticipated additional costs that may develop during detailed engineering and construction such as:

- Higher than anticipated labor rates that are caused by changes in local conditions but not caused by extended strikes.
- Minor changes in equipment and material specifications and pricing.
- Minor changes in construction that are agreed to be within the scope of the estimate.
- Items encountered during design or constructions that were unaccounted for or not determinable at the time the estimate was prepared.

It is expected that contingency funds will be used. Contingency is not intended to cover escalation of major, unanticipated costs nor does it cover increases in project costs due to scope changes.

The contingency factor is applied to the sum of the total construction cost and indirect costs, and the combined total is called the Process Plant & Equipment (PP&E) cost.

5.4. Additional Indirect Costs

The following indirect costs are added to the PP&E cost to produce the grand total, otherwise known as the total project investment (TPI) for the estimates:

5.4.1. Escalation

Escalation costs are not included.

5.4.2. Capitalized Interest

Capitalized interest costs are not included.

5.4.3. Deferred Start-Up Costs

Deferred start-up costs are not included.

5.4.4. Working Capital

Working capital is not included.

5.4.5. Operator Training

Operator training costs are included at a rate of 1.0% of the total construction cost.

5.4.6. Start-Up

Startup and commissioning services are included at a rate of 1.0% of the total construction cost.

5.5. Cost Exclusions

The following costs are not included in this estimate:

- Any costs beyond startup.
- Costs for lost production.

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SECTION 6
DETAILED CAPITAL COST ESTIMATE – CFB GASIFIER

1. TECHNOLOGY DESCRIPTION

1.1. General

To assist in the design and cost estimating of gasifier systems, four Microsoft Excel workbook models were developed (CFB gasifier, BFB gasifier, high pressure biomass feed system and low pressure biomass feed system). The models can be used to analyze the impact of various design parameters on capital costs. Each model produces a material balance, equipment list, capital cost estimate, equipment drawings and preliminary general arrangement drawings. Example outputs of each model are included in the Appendixes.

The Circulating Fluid Bed Gasification System Model (CFB gasifier model), which is discussed below, is based on an allothermal circulating fluid bed gasification system with an allothermal circulating fluid bed syngas reforming system. This particular gasification process uses four fluid bed reactors: a gasifier reactor, a char combustion reactor in the gasifying loop, a syngas reformer reactor and reformer bed media heating reactor in the reforming loop.

The CFB gasifier model requires a gasifier reactor pressure input in the range of 20-150 PSIG and a biomass feed rate input in order to size the entire gasification system. Pressure drop inputs are used to establish the design pressures for all of the other reactors, cyclones and pressure vessels.

1.2. Biomass Storage and Metering System

Dried biomass is metered to the gasifier reactor through four parallel lines of storage bins and screw conveyors. The number of lines can be reduced, depending on the production rate of the system. Dried biomass is transported to the gasifier/reformer building by a conveyor. The biomass delivery conveyor and biomass feed system are outside the battery limits of the cost estimate, although a proposed biomass feed system is described.

The biomass is deposited in a weigh-bin. The weigh bin feeds a lock hopper via twin screw dischargers. Actuated gate type vales are used to isolate the inlet and outlet lines on the lock hopper. Biomass is discharged from the lock hopper to a pressurized metering bin, equipped with live bottom screws, that feeds a transfer screw conveyor. Transferred biomass is discharged to the gasifier feed screw.

The lock hoppers, metering bins, transfer screws and gasifier feed screws are all designed for pressurized operation. A somewhat simpler biomass feed system can be used when the gasifier reactor is operated at low pressure.

All other biomass unloading, handling and storage equipment is outside the battery limits of the CFB gasifier model. These items include but are not limited to truck unloading, screening, storage, drying, dryer air emissions abatement equipment, dry storage, and all conveyance and transport equipment prior to the weigh bins.

1.3. Gasifier Reactor

The gasifier is designed for a wood chip biomass feed and uses steam and hot bed media to gasify the wood chips and form hydrogen and carbon monoxide. All of the oxygen for the gasification process is supplied by the water molecules in the steam and no other air or oxygen gas is added. The biomass and hot bed media are both introduced near the bottom of the upflow gasifier reactor. Medium pressure steam is introduced into the bottom of the gasifier reactor through a refractory insulated distribution header to facilitate fluidization. No air or oxygen is added to the gasifier; however, nitrogen gas may be used to pressurize the biomass feed system and to assist with fluidization during startups. Nozzles are either refractory lined or water cooled. Due to the high gasifier temperature (approximately 1,560 °F), the reactor vessel is completely lined with refractory to protect the integrity of the steel shell.

The gasifier reactor is sized to accommodate the expanding gas stream as it passes up through the vessel. This is accomplished by using a small diameter lower section combined with a larger diameter upper section. All of the bed media, some partially gasified biomass (char particles) and syngas exit at the top of the reactor. The syngas and entrained solids are routed through a large diameter duct to the primary gasifier cyclone. Due to the fast fluidization and the high gas velocities, the biomass material becomes thoroughly mixed with the bed material to enhance the heat and mass transfer and rapidly convert the biomass into syngas. NREL provided the composition (Reference Phillips et al., NREL/TP-510-41168) of the syngas produced by this type of circulating fluid bed gasification reactor.

1.4. Gasifier Cyclones

The entrained char and bed media mixture in the syngas from the gasifier reactor is separated by two cyclones mounted in series. The bed media and char mixture is discharged from the bottom cones of both the primary cyclone (Gasifier Reactor No.1 Cyclone) and secondary cyclone (Gasifier Reactor No.2 Cyclone) through refractory lined pipes to a solids collection bin (Gasifier Reactor Cyclone Solids Collection Bin). The solids discharge lines from the two cyclones enter the collection bin through vertical drop legs. Solids levels are maintained in the drop legs by the differential pressure between the cyclones and the collection bin to form a seal. Steam is added at the bottom of the collection bin to fluidize the contents and transport the bed media and char to the overflow line feeding the char combustion reactor. Nitrogen gas may be used for fluidization during startups.

Syngas exits from the top of the secondary gasifier cyclone and is routed through a large diameter duct to a header that feeds the bottom of the syngas reformer reactor.

1.5. Gasifier Reactor Startup Burner

The gasifier reactor is equipped with a natural gas/process syngas burner for pre-heating the refractory linings and the bed media in the gasifier and the syngas reformer reactors, and their cyclones, bed media collection bins and the interconnecting gas ducts and bed media lines during startups.

1.6. Char Combustion Reactor and Combustion Air System

The bed media and char mixture from the gasifier cyclones collection bin enters the char combustion reactor through a side wall nozzle near the bottom of the reactor. The circulating fluid bed combustion reactor is a pressure vessel, which operates at a somewhat lower pressure (approximately 10 PSIG) than the gasifier reactor. The reactor is refractory lined and is equipped with an air distribution header located at the bottom of the vessel to facilitate fluidization. A centrifugal fan blows ambient air through an air heater located in the flue gas duct on the discharge of the secondary char combustion cyclone, where the air is indirectly heated to approximately 800 °F. The heated combustion air is then routed through a duct to the char combustion reactor air distributor to combust the char and promote fluidization. The combustion process produces a hot flue gas stream (approximately 1,800 °F) containing carbon-free ash and reheated bed media.

1.7. Char Combustion Cyclones

A mixture of entrained ash and bed media in the syngas from the char combustion reactor is separated by two cyclones mounted in series. Most of the bed media and a small percentage of the ash are discharged from the bottom cone of the primary cyclone (Char Combustion Reactor No.1 Cyclone) through a refractory lined pipe to a solids collection bin (Char Combustion Reactor No.1 Cyclone Solids Collection Bin). The solids discharge line enters the collection bin through a vertical drop leg. A solids level is maintained in the drop leg by the differential pressure between the cyclone and the collection bin to form a seal. Steam is added at the bottom of the collection bin to fluidize the contents and transport the bed media and char to the overflow line feeding the gasifier reactor. Nitrogen gas may be used for fluidization during startups.

The syngas, entrained ash and depleted bed media (small particle size) from the primary cyclone are ducted to the secondary cyclone where the remaining ash and bed media are removed. Flue gas exits from the top of the char combustion secondary cyclone and is ducted to the char combustion reactor air heater. The cooled flue gas is then pulled through an exhaust fan to a vent stack, where it is vented to the atmosphere. The fan and vent stack are outside the battery limit of the capital cost estimate. Note that there is sufficient heat remaining in the flue gas that it could be used for further heat recovery prior to venting.

1.8. Char Combustion Reactor Startup Burner

The char combustion reactor is equipped with a natural gas/process syngas burner for pre-heating the refractory linings and the bed media in the char combustion reactor, its cyclones, bed media collection bin and the interconnecting gas ducts during startups.

1.9. Gasifier Loop Ash Discharge System

The ash and bed media mixture discharged from the bottom cone of the secondary char combustion reactor cyclone is routed through a refractory lined pipe to the gasifier loop depleted bed media and ash cooling screw conveyor. The screw conveyor is water-cooled. A rotary valve in the discharge chute from the screw conveyor is used to maintain a seal on the secondary cyclone. Cooled ash and bed media are discharged from the screw conveyor to the gasifier loop depleted bed media and ash storage bin for accumulation until offloaded for disposal. A water misting spray is used to dampen the ash as it is discharged from the cooling screw to reduce dusting in the storage bin. Bin discharge is outside the battery limit.

1.10. Gasifier Loop Bed Media Makeup System

The gasifier loop bed media makeup system begins with a truck unloading station for receipt and offloading of bed media. Trucks equipped with self contained blowers will connect to a pneumatic line feeding the top of the gasifier loop bed media feed bin. Bed Media is discharged from the feed bin to a blower equipped pneumatic transfer line, which transfers bed media to the char combustion reactor.

1.11. Syngas Reformer Reactor

The syngas reformer reactor is a circulating fluid bed reactor designed to convert hydrocarbon molecules in syngas to carbon monoxide and hydrogen using steam and hot catalytic bed media. Syngas from the gasifier loop and hot bed media (the heat source) are both introduced at the bottom of the upflow reformer reactor, with the syngas fluidizing the bed media. Medium pressure steam is introduced into the bottom of the syngas reformer reactor through a refractory insulated distribution header. No air or oxygen is added to the reformer. Nozzles are either refractory lined or water cooled. Due to the high reformer reactor temperature (approximately 1.652 °F), the reactor vessel is completely lined with refractory to protect the integrity of the steel shell.

The reformer reactor is a cylindrical vessel sized to accommodate syngas from the gasifier as well as syngas from a supplementary source such as natural gas. Reformed syngas and all of the bed media exit at the top of the reactor and are routed through a large diameter duct to the primary reformer cyclone.

1.12. Syngas Reformer Cyclones

The entrained bed media in the reformed syngas from the reformer reactor is separated by two cyclones mounted in series. Bed media is discharged from the bottom cones of both the primary cyclone (Syngas Reformer Reactor No.1 Cyclone) and secondary cyclone (Syngas Reformer Reactor No.2 Cyclone) through refractory lined pipes to a solids collection bin (Syngas Reformer Reactor Cyclone Solids Collection Bin). The solids discharge lines from the two cyclones enter the collection bin through vertical drop legs. Solids levels are maintained in the drop legs by the differential pressure between the cyclones and the collection bin to form a seal. Steam is added at the bottom of the collection bin to fluidize the contents and transport the bed media to the overflow line feeding the reformer bed media heating reactor.

Reformed syngas exits from the top of the secondary reformer cyclone and is routed through a large diameter duct to the battery limit of the gasifier/reformer building.

1.13. Reformer Bed Media Heating Reactor and Burner System

Bed media from the reformer cyclones collection bin enters the reformer bed media heating reactor through a side wall nozzle near the bottom of the reactor. The circulating fluid bed reactor is a pressure vessel, which operates at a somewhat lower pressure (approximately 10 PSIG) than the reformer reactor. The reactor is refractory lined and is equipped with a natural gas/process syngas burner assembly for heating the bed media. The combustion products from the burner provide the gas to facilitate fluidization. A centrifugal fan blows ambient air through an air heater located in the flue gas duct on the discharge of the secondary reformer bed media heating cyclone, where the air is indirectly heated to approximately 800 °F. The heated combustion air is then routed through a duct to the reformer bed media heating reactor burner.

1.14. Reformer Bed Media Heating Reactor Cyclones

Entrained bed media in the syngas from the reformer bed media heating reactor is separated by two cyclones mounted in series. Most of the bed media is discharged from the bottom cone of the primary cyclone (Reformer Bed Media Heating Reactor No.1 Cyclone) through a refractory lined pipe to a solids collection bin (Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin). The solids discharge line enters the collection bin through a vertical drop leg. A solids level is maintained in the drop leg by the differential pressure between the cyclone and the collection bin to form a seal. Steam is added at the bottom of the collection bin to fluidize the contents and transport the bed media to the overflow line feeding the syngas reformer reactor.

The reformed syngas and entrained, depleted, small particle size bed media from the primary cyclone are ducted to the secondary cyclone where the remaining bed media is removed. Flue gas exits from the top of the reformer bed media heating reactor secondary cyclone and is ducted to the bed media heating reactor air heater. The cooled flue gas is then pulled through an exhaust fan to a vent stack, where it is vented to the atmosphere. The fan and vent stack are outside the battery limit of the capital cost estimate. Note that there is sufficient heat remaining in the flue gas that it could be used for further heat recovery prior to venting.

1.15. Reformer Loop Ash Discharge System

The bed media and leftover ash (carryover from the gasifier loop) discharged from the bottom cone of the secondary reformer bed media heating reactor cyclone is routed through a refractory lined pipe to the reformer loop depleted bed media and ash cooling screw conveyor. The screw conveyor is water-cooled. A rotary valve in the discharge chute from the screw conveyor is used to maintain a seal on the secondary cyclone. Cooled bed media is discharged from the screw conveyor to the reformer loop depleted bed media storage bin for accumulation until offloaded for disposal. A water misting spray is used to dampen the ash as it is discharged from the cooling screw to reduce dusting in the storage bin. Bin discharge is outside the battery limit.

1.16. Reformer Loop Bed Media Makeup System

The reformer loop bed media makeup system begins with a truck unloading station for receipt and offloading of bed media. Trucks equipped with self contained blowers will connect to a pneumatic line feeding the top of the reformer loop bed media feed bin. Bed Media is discharged from the feed bin to a blower equipped pneumatic transfer line, which transfers bed media to the reformer bed media heating reactor.

1.17. Utilities

The gasifier/reformer building is equipped with piping from the battery limits to the point of use. The following utilities are required:

1.17.1. Steam – to provide medium pressure steam at a pressure of 20-150 PSIG for the gasifier and syngas reformer reactors and to provide fluidizing steam for the four cyclone solids collection bins.

1.17.2. Cooling Water System – cooling water supply and return for the depleted bed media and ash cooling water screw conveyors.

1.17.3. Flare Stack - during start-ups, shutdowns and emergency stop events, syngas is routed to a flare stack outside the battery limits of the gasifier/reformer building for incineration and exhaust to the atmosphere.

1.17.4. Natural Gas – to provide fuel for the gasifier reactor startup burner, the char combustion reactor startup burner and the reformer bed media heating reactor burner.

1.17.5. Supplemental Syngas – to provide feed gas for the reformer loop when the gasifier loop is shutdown.

1.17.6. Instrument Air – to provide air for operation of valve actuators, etc.

1.17.7. Plant Air – to provide air for building services and cleanup.

1.17.8. Hose Station Water – to provide water for building services and cleanup.

1.17.9. Potable Water – to provide water for emergency eye wash stations and showers.

2. MODEL BASIS AND ASSUMPTIONS

2.1. The CFB gasifier model is a material balance model, not a material and energy balance model. The CFB gasifier model provides inputs for the estimated temperature in each of the four reactors.

2.2. The CFB gasifier model requires inputs for scheduled and unscheduled downtime from which the total annual operating hours are calculated. The operating hours and an input of the annual capacity (short tons/year) are then used as the basis for calculating the design operating rate (short tons/hour) for the model.

2.3. Dried biomass is metered to the gasifier reactor through four parallel lines of storage bins and screw conveyors. The CFB gasifier model does not automatically calculate the size, cost or weight of this equipment when the biomass feed rate changes but provides for input of the cost and weight values in the 04-Equip List spreadsheet (see Appendix E). Depending on the biomass feed rate, the number of lines can be reduced be inputting zero values for the cost and weight of each piece of equipment on a given line or by reducing the cost and weight of the equipment on each line. The biomass feed lines include lock hoppers to isolate the feed lines from the gasifier for pressures up to 150 PSIG. If desired, the lock hoppers can be eliminated for low pressure operation by inputting zero values in the 04-Equip List spreadsheet for the cost and weight of the lock hoppers.

2.4. The biomass composition and physical properties were provided by NREL. These values were used in the Excel workbook example shown in this report. However, the biomass composition can be changed by adjusting the values in the 06-Design Criteria spreadsheet.

2.5. The CFB gasifier model example shown in this report specifies the dried biomass moisture content at 5.0%. However, the biomass moisture content is an input value which can be changed in the 06-Design Criteria spreadsheet.

2.6. Not all the input values in the 06-Design Criteria spreadsheet are used in calculations. Some values (e.g. biomass bulk density and biomass type) are provided for information only.

2.7. Bed media is considered to be inert for calculations in the model. Moisture content of the bed media is an input value in the 06-Design Criteria spreadsheet. There are inputs for two types of bed media, Type-A for the gasifier loop and Type-B for the reformer loop.

2.8. The CFB gasifier model provides inputs for nitrogen gas composition, physical properties and feedrate to the process in the 06-Design Criteria spreadsheet. All of the nitrogen is added to the gasifier reactor even if it is actually added elsewhere. This was done to simplify the model since any nitrogen added would eventually end up in the reformed syngas stream.

2.9. The CFB gasifier model provides inputs for oxygen gas composition and physical properties. Oxygen can be added to the gasifier reactor, and an input for oxygen feedrate is provided in the 06-Design Criteria spreadsheet. The workbook example used in this report does not use any oxygen, and the feedrate input value is set to zero. If oxygen is used, the workbook will automatically reduce the amount of steam added to the gasifier reactor.

2.10. The CFB gasifier model provides inputs for natural gas composition and physical properties in the 06-Design Criteria spreadsheet. Natural gas is used as the fuel source for heat generation in the reformer bed media heating reactor. The natural gas feed rate is automatically calculated to provide the heat needed to reheat the bed media fed to the reformer bed media heating reactor. Natural gas is also used in the gasifier reactor and the char combustion reactor during startups; however, since the material balance is a steady state model, this additional natural gas is not part of the material balance.

2.11. The CFB gasifier model provides inputs for air composition and physical properties in the 06-Design Criteria spreadsheet. Air is used for combustion oxidation in the char combustion reactor and the reformer bed media heating reactor.

2.12. The CFB gasifier model provides inputs for steam pressure and degrees of superheat. There are two locations where steam is added to the process, one is the gasifier reactor and other is the syngas reformer reactor. Inputs for the addition of fluidization steam to the bed media solids collection bins are not provided. However, if fluidization steam were added, it would end up in the four reactor vessels. In the case of the gasification reactor and the syngas reformer reactor bin fluidization steam would diminish the steam added directly, but the total steam would remain the same. In the case of the char combustion reactor the bin fluidization steam would, however, slightly increase the total water vapor in the flue gas.

2.13. The gasifier syngas composition and physical properties for an allothermal circulating fluid bed gasification reactor were provided by NREL. These values were used in the Excel workbook example shown in this report. However, the gasifier syngas composition can be changed by adjusting the values in the 06-Design Criteria spreadsheet.

2.14. The CFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for composition and physical properties of a supplemental syngas stream. Supplemental syngas can replace or supplement the gasifier loop syngas. The supplemental syngas is added to the syngas header feeding the bottom of the syngas reformer reactor.

2.15. Syngas reforming calculations involve converting carbon in the hydrocarbon gases to carbon monoxide with the oxygen from water molecules. The CFB gasifier model provides cells in the 06-Design Criteria spreadsheet for inputting the percent conversion of each hydrocarbon compound, which might be a function of the catalytic bed media chosen. Some of the water molecules are provided by the water vapor present in the incoming syngas. The remaining amount of water is determined by calculation and forms the basis for the amount of steam added to the syngas reformer reactor. The hydrogen from the reacted water molecules increases the overall hydrogen content of the reformed syngas. Since the CFB gasifier model does not include an energy balance, heats of reaction are not used in any calculations.

2.16. The CFB gasifier model is designed for a gasifier reactor pressure input in the range of 20-150 PSIG. These inputs are made in the 06-Design Criteria spreadsheet. Differential pressure values are entered for the other three reactors (char combustion reactor, syngas reformer reactor, and reformer bed media heating reactor) to provide the motive force for moving bed media and syngas through the system.

2.17. The gasifier loop is designed for a maximum temperature of 1,900 °F. The reformer loop is designed for a maximum temperature of 2,000 °F. These values are important for the selection of refractory linings in all high temperature vessels, ducts and lines. The refractory linings used in the CFB gasifier model are based on a steel shell skin temperature of 300 °F. If a different skin temperature is desired, the refractory inputs also need to be changed.

2.18. The CFB gasifier model provides cells in the 06-Design Criteria spreadsheet for the design of each piece of refractory lined equipment (reactors, cyclones, ducts and lines). The refractory thickness is not automatically calculated but requires an entry specifying the refractory thickness for each piece of equipment.

2.19. The CFB gasifier model designs refractory lined reactors, cyclones and tanks from two basic shapes: cylinders and cones (or frustums of a cone). The vessels are designed in sections and a cost and weight is automatically calculated for each section using data from the material balance and lookup tables containing unit weights and costs. The design includes nozzles, support lugs, refractory anchors, inserts (e.g. distribution headers for air and steam) and refractory. The total cost is broken into a material cost and a fabrication cost.

2.20. The CFB gasifier model provides cells in the 06-Design Criteria spreadsheet for eleven nozzles on each vessel (i.e. reactors, cyclones and tanks). Some nozzles are automatically sized while others require an input.

2.21. Reactor diameters are calculated from an input of the gas upflow velocity target, and the reactor heights are calculated from an input of the retention time target.

2.22. Equipment items named "lines" are used to transport bed media and ash and are relatively free of gases (e.g. drop legs from cyclones to collection bins). These lines are not automatically sized and require a size input in the 06-Design Criteria spreadsheet.

2.23. Refractory lined ducts and lines require flanges every 10 feet to provide sections that can reasonably lined with refractory. The CFB gasifier model automatically adds flanges to account for this requirement. Each duct and line contains one expansion joint.

2.24. The gasification and syngas reforming equipment is all located in a single multi-story building.

2.25. The gasifier/reformer building is comprised of (1) – 35′ x 40′ gasifier bay and (11) – 25′ x 25′ bays for the rest of the system. The footprint does not automatically change with changes is the overall system design. The footprint is used to determine the number of piles and the quantity of concrete needed for the foundation. The bay sizes are changeable input values in the 03-Cost Est and can be modified as desired.

2.26. The weight of structural steel, grating, handrails, etc. for building construction is automatically calculated from the total equipment weight.

3. EXCEL WORKBOOK MODEL OPERATION

The CFB gasifier model is an Excel workbook containing 51 Excel spreadsheet tabs that interact to produce a capital cost estimate for an allothermal circulating fluid bed gasification and an allothermal circulating fluid bed syngas reforming system. The CFB gasifier model includes a mass balance, equipment list and capital cost estimate, and it produces a set of equipment drawings for the reactor vessels, cyclones and tanks.

3.1. Excel Options

Before manipulating the CFB gasifier model, the Excel Options entry screen must be accessed. Under the "Formulas" selection, the "Enable iterative calculation" box must be selected and set for 100 Maximum Iterations and 0.001 Maximum Change. Under the "Advanced" selection, the "Allow editing directly in cells" box must be turned deselected. With "Allow editing directly in cells" turned off, the operator is able to jump from a cell containing a formula to the referenced cell by double clicking on the cell with the formula. This is important in navigating the Excel workbook.

3.2. Cell Colors

3.2.1. Bright Yellow - Cells backlighted in bright yellow are input cells containing values that can be altered.

3.2.2. Light Yellow - Cells backlighted in light yellow are input cells containing values that can be altered but which normally remain the same.

3.2.3. Bright Green - Cells backlighted in bright green contain constants that are not to be altered.

3.2.4. Pink - Cells backlighted in pink contain a reference to cells in another spreadsheet(s) within the model and may display the referenced cell or use it in a calculation.

3.2.5. Lavender - Cells backlighted in lavender are usd in the materials spreadsheets (e.g. spreadsheets 07-Plate Steel) to display material values and prices obtained from vendors.

3.2.6. White – Cells backlighted in white contain calculations that reference cells only within the same spreadsheet.

3.2.7. Light Green - Cells backlighted in light green contain text used for line item headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.8. Medium Blue - Cells backlighted in medium blue contain text used for column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.9. Light Blue - Cells backlighted in light blue contain text used for sub-column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.10. Dark Blue (With White Text) - Cells backlighted in dark blue contain references to other cells in the workbook and are only used for navigating (double clicking) to jump to other points in the workbook.

3.3. Individual Spreadsheet Descriptions

3.3.1. 00-Color Codes & Tab Index: This spreadsheet contains descriptions for each cell color used in the spreadsheets and provides a tab index with descriptions.

3.3.2. 01–Contact List: This spreadsheet contains a list of NREL, HGI and equipment vendor contacts who participated in this project.

3.3.3. 02-Dwg List: This spreadsheet is the control document for assigning drawing numbers and names to material balance drawings (MB-1-XX) and equipment drawings (EQ-1-XX).

3.3.4. 03-Cost Est: This spreadsheet contains the capital cost estimate summary and cost estimate details.

- Inputs are made for quantities of materials, unit prices and labor rates for site preparation (civil earthwork) equipment foundations, non refractory lined pipe (e.g. steam, natural gas, water), electrical equipment and wiring (motors are included with equipment), insulation and painting, and demolition.
- Inputs are made for the gasifier/reformer building footprint and factors for calculating structural steel quantities as a function of the total weight of all equipment and refractory lined ducts and pipe.
- Inputs are made for calculating factored costs (e.g. instrumentation, engineering, contingency, etc.) as a percentage of capital costs.

3.3.5. 04-Equip List: This spreadsheet is the control document for assigning equipment names and equipment numbers. Also, the spreadsheet provides cells for inputting the biomass feed system costs and weights.

3.3.6. 05-Map: This spreadsheet is a navigation tool for locating specific pieces of equipment in the 06-Design Criteria spreadsheet. This spreadsheet also displays brief summaries of all the refractory lined reactors, cyclones, tanks, ducts and lines.

3.3.7. 06-Design Criteria: This spreadsheet is the primary document for entering/changing data inputs.

3.3.8. 07-MB: This spreadsheet contains all of the material balance calculations. There are no data input cells in this spreadsheet except for the naming of some streams.

3.3.9. 08-Plate Steel: This spreadsheet contains a lookup table which lists plate steel cost as a function of plate thickness for plate steel manufactured from ASME SA-516, Grade 70 carbon steel. All vessels (reactors, cyclones and tanks) are priced based on this grade of steel. The table also shows the maximum allowable stress for the steel plate at various temperatures.

3.3.10. 09-Fab Cost: This spreadsheet contains a lookup table which lists vessel fabrication cost as a function of total vessel weight for vessels fabricated with ASME SA-516, Grade 70 carbon steel.

3.3.11. 10-Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.12. 11-Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½" to 24" the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26" to 96" the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.13. 12-Exp Joints: This spreadsheet contains a lookup table which lists expansion joint properties and cost as a function of diameter.

3.3.14. 13-Vessel-Anchors: This spreadsheet contains a lookup table which lists refractory anchor properties and costs for a refractory system that will prevent vessel skin temperatures from exceeding 300 °F.

3.3.15. 14-Vessel-Refractory: This spreadsheet contains a lookup table which lists refractory properties and costs for a refractory system that will prevent vessel skin temperatures from exceeding 300 °F.

3.3.16. 15-Nozzle-Anchors: This spreadsheet contains a lookup table which lists refractory anchor properties and costs for a refractory system that will prevent nozzle skin temperatures from exceeding 300 °F.

3.3.17. 16-Nozzle-Refractory: This spreadsheet contains a lookup table which lists refractory properties and costs for a refractory system that will prevent nozzle skin temperatures from exceeding 300 °F.

3.3.18. 17-Sat Stm: This spreadsheet contains a Saturated Steam Table which is used as a lookup table for steam properties.

3.3.19. 18-Water: This spreadsheet contains a lookup table for water properties.

3.3.20. 19-Sheet Steel Allowable Stress: This spreadsheet contains a lookup table for determining the maximum allowable stress in tension for carbon and low alloy steel.

3.3.21. 20-Weld Joint Eff: This spreadsheet contains a lookup table that lists the weld efficiency for steel subjected to various degrees of radiographic examination.

3.3.22. 21-Steel Info: This spreadsheet contains a list of acceptable materials of construction for various components of fabricated vessels, ducts and lines.

3.3.23. 22-Columns: This spreadsheet contains a lookup table for assigning an identification number to columns in other lookup tables.

3.3.24. 23-Excel Help: This spreadsheet contains examples of a number of formulas used in the workbook.

3.3.25. 24-Scratch Sheet: This spreadsheet is to be used for making temporary calculations.

3.3.26. MB-1-01 Thru MB-1-06: These 6 spreadsheets contain the material balance flow diagrams.

3.3.27. EQ-1-01 Thru EQ-1-20: These 20 spreadsheets contain the equipment drawings of the reactors, cyclones and tanks.

4. CAPITAL COST SUMMARY

The capital cost estimate in the CFB gasifier model is considered a Class 3 budgetary estimate according to The Association for the Advancement of Cost Engineering (AACE) guidelines.

The cost estimate is the end product of the CFB gasifier model. Pricing and pricing guidelines were obtained from vendors in order to populate the material pricing lookup tables in the model. The costs of all the major equipment are calculated in the model. The remaining cost inputs are factored from the major equipment pricing and are shown in the 03-Cost Est spreadsheet tab in the model.

Cost estimates produced by the model are stated in 2011 dollars. According to AACE, the expected level of accuracy for a Class 3 estimate should average +40%/-20%.

The capital cost estimate from the CFB gasifier model is shown in Appendix H for installation of a 1,000 oven dry metric tons per day biomass gasification and tar reformer system.

5. BASIS OF ESTIMATE – DIRECT COSTS

A summary of the methods and assumptions that were used in preparing the detailed capital cost estimate are listed below:

5.1. Labor

Total direct labor costs were determined by applying hourly labor rates to work hour estimates. Note that the estimate assumes an average hourly labor rate of $85 for most of the installation, erection and construction activities. The estimated labor rate is loosely based on union wage rates for the Southeastern United States. It is understood that most crafts and disciplines charge differing rates, however to simplify the estimate a single average rate was used. The labor rate is modifiable by the user to represent a location of higher or lower labor rates.

No added labor costs for overtime work were taken into account in the estimate. The labor rates are fully loaded rates, thus all contractor premium pay, indirects and markups are included in the base rate.

5.2. Land

The cost of land is not included in the capital cost estimate.

5.3. Civil/Earthwork

5.3.1. Site Clearing

The project site is assumed to be a relatively flat, greenfield site, free of equipment and buildings. The prepared site is assumed to only account for the area that the gasifier island structure occupies, thus an assumption of 200′ by 200′ is used. This 200′ by 200′ site rounds to approximately one acre of area that requires clearing and grubbing. Note that clearing and grubbing refers to removing trees and brush from the site, grinding the stumps and removing the wood chips. Note that an allowance for equipment rental associated with site clearing is also included.

Fill and compaction is required for the same assumed area. A 3′ cut depth was assumed for the volume calculations.

The unit price and the labor hours per unit for the site clearing activities was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.2. Foundation Preparation

Based on the preliminary design of the gasifier structure as seen in drawing GA-01, located in Appendix G, the foundation area was estimated. An assumption for excavation and backfill depth was made resulting in the volume of excavation and backfill used for the pricing. Note that an allowance for equipment rental associated with foundation preparation is also included.

The unit price and the labor hours per unit for the excavation and backfill was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.3. Piles

The loads of the gasification and tar reforming equipment are expected to necessitate piles. The number of piles depends on the site location and the soil conditions. For the purposes of this estimate, the soils are assumed to have a 3,000-4,000 psi bearing pressure for foundation design. A factor is included for the pile density and pile length for these assumed soil conditions. Both the pile density and pile length can be modified if actual soil conditions are known. Note that an allowance for equipment rental associated with pile driving is also included.

The unit price and the labor hours per unit for the installation of the piles was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.4. Other

The following Civil/Earthwork items are NOT included in the capital cost estimate:

- Trenching and backfill for any underground utilities. This could include natural gas lines, electrical feeders, fire water piping, process or sanitary sewer lines, storm water drainage piping/culverts, etc.

- Storm water collection systems, ditches and containment systems (retention pond, etc.).

- Roadways and/or paving.

5.4. Buildings

5.4.1. Gasifier Island Structure

Based on the equipment sizing and loads, the gasifier island structure was preliminarily designed and sized. Drawings of the structure are located in Appendix G. Note that the estimate only includes the structural steel, miscellaneous access steel, grating and guardrail, and access stairs. The estimate calculates the steel quantities based on ratios of the various steel categories to the total equipment weight. It does not include any masonry or carpentry work, sprinkler systems, roofing or siding.

The unit price and the labor hours per unit for the installation of the steel was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.4.2. Gasifier Island Foundation

The entire gasifier island structure will sit on foundations that are optimized for the arrangement of building columns and actual loads, however to simplify the estimate, a 30" slab throughout is assumed. The slab will be sloped to a u-drain which will drain to a storm water system (piping and retention pond) that is NOT included in the estimate. Mat type foundations are used. All mat foundations include rebar rather than mesh, and include form work, hardware (anchor bolts, iron, etc.), concrete, finishing and stripping. The estimate includes factors for all of the above items.

The unit price and the labor hours per unit for the installation of the mat foundation was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.4.3. Miscellaneous Building Items Not Included

- An electrical/MCC/controls room.
- An operator control room.
- Locker room.
- Lunch rooms (cafeterias).
- Office space or meeting space.

5.5. Equipment Foundations and Supports

Large equipment will require concrete pedestals for support. An allowance is included for large equipment pedestal volume.

The unit price and the labor hours per unit for the installation of the equipment foundations was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.6. Piping

All refractory lined syngas piping/ductwork and expansion joints are included in the equipment section of the estimate. The remaining process piping, manual and check valves are included in the piping estimate.

An allowance for piping was made for 1″, 2″, 3″ 4″ and 6″ carbon steel piping. These allowances are meant to account for process items such as, natural gas, process water, potable water, cooling water, inert gas, process air, and steam.

The unit price and the labor hours per unit for the installation of the piping was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

No structures or bridges are included to support interconnecting piping between the gasifier island and any other process areas. Piping is assumed to terminate at the gasifier island structure boundary. All piping supports within the gasifier island boundary are included in the estimate.

5.6.1. Piping Items Included in Cost Estimate

- Wash up hose stations.
- Eyewash and shower stations.

5.6.2. Piping Items Not Included in Cost Estimate

- Any piping outside the gasifier island boundary.
- Piping related to storm water runoff systems.
- Piping related to process and/or sanitary sewer systems.
- Fire water systems (piping, hydrants, sprinklers etc.).

5.7. Electrical

5.7.1. Only the installation of the motors is currently included in the electrical systems estimate. Allowances for 5, 10, 25, 50, 100, 200 and 250 horsepower motors are included. The estimate includes an allowance for 200′ of motor wiring and conduit, terminations, motor and motor starter.

5.7.2. The unit price and the labor hours per unit for the installation of the motors was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.7.3. Electrical Items Not Included in Cost Estimate

- MCCs
- Control cabling, terminations, conduit, and cable ways.
- Control systems' uninterrupted power supplies (UPS).
- Lightning protection.
- Lighting.
- Grounding.
- High voltage feeder and breaker.
- Unit substations (transformers/primary switch/secondary switch gear).

- Medium voltage feeder (this feeder will feed a single substation or loop feed multiple unit substations).

- Cable and conduit for the power distribution feeders between the transformers and the indoor switchgear, and between the switchgear and the MCCs.

5.8. Instrumentation

The estimate includes one allowance for all of the instrumentation and controls equipment and installation, based on a percentage of the project direct costs. Field instruments and transducers are 4-20mA type with twisted shield pair wiring and discrete devices are normally 120VAC.

5.8.1. Items Included in Instrumentation Allowance

- All field instruments for the measurement and control of such parameters as pressure, temperature and flow. The wiring, termination, and installation costs are also included.

- A programmable logic controller (PLC) based control system with a human machine interface (HMI).

- The necessary computer software and hardware to operate the control system.

- Control system I/O racks.

- Actuated valves and valve hook up.

5.8.2. Items Not Included in Instrumentation Allowance

- Special instruments such as various gas analysis devices and special reactor bed level control devices and their installation.

- Any continuous emissions monitoring system (CEMS) to monitor air emissions.

5.9. Process Insulation and Painting

An allowance for 200′ of 4″ piping insulation is included for the steam piping only.

An allowance for high temperature indicating paint for use on the reactors, ducts and cyclones is included.

Labor as well as materials related to the above insulation and painting is included in the estimate.

The unit price and the labor hours per unit for the insulation and painting was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

Process equipment insulation is NOT included in the capital cost estimate.

5.10. Equipment

5.10.1. Fuel Handling And Storage Systems

The gasifier island fuel handling and storage systems were priced based on vendor quotes and vendor correspondence. The fuel handling and storage systems are not variable in size or cost based on the gasifier process throughput or sizing. Modifying the count or size must be done manually.

The base system includes 4 complete fuel handling and storage systems. Note also that the fuel handling and storage systems are a lock hopper type design with a weigh bin and a metering bin included. A lock hopper system is only needed for higher pressure applications, however this feed system is thought to be the worst case, or highest cost scenario. The user must manually change the feed system count or pricing to better represent a low pressure system, or a system with lower production rates.

5.10.2. Reactors, Cyclones and Bins

The reactors (gasifier, char combustor, reformer, and reformer heater), cyclones and bins are sized in the model based on a user provided production rate. The total steel is then calculated and priced. Installation is included based on vendor information. Refractory cost and installation is also included.

5.10.3. Miscellaneous Equipment Included

- Gasifier loop bed media makeup system.
- Reformer loop bed media makeup system.
- Char combustor bed media and ash disposal system.
- Reformer heater bed media and ash disposal system.

- Flare system.

5.10.4. Miscellaneous Equipment Not Included

- Inert gas system.
- Natural gas compression (if necessary).
- Process water treatment system (filters, pumps, tanks, etc.).
- Potable water system (pumps, tanks, etc.).
- Cooling water system (cooling tower, pumps, etc.).
- Steam generation system (heat recovery steam generator or fired boiler).
- Flue gas scrubbers or other abatement equipment.
- Flue gas ID fans.
- Stack.
- Fire water system (pumps, tanks, etc.).
- Waste water treatment facility.

5.11. Demolition

It is assumed that the gasifier system is erected on a greenfield site, thus no demolition is included in any of the estimates.

6. BASIS OF ESTIMATE – INDIRECT AND OTHER COSTS

6.1. Contractor indirect costs included in the labor rate:

6.1.1. Home office job management costs.

6.1.2. Statutory taxes and insurance.

6.1.3. Welfare and fringes.

6.1.4. Workers compensation.

6.1.5. Contractor's general liability insurance.

6.1.6. Small tools / consumables.

6.1.7. Field office job management costs.

6.1.8. Support craft - fire watch, snorkel watch, cleanup, warehousing.

6.1.9. Scaffolding.

6.1.10. Temporary construction – power, air, ice, water, toilets, barricades.

6.1.11. Rental of construction equipment and required supplies and services.

6.1.12. Field office and miscellaneous expenses.

6.1.13. Supervision (above first level 'pusher' foreman).

6.1.14. Casual overtime premium pay (i.e., not scheduled).

6.1.15. Contractor markup.

6.2. Indirect Costs

Direct costs and contractor's indirect costs are combined in the estimates and result in the total construction cost, otherwise known as total installed cost (TIC). To this were added the following indirect costs:

6.2.1. Engineering (Consultant)

Engineering costs are included at a rate of 10.0% of the total direct cost. This rate includes both feasibility and detailed design engineering.

6.2.2. Owner Engineering

Owner engineering costs are included at a rate of 2.0% of the total direct cost. This includes the owners engineering and oversight efforts.

6.2.3. Pre-Project Cost

Pre-project costs such as those associated with surveying, soil testing, ecological studies, etc. are included at a rate of 0.5% of the total construction cost.

6.2.4. Construction Management

Construction Management costs are included at a rate of 2.0% of the total construction cost.

6.2.5. Environmental or Legislative Costs

Environmental or legislative costs such as those associated with environmental permitting are included at a rate of 1.0% of the total construction cost.

6.2.6. Capitalized Spares

The costs of recommended spare parts are included at a rate of 3.0% of the total construction cost.

6.2.7. Sales Taxes

Sales taxes are included for owner and contractor furnished materials, including equipment, consumables and rentals. Sales taxes are included at a rate of 3.5% of the total construction cost, which approximates a 7.0% sales tax on the sum of the owner and contractor furnished materials.

6.2.8. Freight

Freight costs are included at a rate of 3.0% of the owner direct cost of equipment and materials.

6.3. Contingency

This category covers unforeseen costs that are expected but not identified at the time of the estimate. Contingency costs are included at a rate of 15% of the total direct and indirect costs. The percentage is based on HGI experience and the class of the estimate. Contingency is used to cover unanticipated additional costs that may develop during detailed engineering and construction such as:

6.3.1. Higher than anticipated labor rates that are caused by changes in local conditions but not caused by extended strikes.

6.3.2. Minor changes in equipment and material specifications and pricing.

6.3.3. Minor changes in construction that are agreed to be within the scope of the estimate.

6.3.4. Items encountered during design or constructions that were unaccounted for or not determinable at the time the estimate was prepared.

It is expected that contingency funds will be used. Contingency is not intended to cover escalation of major, unanticipated costs nor does it cover increases in project costs due to scope changes.

The contingency factor is applied to the sum of the total construction cost and indirect costs, and the combined total is called the Process Plant & Equipment (PP&E) cost.

6.4. Additional Indirect Costs

The following indirect costs are added to the PP&E cost to produce the grand total, otherwise known as the total project investment (TPI) for the estimates:

6.4.1. Escalation

Escalation costs are not included.

6.4.2. Capitalized Interest

Capitalized interest costs are not included.

6.4.3. Deferred Start-Up Costs

Deferred start-up costs are not included.

6.4.4. Working Capital

Working capital is not included.

6.4.5. Operator Training and Start-Up

Operator training and startup and commissioning costs are included at a rate of 2.0% of the total construction cost.

6.5. Cost Exclusions

The following costs are not included in this estimate:

6.5.1. Any costs beyond startup.

6.5.2. Costs for lost production.

August 3, 2012

REPORT 30300/01
GASIFIER TECHNOLOGY ASSESSMENT – CONSOLIDATED REPORT

SECTION 7
DETAILED CAPITAL COST ESTIMATE – BFB GASIFIER

1. TECHNOLOGY DESCRIPTION

1.1. General

To assist in the design and cost estimating of gasifier systems, four Microsoft Excel workbook models were developed (CFB gasifier, BFB gasifier, high pressure biomass feed system and low pressure biomass feed system). The models can be used to analyze the impact of various design parameters on capital costs. Each model produces a material balance, equipment list, capital cost estimate, equipment drawings and preliminary general arrangement drawings. Example outputs of each model are included in the Appendixes.

The Bubbling Fluid Bed Gasification System Model (BFB gasifier model) is based on a bubbling fluid bed design using a single gasifier reactor vessel. The gasifier is designed to use oxygen to combust a portion of the biomass material (autothermal) to generate the heat required for gasification of the biomass. Steam is also added to provide the motive force to keep the bed material in suspension in the bottom section of the gasifier reactor.

The BFB gasifier model requires a gasifier reactor pressure input, which may be as high as 600 PSIG, and a biomass feed rate input to size the entire system. A pressure drop input is used to establish the design pressures for the gasifier cyclone.

1.2. Biomass Storage and Metering System

Dried biomass is metered to the gasifier reactor through parallel lines of storage bins and screw conveyors. The number of biomass feed lines is calculated as a function of the diameter of the bubbling fluid bed section of the gasifier reactor vessel and the diameter of the screw feeders. The cost of the biomass feed system is calculated in a separate workbook model; therefore, the feed system cost is not included in the BFB gasifier model.

1.3. Gasifier Reactor

The gasifier is designed for a wood chip or pellet biomass feed and uses steam and oxygen, along with bed media, to produce a bubbling fluid bed to gasify the wood chips and form hydrogen and carbon monoxide. Oxygen for the gasification process is added to the steam line prior to introduction to the gasifier reactor vessel. All of the oxygen bound in the biomass and the elemental oxygen added to the gasifier is converted to either carbon monoxide or carbon dioxide Depending on the desired oxygen content in the syngas, water molecules in the steam or in the biomass can provide oxygen and generate additional hydrogen. The biomass is introduced near the bottom of the upflow gasifier reactor. Steam and oxygen are introduced into the bottom of the gasifier reactor through a refractory insulated distribution header to facilitate fluidization. Nitrogen gas is used to pressurize the biomass feed system and to assist with fluidization during startups.

Nozzles are either refractory lined or water cooled. Due to the high gasifier temperature (approximately 1,600 °F), the reactor vessel is completely lined with refractory insulation to protect the integrity of the steel shell.

The gasifier reactor is sized to accommodate the expanding gas stream as it passes up through the vessel. This is accomplished by using a small diameter lower section combined with a larger diameter upper section. A small portion of the bed media, some partially gasified biomass (char particles) and syngas exit at the top of the reactor. The syngas and entrained solids are routed through a large diameter duct to the gasifier cyclone. NREL provided the composition (Reference Phillips et al., NREL/TP-510-41168) of the syngas produced by this type of gasification reactor.

1.4. Gasifier Cyclone

The entrained char and bed media mixture in the syngas from the gasifier reactor is separated by a single cyclone. The ash, char and bed media mixture is discharged from the bottom cone of the gasifier cyclone back into the gasifier.

1.5. Gasifier Reactor Startup Burner

The gasifier reactor is equipped with a natural gas burner for pre-heating the refractory linings and the bed media in the gasifier, cyclone, interconnecting refractory lined gas ducts and solids transport lines during startups.

1.6. Ash Discharge System

The ash, char and bed media mixture is discharged from the bottom of the gasifier reactor to the ash cooling screw conveyor. The screw conveyor is water-cooled. Cooled ash, char and bed media are discharged from the cooling screw conveyor to the ash discharge hopper, which is maintained at the same pressure as the gasifier reactor. An ash lock hopper is located directly below the ash discharge hopper to provide a means to depressurize the ash for disposal. The ash, char and bed media mixture is discharged into the ash lock hopper by gravity through an inlet block valve. The lock hopper outlet block valve is located on the discharge side of the ash lock hopper discharge screw conveyor. The ash, char and bed media mixture is conveyed by the lock hopper discharge screw conveyor to the battery limits of the system.

1.7. Bed Media Makeup System

The gasifier bed media makeup system begins with a truck unloading station for receipt and offloading of bed media. Trucks equipped with self contained blowers will connect to a pneumatic line feeding the top of the bed media storage bin. Bed media is discharged from the storage bin to a pneumatic transporter which uses pressurized nitrogen to transfer bed media to the gasifier reactor.

1.8. Utilities

The gasifier/reformer building is equipped with piping from the battery limits to the point of use. The following utilities are required:

1.8.1. Steam – to provide high pressure steam at a pressure of 150-600 PSIG to the gasifier reactor for fluidization of the bubbling fluidized bed.

1.8.2. Cooling Water System – cooling water supply and return for the ash cooling water screw conveyor.

1.8.3. Natural Gas – to provide fuel for the gasifier reactor startup burner.

1.8.4. Instrument Air – to provide air for operation of valve actuators, etc.

1.8.5. Plant Air – to provide air for building services and cleanup.

1.8.6. Hose Station Water – to provide water for building services and cleanup.

1.8.7. Potable Water – to provide water for emergency eye wash stations and showers.

2. MODEL BASIS AND ASSUMPTIONS

2.1. The BFB gasifier model is a material balance model; it does not have an energy balance component.

2.2. The BFB gasifier model requires inputs for scheduled and unscheduled downtime from which the total annual operating hours are calculated. The operating hours and an input of the annual capacity (metric tons/year) are then used as the basis for calculating the design operating rate (short tons/hour) for the model.

2.3. Dried biomass is metered to the gasifier reactor through injection screw conveyors. The BFB gasifier model calculates the number of injection screw conveyors. The equipment for the biomass feed system (single or multiple lines is not included in the cost estimate.

2.4. The biomass composition and physical properties were provided by NREL. These values were used in the Excel workbook example shown in this report. However, the biomass composition can be changed by adjusting the values in the 06-Design Criteria spreadsheet.

2.5. The BFB gasifier model example shown in this report specifies the dried biomass moisture content at 5.0%. However, the biomass moisture content is an input value which can be changed in the 06-Design Criteria spreadsheet.

2.6. Not all the input values in the 06-Design Criteria spreadsheet are used in calculations. Some values (e.g. biomass bulk density and biomass type) are provided for information only.

2.7. Bed media is considered to be inert for calculations in the model. Moisture content of the bed media is an input value in the 06-Design Criteria spreadsheet and the BFB GASIFIER MODEL accounts for this contribution to the moisture content of the syngas.

2.8. The BFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for nitrogen gas composition, physical properties and feedrate to the process. All of the nitrogen required for pressurization, seals, etc. is added to the gasifier reactor even if it is actually added elsewhere. This was done to simplify the model since any nitrogen added would eventually end up in the syngas stream.

2.9. Natural gas is used in the gasifier reactor startup burner during startups; however, since the material balance is a steady state model, this natural gas usage is not part of the material balance.

2.10. The BFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for oxygen gas composition, physical properties and an oxygen to biomass percentage. The oxygen feed rate to the gasifier reactor is calculated as a percentage of the oven dry biomass being added. Oxygen is added to the steam line feeding the gasifier reactor.

2.11. The BFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for degrees of superheat and feedrate to the process. The steam pressure is a function of the gasifier reactor pressure.

2.12. The BFB gasifier model provides an input in the 06-Design Criteria spreadsheet for gasifier reactor pressure. The BFB gasifier model is designed for a gasifier reactor pressure input in the range of 150-600 PSIG.

2.13. The gasifier reactor is designed for a maximum temperature of 1,900 °F. This temperature is important for the selection of refractory linings in all high temperature vessels, ducts and lines. The refractory linings used in the BFB gasifier model are based on a steel shell skin temperature of 300 °F. If a different skin temperature is desired, the refractory inputs will also need to be changed.

2.14. The gasifier syngas composition and the char composition for an autothermal bubbling fluid bed gasification reactor are calculated from algorithms published in Technical Report NREL/TP-510-45913, Appendix G, Table G-1 GTI Gasifier Correlation, pg 107, July 2009, provided by NREL. The algorithm constants are inputs in the 06-Design Criteria spreadsheet. Using these algorithms the following syngas and char components are calculated as a function of the biomass composition and the oxygen feedrate:

- Syngas - Hydrogen as H_2
- Syngas - Carbon Monoxide as CO
- Syngas - Carbon Dioxide as CO_2
- Syngas - Methane as CH_4
- Syngas - Ethylene as C_2H_4
- Syngas - Ethane as C_2H_6
- Syngas - Benzene as C_6H_6
- Syngas - Naphthalene (Tars) as $C_{10}H_8$

- Char - Nitrogen as N
- Char - Sulfur as S
- Char - Oxygen as O

2.15. Drawing SK-2-01 Gasification Reaction Diagram depicts the calculation sequence for determining the ultimate composition of the syngas and char produced from biomass, oxygen gas, steam, nitrogen gas and bed media in the gasifier.

2.15.1. A portion of the carbon (C) in the biomass is converted to compounds in the syngas as determined by the NREL algorithms, thus accounting for the amount of carbon dioxide (CO_2), carbon monoxide (CO) and all of the hydrocarbons (C_xH_x) in the syngas. The remainder of the carbon (C) in the biomass becomes part of the char.

2.15.2. A portion of the sulfur (S) in the biomass becomes part of the char as determined by the NREL algorithms. The remainder of the sulfur (S) in the biomass is converted to hydrogen sulfide (H_2S) in the syngas.

2.15.3. A portion of the nitrogen (N) in the biomass becomes part of the char as determined by the NREL algorithms. The remainder of the nitrogen (N) in the biomass is converted to ammonia (NH_3) in the syngas. All of the nitrogen (N) in the oxygen gas and nitrogen gas remains as nitrogen (H_2) gas in the syngas.

2.15.4. A portion of the oxygen (O) in the biomass becomes part of the char as determined by the NREL algorithms. The remainder of the oxygen (O) in the biomass, plus all of the oxygen from the oxygen gas and the nitrogen gas, is used in the formation of carbon dioxide (CO_2) and carbon monoxide (CO) in the syngas. However, since the total amount of oxygen from these three sources is insufficient to satisfy the amount needed to form carbon dioxide (CO_2) and carbon monoxide (CO) in the syngas, additional oxygen (O) is furnished from decomposition of water that is present in the system.

2.15.5. A portion of the water (H_2O) carried into the gasifier with the biomass, bed media makeup, oxygen gas, hydrogen gas and steam is decomposed to make up the shortfall in the amount of oxygen needed to form carbon dioxide (CO_2) and carbon monoxide (CO) in the syngas. The remainder of the water carried into the gasifier will remain as water vapor in the syngas.

2.15.6. Hydrogen (H) in the biomass plus the hydrogen released by water decomposition mentioned above is used to provide the hydrogen required for the formation of hydrocarbons (C_xH_x), hydrogen sulfide (H_2S), ammonia (NH_3) and hydrogen gas (H_2) in the syngas. Excess hydrogen (H) becomes part of the char.

2.16. All of the char formed in the gasifier reactor is carried over to the gasifier cyclone. The BFB gasifier model provides an input in the 06-Design Criteria spreadsheet for entering the percentage of char which is carried over in the syngas from the gasifier cyclone. The remaining char is recycled back to the gasifier reactor from the gasifier cyclone where it is discharged to the ash collection system.

2.17. The BFB gasifier model calculates the quantity of bed media in the bubbling fluid based on the volume of the small diameter lower cylinder section of the gasifier reactor. The BFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for entering the percentage of bed media which is carried over in the syngas from the gasifier reactor to the gasifier cyclone and the percentage of bed media which is discharged from the gasifier reactor to the ash discharge system. These bed media losses are used to determine the bed media makeup flowrate.

2.18. The BFB gasifier model provides an input in the 06-Design Criteria spreadsheet for entering the percentage of ash which is carried over in the syngas from the gasifier reactor to the gasifier cyclone. A second input is provided for entering the percentage of ash which is carried over in the syngas from the gasifier cyclone. The remaining ash is recycled back to the gasifier reactor from the gasifier cyclone where it is discharged to the ash collection system.

2.19. The BFB gasifier model provides cells in the 06-Design Criteria spreadsheet for the design of each piece of refractory lined equipment (reactor, cyclone, ducts and lines). The refractory thickness is not automatically calculated but requires an entry specifying the refractory thickness for each piece of equipment.

2.20. The BFB gasifier model designs refractory lined reactors, cyclones and tanks from three basic shapes: cylinders, cones (or frustums of a cone) and flat plates. The vessels are designed in sections and a cost and weight is automatically calculated for each section using data from the material balance and lookup tables containing unit weights and costs. The design includes nozzles, support lugs, refractory anchors, inserts (e.g. distribution headers for oxygen and steam) and refractory. The total cost is broken into a material cost and a fabrication cost.

2.21. The BFB gasifier model provides inputs in the 06-Design Criteria spreadsheet for thirteen nozzles on the gasifier reactor and gasifier cyclone and fourteen nozzles on tanks and bins. Some nozzles are automatically sized while others require an input.

2.22. The gasifier reactor diameter is calculated from an input of the gas upflow velocity target, and the reactor height is calculated from an input of the retention time target.

2.23. Equipment items named "lines" are where refractory lined steel lines are required for the transport of hot bed media and ash which is relatively free of gases (drop legs from gasifier cyclone to gasifier reactor and from gasifier reactor to ash discharge system). These lines are automatically sized from a solids velocity target input in the 06-Design Criteria spreadsheet.

2.24. Refractory lined ducts and lines require flanges every 10 feet (a changeable value in the 06-Design Criteria spreadsheet) to provide access for installation of refractory linings. The BFB gasifier model automatically adds flanges to account for this requirement. Each duct and line also contains one expansion joint.

2.25. The gasification equipment is all located in a single multi-story building.

2.26. The gasifier/reformer building is comprised of (4) – 30′ x 30′ bays. There are inputs in the 03-Cost Est spreadsheet, but they do not automatically change with changes is the overall system design. The footprint is used to determine the number of piles and the quantity of concrete needed for the foundation.

2.27. The weight of structural steel, grating, handrails, etc. for building construction is automatically calculated from the total equipment weight.

3. EXCEL WORKBOOK MODEL OPERATION

The BFB gasifier model is an Excel workbook containing 38 Excel spreadsheet tabs that interact to produce a capital cost estimate for an allothermal circulating fluid bed gasification and an allothermal circulating fluid bed syngas reforming system. The BFB gasifier model includes a mass balance, equipment list and capital cost estimate, and it produces a set of equipment drawings for the reactor vessel, cyclone and tanks.

3.1. Excel Options

Before manipulating the BFB gasifier model, the Excel Options entry screen must be accessed. Under the "Formulas" selection, the "Enable iterative calculation" box must be selected and set for 100 Maximum Iterations and 0.001 Maximum Change. Under the "Advanced" selection, the "Allow editing directly in cells" box must be turned deselected. With "Allow editing directly in cells" turned off, the operator is able to jump from a cell containing a formula to the referenced cell by double clicking on the cell with the formula. This is important in navigating the Excel workbook.

3.2. Cell Colors

3.2.1. Bright Yellow - Cells backlighted in bright yellow are input cells containing values that can be altered.

3.2.2. Light Yellow - Cells backlighted in light yellow are input cells containing values that can be altered but which normally remain the same.

3.2.3. Bright Green - Cells backlighted in bright green contain constants that are not to be altered.

3.2.4. Pink - Cells backlighted in pink contain a reference to cells in another spreadsheet(s) within the model and may display the referenced cell or use it in a calculation.

3.2.5. Lavender - Cells backlighted in lavender are used in the materials spreadsheets (e.g. spreadsheets 07-Plate Steel) to display material values and prices obtained from vendors.

3.2.6. White – Cells backlighted in white contain calculations that reference cells only within the same spreadsheet.

3.2.7. Light Green - Cells backlighted in light green contain text used for line item headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.8. Medium Blue - Cells backlighted in medium blue contain text used for column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.9. Light Blue - Cells backlighted in light blue contain text used for sub-column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.10. Dark Blue (With White Text) - Cells backlighted in dark blue contain references to other cells in the workbook and are only used for navigating (double clicking) to jump to other points in the workbook.

3.3. Individual Spreadsheet Descriptions

3.3.1. 00-Color Codes & Tab Index: This spreadsheet contains descriptions for each cell color used in the spreadsheets and provides a tab index with descriptions.

3.3.2. 01–Contact List: This spreadsheet contains a list of NREL, HGI and equipment vendor contacts who participated in this project.

3.3.3. 02-Dwg List: This spreadsheet is the control document for assigning drawing numbers and names to material balance drawings (MB-2-XX) and equipment drawings (EQ-2-XX).

3.3.4. 03-Cost Est: This spreadsheet contains the capital cost estimate summary and cost estimate details.

- Inputs are made for quantities of materials, unit prices and labor rates for site preparation (civil earthwork) equipment foundations, non refractory lined pipe (e.g. steam, natural gas, water), electrical equipment and wiring (motors are included with equipment), insulation and painting, and demolition.
- Inputs are made for the gasifier building footprint and factors for calculating structural steel quantities as a function of the total weight of all equipment and refractory lined ducts and pipe.
- Inputs are made for calculating factored costs (e.g. instrumentation, engineering, contingency, etc.) as a percentage of capital costs.

3.3.5. 04-Equip List: This spreadsheet is the control document for assigning equipment names and equipment numbers. Also, the spreadsheet provides cells for inputting the biomass feed system costs and weights.

3.3.6. 05-Map: This spreadsheet is a navigation tool for locating specific pieces of equipment in the 06-Design Criteria spreadsheet. This spreadsheet also displays brief summaries of all the refractory lined reactors, cyclones, tanks, screw conveyors, ducts and lines.

3.3.7. 06-Design Criteria: This spreadsheet is the primary document for entering/changing data inputs.

3.3.8. 07-MB: This spreadsheet contains all of the material balance calculations. There are no data input cells in this spreadsheet except for the naming of some streams.

3.3.9. 08-Plate Steel: This spreadsheet contains a lookup table which lists plate steel cost as a function of plate thickness for plate steel manufactured from ASME SA-516, Grade 70 carbon steel. All vessels (reactors, cyclones and tanks) are priced based on this grade of steel. The table also shows the maximum allowable stress for the steel plate at various temperatures.

3.3.10. 09-Fab Cost: This spreadsheet contains a lookup table which lists vessel fabrication cost as a function of total vessel weight for vessels fabricated with ASME SA-516, Grade 70 carbon steel.

3.3.11. 10-900# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.12. 11-150# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.13. 12-900# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½" to 24" the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26" to 96" the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.14. 13-150# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½" to 24" the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26" to 96" the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.15. 14-Exp Joints: This spreadsheet contains a lookup table which lists expansion joint properties and cost as a function of diameter.

3.3.16. 15-Vessel-Anchors: This spreadsheet contains a lookup table which lists refractory anchor properties and costs for a refractory system that will prevent vessel skin temperatures from exceeding 300 °F.

3.3.17. 16-Vessel-Refractory: This spreadsheet contains a lookup table which lists refractory properties and costs for a refractory system that will prevent vessel skin temperatures from exceeding 300 °F.

3.3.18. 17-Nozzle-Anchors: This spreadsheet contains a lookup table which lists refractory anchor properties and costs for a refractory system that will prevent nozzle skin temperatures from exceeding 300 °F.

3.3.19. 18-Nozzle-Refractory: This spreadsheet contains a lookup table which lists refractory properties and costs for a refractory system that will prevent nozzle skin temperatures from exceeding 300 °F.

3.3.20. 19-Screw Conv: This spreadsheet contains a lookup table for determining the weight, cost and horsepower for pressurized screw conveyors as a function of screw diameter and trough shell thickness.

3.3.21. 20-Motors: This spreadsheet contains lookup table for determining weight and cost of motors as a function of horsepower.

3.3.22. 21-Spare: Not Used

3.3.23. 22-Sat Stm: This spreadsheet contains a Saturated Steam Table which is used as a lookup table for steam properties.

3.3.24. 23-Water: This spreadsheet contains a lookup table for water properties.

3.3.25. 24-Sheet Steel Allowable Stress: This spreadsheet contains a lookup table for determining the maximum allowable stress in tension for carbon and low alloy steel.

3.3.26. 25-Weld Joint Eff: This spreadsheet contains a lookup table that lists the weld efficiency for steel subjected to various degrees of radiographic examination.

3.3.27. 26-Steel Info: This spreadsheet contains a list of acceptable materials of construction for various components of fabricated vessels, ducts and lines.

3.3.28. 27-Columns: This spreadsheet contains a lookup table for assigning an identification number to columns in other lookup tables.

3.3.29. 28-Excel Help: This spreadsheet contains examples of a number of formulas used in the workbook.

3.3.30. 29-Scratch Sheet: This spreadsheet is to be used for making temporary calculations.

3.3.31. MB-2-01 Thru MB-2-02: These 2 spreadsheets contain the material balance flow diagrams.

3.3.32. EQ-2-01 Thru EQ-2-06: These 6 spreadsheets contain the equipment drawings of the reactors, cyclones and tanks.

4. CAPITAL COST SUMMARY

The detailed capital cost estimate in the BFB gasifier model is considered a Class 3 budgetary estimate according to The Association for the Advancement of Cost Engineering (AACE) guidelines.

The cost estimate is the end product of the CFB gasifier model. Pricing and pricing guidelines were obtained from vendors in order to populate the material pricing lookup tables in the model. The costs of all the major equipment are calculated in the model. The remaining cost inputs are factored from the major equipment pricing and are shown in the 03-Cost Est spreadsheet tab in the model.

Cost estimates produced by the model are stated in 2012 dollars. According to AACE, the expected level of accuracy for a Class 3 estimate should average +40%/-20%.

The capital cost estimate from the BFB gasifier model is shown in Appendix H for installation of a 1,000 oven dry metric tons per day biomass gasification system.

5. BASIS OF ESTIMATE – DIRECT COSTS

A summary of the methods and assumptions that were used in preparing the detailed capital cost estimate is listed below:

5.1. Labor

Total direct labor costs were determined by applying hourly labor rates to work hour estimates. Note that the estimate assumes an average hourly labor rate of $85 for most of the installation, erection and construction activities. The estimated labor rate is loosely based on union wage rates for the Southeastern United States. It is understood that most crafts and disciplines charge differing rates, however to simplify the estimate a single average rate was used. The labor rate is modifiable by the user to represent a location of higher or lower labor rates.

No added labor costs for overtime work were taken into account in the estimate. The labor rates are fully loaded rates, thus all contractor premium pay, indirects and markups are included in the base rate.

5.2. Land

The cost of land is not included in the capital cost estimate.

5.3. Civil/Earthwork

5.3.1. Site Clearing

The project site is assumed to be a relatively flat, greenfield site, free of equipment and buildings. The prepared site is assumed to only account for the area that the gasifier island structure occupies, thus an assumption of 60′ by 60′ is used. The cost for clearing and grubbing this site is included in the estimate. Note that clearing and grubbing refers to removing trees and brush from the site, grinding the stumps and removing the wood chips. Note that an allowance for equipment rental associated with site clearing is also included.

Fill and compaction is required for the same assumed area. A 3′ cut depth was assumed for the volume calculations.

The unit price and the labor hours per unit for the site clearing activities was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.2. Foundation Preparation

Based on the preliminary design of the gasifier structure as seen in drawing GA-01, located in Appendix G, the foundation area was estimated. An assumption for excavation and backfill depth was made resulting in the volume of excavation and backfill used for the pricing. Note that an allowance for equipment rental associated with foundation preparation is also included.

The unit price and the labor hours per unit for the excavation and backfill was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.3. Piles

The loads of the gasification and tar reforming equipment are expected to necessitate piles. The number of piles depends on the site location and the soil conditions. For the purposes of this estimate, the soils are assumed to have a 3,000-4,000 psi bearing pressure for foundation design. A factor is included for the pile density and pile length for these assumed soil conditions. Both the pile density and pile length can be modified if actual soil conditions are known. Note that an allowance for equipment rental associated with pile driving is also included.

The unit price and the labor hours per unit for the installation of the piles was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.3.4. Other

The following Civil/Earthwork items are NOT included in the capital cost estimate:

Trenching and backfill for any underground utilities. This could include natural gas lines, electrical feeders, fire water piping, process or sanitary sewer lines, storm water drainage piping/culverts, etc.

Storm water collection systems, ditches and containment systems (retention pond, etc.).

Roadways and/or paving.

5.4. Buildings

5.4.1. Gasifier Island Structure

Based on the equipment sizing and loads, the gasifier island structure was preliminarily designed and sized. Note that the estimate only includes the structural steel, miscellaneous access steel, grating and guardrail, and access stairs. The estimate calculates the steel quantities based on ratios of the various steel categories to the total equipment weight. It does not include any masonry or carpentry work, sprinkler systems, roofing or siding.

The unit price and the labor hours per unit for the installation of the steel was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.4.2. Gasifier Island Foundation

The entire gasifier island structure will sit on foundations that are optimized for the arrangement of building columns and actual loads, however to simplify the estimate, a 30″ slab throughout is assumed. The slab will be sloped to a u-drain which will drain to a storm water system (piping and retention pond) that is NOT included in the estimate. Mat type foundations are used. All mat foundations include rebar rather than mesh, and include form work, hardware (anchor bolts, iron, etc.), concrete, finishing and stripping. The estimate includes factors for all of the above items.

The unit price and the labor hours per unit for the installation of the mat foundation was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.4.3. Miscellaneous Building Items Not Included

- An electrical/MCC/controls room.
- An operator control room.
- Locker room.
- Lunch rooms (cafeterias).
- Office space or meeting space.

5.5. Equipment Foundations and Supports

Large equipment will require concrete pedestals for support. An allowance is included for large equipment pedestal volume.

The unit price and the labor hours per unit for the installation of the equipment foundations was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.6. Piping

All refractory lined syngas piping/ductwork and expansion joints are included in the equipment section of the estimate. The remaining process piping, manual and check valves are included in the piping estimate.

An allowance for piping was made for 1″, 2″, 3″ 4″ and 6″ carbon steel piping. These allowances are meant to account for process items such as, natural gas, process water, potable water, cooling water, inert gas, process air, and steam.

The unit price and the labor hours per unit for the installation of the piping was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

No structures or bridges are included to support interconnecting piping between the gasifier island and any other process areas. Piping is assumed to terminate at the gasifier island structure boundary. All piping supports within the gasifier island boundary are included in the estimate.

5.6.1. Piping Items Included in Cost Estimate

- Wash up hose stations.
- Eyewash and shower stations.

5.6.2. Piping Items Not Included Cost Estimate

- Any piping outside the gasifier island boundary.
- Piping related to storm water runoff systems.
- Piping related to process and/or sanitary sewer systems.
- Fire water systems (piping, hydrants, sprinklers etc.).

5.7. Electrical

5.7.1. Only the installation of the motors is currently included in the electrical systems estimate. Allowances for 5, 10, 25, 50, 100, 200 and 250 horsepower motors are included as needed.

5.7.2. The unit price and the labor hours per unit for the installation of the motors was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.7.3. Electrical Items Not Included in Cost Estimate

- MCCs
- Control cabling, terminations, conduit, and cable ways.
- Control systems’ uninterrupted power supplies (UPS).
- Lightning protection.
- Lighting.

- Grounding.
- High voltage feeder and breaker.
- Unit substations (transformers/primary switch/secondary switch gear).
- Medium voltage feeder (this feeder will feed a single substation or loop feed multiple unit substations).
- Cable and conduit for the power distribution feeders between the transformers and the indoor switchgear, and between the switchgear and the MCCs.

5.8. Instrumentation

The estimate includes one allowance for all of the instrumentation and controls equipment and installation, based on a percentage of the project direct costs. Field instruments and transducers are 4-20mA type with twisted shield pair wiring and discrete devices are normally 120VAC.

5.8.1. Items Included in Instrumentation Allowance

- All field instruments for the measurement and control of such parameters as pressure, temperature and flow. The wiring, termination, and installation costs are also included.
- A programmable logic controller (PLC) based control system with a human machine interface (HMI).
- The necessary computer software and hardware to operate the control system.
- Control system I/O racks.
- Actuated valves and valve hook up.

5.8.2. Items Not Included in Instrumentation Allowance

- Special instruments such as various gas analysis devices and special reactor bed level control devices and their installation.
- Any continuous emissions monitoring system (CEMS) to monitor air emissions.

5.9. Process Insulation and Painting

An allowance for 200′ of 4″ piping insulation is included for the steam piping only.

An allowance for high temperature indicating paint for use on the reactors, ducts and cyclones is included.

Labor as well as materials related to the above insulation and painting is included in the estimate.

The unit price and the labor hours per unit for the insulation and painting was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

Process equipment insulation items are not included in the capital cost estimate.

5.10. Equipment

5.10.1. Reactors, Cyclones and Bins

The gasifier, gasifier cyclone, bed media makeup bins, bed media makeup screw conveyor, ash discharge system bins and ash discharge screw conveyors are sized in the model based on a user provided production rate. The total steel is then calculated and priced. Equipment installation is included based on vendor information. Refractory cost and installation is also included.

5.10.2. Miscellaneous Equipment Included

- Bed media makeup system.
- Ash disposal system.

5.10.3. Miscellaneous Equipment Not Included

- Inert gas system other than ability to add nitrogen gas to the gasification system for equipment sizing purposes.
- Process water treatment system (filters, pumps, tanks, etc.).
- Potable water system (pumps, tanks, etc.).
- Cooling water system (cooling tower, pumps, etc.).

- Steam generation system (heat recovery steam generator or fired boiler).
- Gas scrubbers or other abatement equipment.
- Stack.
- Fire water system (pumps, tanks, etc.).
- Waste water treatment facility.

5.11. Demolition

It is assumed that the gasifier system is erected on a greenfield site, thus no demolition is included in any of the estimates.

6. BASIS OF ESTIMATE – INDIRECT AND OTHER COSTS

6.1. Contractor indirect costs included in the labor rate:

6.1.1. Home office job management costs.

6.1.2. Statutory taxes and insurance.

6.1.3. Welfare and fringes.

6.1.4. Workers compensation.

6.1.5. Contractor's general liability insurance.

6.1.6. Small tools / consumables.

6.1.7. Field office job management costs.

6.1.8. Support craft - fire watch, snorkel watch, cleanup, warehousing.

6.1.9. Scaffolding.

6.1.10. Temporary construction – power, air, ice, water, toilets, barricades.

6.1.11. Rental of construction equipment and required supplies and services.

6.1.12. Field office and miscellaneous expenses.

6.1.13. Supervision (above first level 'pusher' foreman).

6.1.14. Casual overtime premium pay (i.e., not scheduled).

6.1.15. Contractor markup.

6.2. Indirect Costs

Direct costs and contractor's indirect costs are combined in the estimates and result in the total construction cost, otherwise known as total installed cost (TIC). To this were added the following indirect costs:

6.2.1. Engineering (Consultant)

Engineering costs are included at a rate of 10.0% of the total direct cost. This rate includes both feasibility and detailed design engineering.

6.2.2. Owner Engineering

Owner engineering costs are included at a rate of 2.0% of the total direct cost. This includes the owners engineering and oversight efforts.

6.2.3. Pre-Project Cost

Pre-project costs such as those associated with surveying, soil testing, ecological studies, etc. are included at a rate of 0.5% of the total construction cost.

6.2.4. Construction Management

Construction Management costs are included at a rate of 2.0% of the total construction cost.

6.2.5. Environmental or Legislative Costs

Environmental or legislative costs such as those associated with environmental permitting are included at a rate of 1.0% of the total construction cost.

6.2.6. Capitalized Spares

The costs of recommended spare parts are included at a rate of 3.0% of the total construction cost.

6.2.7. Sales Taxes

Sales taxes are included for owner and contractor furnished materials, including equipment, consumables and rentals. Sales taxes are included at a rate of 3.5% of the total construction cost, which approximates a 7.0% sales tax on the sum of the owner and contractor furnished materials.

6.2.8. Freight

Freight costs are included at a rate of 3.0% of the owner direct cost of equipment and materials.

6.3. Contingency

This category covers unforeseen costs that are expected but not identified at the time of the estimate. Contingency costs are included at a rate of 15% of the total direct and indirect costs. The percentage is based on HGI experience and the class of the estimate. Contingency is used to cover unanticipated additional costs that may develop during detailed engineering and construction such as:

6.3.1. Higher than anticipated labor rates that are caused by changes in local conditions but not caused by extended strikes.

6.3.2. Minor changes in equipment and material specifications and pricing.

6.3.3. Minor changes in construction that are agreed to be within the scope of the estimate.

6.3.4. Items encountered during design or constructions that were unaccounted for or not determinable at the time the estimate was prepared.

6.3.5. It is expected that contingency funds will be used. Contingency is not intended to cover escalation of major, unanticipated costs nor does it cover increases in project costs due to scope changes.

6.3.6. The contingency factor is applied to the sum of the total construction cost and indirect costs, and the combined total is called the Process Plant & Equipment (PP&E) cost.

6.4. Additional Indirect Costs

The following indirect costs are added to the PP&E cost to produce the grand total, otherwise known as the total project investment (TPI) for the estimates:

6.4.1. Escalation - Escalation costs are not included.

6.4.2. Capitalized Interest - Capitalized interest costs are not included.

6.4.3. Deferred Start-Up Costs - Deferred start-up costs are not included.

6.4.4. Working Capital - Working capital is not included.

6.4.5. Operator Training and Start-Up - Operator training and startup and commissioning costs are included at a rate of 2.0% of the total construction cost.

6.5. Cost Exclusions

The following costs are not included in this estimate:

6.5.1. Any costs beyond startup.

6.5.2. Costs for lost production.

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REPORT 30300/01
GASIFIER TECHNOLOGY ASSESSMENT – CONSOLIDATED REPORT

SECTION 8
DETAILED CAPITAL COST ESTIMATE – HIGH PRESSURE BIOMASS FEED

1. TECHNOLOGY DESCRIPTION

1.1. General

The High Pressure Biomass Feed System Model (HP biomass feed model) is used to design biomass feed systems feeding gasifiers operating at pressures up to 600 psig. The number of feed lines is a function of the gasifier reactor vessel diameter and the diameter of the biomass feed augers; however, the number is independent of the biomass feed rate. The HP biomass feed model produces a detailed capital cost estimate for purchasing and installing a single line biomass feed system and can be multiplied by the number of required feed lines to determine the cost of a complete system. The cost estimate does not include building/support structure costs as these are included in the gasifier models.

1.2. Biomass Transport to Biomass Feed System

Single or multiple (up to four) biomass feed system lines are to be fed by a bucket elevator and conveyor system which will transport biomass to the lock hopper inlet chutes of each feed system line. The cost of the bucket elevator and conveyor is not a part of the HP biomass feed model.

1.3. Biomass Pressurization and Metering System Equipment

Biomass from the lock hopper inlet chute feeds a cylindrical lock hopper. A rotating screw reclaim device at the bottom of the lock hopper is used to move biomass to a center discharge nozzle. The lock hopper inlet and outlet nozzles are equipped with rotary disc valves to permit the lock hopper to pressurized to the gasifier pressure when the valves are closed. The lock hopper is mounted high in the gasifier building structure so that a cylindrical metering bin can be mounted directly below the lock hopper. The lock hopper and metering bin will be mounted high enough to allow the metering bin to discharge to a transfer screw conveyor and then to the gasifier feed auger. The bottom of the metering bin is also equipped with a rotating screw reclaim device to move biomass to the center discharge nozzle. A horizontal transfer screw conveyor is used to transport biomass to a vertically oriented chute feeding the gasifier feed auger. The chute between the transfer screw conveyor and the gasifier feed auger is equipped with a rotary disc block valve to isolate the bulk of the feed system line from the gasifier feed auger, thus permitting maintenance of an individual biomass feed line while the gasifier continues operating with feed from one of the other feed lines. A pressure equalization line connects the lock hopper and the metering bin.

1.4. Biomass Storage and Metering System Operation

The sequence of steps for delivering biomass to the gasifier is as follows:

1.4.1. The lock hopper inlet valve is in the open position

1.4.2. The lock hopper outlet valve is in the closed position

1.4.3. The lock hopper vent valve is opened to allow air to vent from the lock hopper while it is being filled with biomass.

1.4.4. Biomass is conveyed by the bucket elevator and conveyor system to the lock hopper inlet chute. The biomass passes through the open inlet valve to begin filling the lock hopper.

1.4.5. When the lock hopper is full of biomass the lock hopper vent valve is closed.

1.4.6. The lock hopper inlet valve is closed.

1.4.7. The nitrogen gas line ball valve is opened to pipe nitrogen gas into the lock hopper and pressurize the lock hopper to the gasifier pressure.

1.4.8. A ball valve on the pressure equalization line is opened and the pressures are equalized between the lock hopper and the metering bin.

1.4.9. The lock hopper outlet valve is opened.

1.4.10. The lock hopper rotating discharge screw is started and feeds biomass to the center discharge chute; the biomass then passes through the open lock hopper outlet valve and into the metering bin.

1.4.11. The metering bin rotating discharge screw (this is always running during normal operation) feeds biomass to the center discharge chute which is connected to the transfer screw conveyor.

1.4.12. The horizontal transfer screw conveyor conveys biomass to the vertical chute which feeds the gasifier injection auger. The vertical chute is equipped with an expansion joint and an open transfer screw conveyor chute discharge block valve (this valve is always open during normal operation).

1.4.13. When the lock hopper is empty the lock hopper outlet valve is closed.

1.4.14. The lock hopper vent valve is opened to vent the lock hopper to atmosphere through the vent filter and depressurize the lock hopper.

1.4.15. The lock hopper inlet valve is opened.

1.4.16. The sequence is repeated.

2. MODEL BASIS AND ASSUMPTIONS

2.1. The HP biomass feed model requires inputs for scheduled and unscheduled downtime from which the total annual operating hours are calculated.

2.2. Not all the input values in the 05-Design Criteria spreadsheet are used in calculations. Some values (e.g. biomass temperature) are provided for information only.

2.3. The HP biomass feed model provides an input in the 05-Design Criteria spreadsheet for gasifier reactor pressure. The HP biomass feed model is designed for a gasifier reactor pressure input in the range of 150-600 PSIG.

2.4. The HP biomass feed model provides an input in the 05-Design Criteria spreadsheet for gasifier reactor temperature. The gasifier reactor is designed for a maximum temperature of 1,900 °F.

2.5. The HP biomass feed model provides cells in the 05-Design Criteria spreadsheet for the design of each piece of equipment (lock hopper, metering bin, screw reclaim devices and screw conveyors).

2.6. The HP biomass feed model designs the hoppers and bins from three basic shapes: cylinders, cones (or frustums of a cone) and flat plates. The vessels are designed in sections and a cost and weight is automatically calculated for each section using data from the material balance and lookup tables containing unit weights and costs. The design includes nozzles and support lugs. The total cost is broken into a material cost and a fabrication cost.

2.7. The HP biomass feed model provides inputs in the 05-Design Criteria spreadsheet for fourteen nozzles on hoppers and bins.

2.8. The HP biomass feed model includes one expansion joint between the transfer screw conveyor and the gasifier feed auger.

2.9. All the biomass feed system equipment is to be located in a multi-story gasifier building. The HP biomass feed model does not include any costs for a building or support structure.

3. EXCEL WORKBOOK MODEL OPERATION

The HP biomass feed model is an Excel workbook containing 24 Excel spreadsheet tabs that interact to produce a detailed capital cost estimate for a single line biomass feed system. The HP biomass feed model includes an equipment list and capital cost estimate, and it produces an equipment drawings for the lock hopper and metering bin.

3.1. Excel Options

Before manipulating the HP biomass feed model, the "Excel Options" entry screen must be accessed. Under the "Formulas" selection, the "Enable iterative calculation" box must be selected and set for 100 Maximum Iterations and 0.001 Maximum Change. Under the "Advanced" selection, the "Allow editing directly in cells" box must be deselected. With "Allow editing directly in cells" turned off, the operator is able to jump from a cell containing a formula to the referenced cell by double clicking on the cell with the formula. This is important in navigating the Excel workbook.

3.2. Cell Colors

3.2.1. Bright Yellow - Cells backlighted in bright yellow are input cells containing values that can be altered.

3.2.2. Light Yellow - Cells backlighted in light yellow are input cells containing values that can be altered but which normally remain the same.

3.2.3. Bright Green - Cells backlighted in bright green contain constants that are not to be altered.

3.2.4. Pink - Cells backlighted in pink contain a reference to cells in another spreadsheet(s) within the model and may display the referenced cell or use it in a calculation.

3.2.5. Lavender - Cells backlighted in lavender are used in the materials spreadsheets (e.g. spreadsheets 07-Plate Steel) to display material values and prices obtained from vendors.

3.2.6. White – Cells backlighted in white contain calculations that reference cells only within the same spreadsheet.

3.2.7. Light Green - Cells backlighted in light green contain text used for line item headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.8. Medium Blue - Cells backlighted in medium blue contain text used for column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.9. Light Blue - Cells backlighted in light blue contain text used for sub-column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.10. Dark Blue (With White Text) - Cells backlighted in dark blue contain references to other cells in the workbook and are only used for navigating (double clicking) to jump to other points in the workbook.

3.3. Individual Spreadsheet Descriptions

3.3.1. 00-Color Codes & Tab Index: This spreadsheet contains descriptions for each cell color used in the spreadsheets and provides a tab index with descriptions.

3.3.2. 01–Contact List: This spreadsheet contains a list of NREL, HGI and equipment vendor contacts who participated in this project.

3.3.3. 02-Dwg List: This spreadsheet is the control document for assigning drawing numbers and names to equipment drawings (EQ-3-XX).

3.3.4. 03-Cost Est: This spreadsheet contains the capital cost estimate summary and cost estimate details.

- Inputs are made for quantities of materials, unit prices and labor rates for site preparation (civil earthwork) equipment foundations, non refractory lined pipe (e.g. steam, natural gas, water), electrical equipment and wiring (motors are included with equipment), insulation and painting, and demolition.

- Inputs are made for the gasifier building footprint and factors for calculating structural steel quantities as a function of the total weight of all equipment and refractory lined ducts and pipe.

- Inputs are made for calculating factored costs (e.g. instrumentation, engineering, contingency, etc.) as a percentage of capital costs.

3.3.5. 04-Equip List: This spreadsheet is the control document for assigning equipment names and equipment numbers. Also, the spreadsheet provides cells for inputting the biomass feed system costs and weights.

3.3.6. 05-Design Criteria: This spreadsheet is the primary document for entering/changing data inputs.

3.3.7. 06-Plate Steel: This spreadsheet contains a lookup table which lists plate steel cost as a function of plate thickness for plate steel manufactured from ASME SA-516, Grade 70 carbon steel. All vessels (reactors, cyclones and tanks) are priced based on this grade of steel. The table also shows the maximum allowable stress for the steel plate at various temperatures.

3.3.8. 07-Fab Cost: This spreadsheet contains a lookup table which lists vessel fabrication cost as a function of total vessel weight for vessels fabricated with ASME SA-516, Grade 70 carbon steel.

3.3.9. 08-900# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.10. 09-150# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.11. 10-900# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½″ to 24″ the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26″ to 96″ the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.12. 11-150# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½″ to 24″ the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26″ to 96″ the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.13. 12-Exp Joints: This spreadsheet contains a lookup table which lists expansion joint properties and cost as a function of diameter.

3.3.14. 13-Screw Conv: This spreadsheet contains a lookup table for determining the weight, cost and horsepower for pressurized screw conveyors as a function of screw diameter and trough shell thickness.

3.3.15. 14-Motors: This spreadsheet contains lookup table for determining weight and cost of motors as a function of horsepower.

3.3.16. 15-Spare: Not Used

3.3.17. 16-Sheet Steel Allowable Stress: This spreadsheet contains a lookup table for determining the maximum allowable stress in tension for carbon and low alloy steel.

3.3.18. 17-Weld Joint Eff: This spreadsheet contains a lookup table that lists the weld efficiency for steel subjected to various degrees of radiographic examination.

3.3.19. 18-Steel Info: This spreadsheet contains a list of acceptable materials of construction for various components of fabricated vessels, ducts and lines.

3.3.20. 19-Columns: This spreadsheet contains a lookup table for assigning an identification number to columns in other lookup tables.

3.3.21. 20-Excel Help: This spreadsheet contains examples of a number of formulas used in the workbook.

3.3.22. 21-Scratch Sheet: This spreadsheet is to be used for making temporary calculations.

3.3.23. EQ-3-01 Thru EQ-3-02: These 2 spreadsheets contain the equipment drawings for the lock hopper and metering bin.

4. CAPITAL COST SUMMARY

The detailed capital cost estimate in the HP biomass feed model is considered a Class 3 budgetary estimate according to The Association for the Advancement of Cost Engineering (AACE) guidelines.

The detailed capital cost estimate is produced by the HP biomass feed model. Pricing and pricing guidelines were obtained from vendors in order to populate the material pricing lookup tables in the model. The costs of all the major equipment are calculated in the model. The remaining cost inputs are factored from the major equipment pricing and are shown in the 03-Cost Est spreadsheet tab in the model.

Cost estimates produced by the model are stated in 2012 dollars. According to AACE, the expected level of accuracy for a Class 3 estimate should average +40%/-20%.

The capital cost estimate from the HP biomass feed system model is shown in Appendix H for installation of a 500 oven dry metric tons per day single line.

5. BASIS OF ESTIMATE – DIRECT COSTS

Below is a summary of the methods and assumptions that were used in preparing the detailed capital cost estimate.

5.1. Labor

Total direct labor costs were determined by applying hourly labor rates to work hour estimates. Note that the estimate assumes an average hourly labor rate of $85 for most of the installation, erection and construction activities. The estimated labor rate is loosely based on union wage rates for the Southeastern United States. It is understood that most crafts and disciplines charge differing rates, however to simplify the estimate a single average rate was used. The labor rate is modifiable by the user to represent a location of higher or lower labor rates.

No added labor costs for overtime work were taken into account in the estimate. The labor rates are fully loaded rates, thus all contractor premium pay, indirects and markups are included in the base rate.

5.2. Land

The cost of land is not included in the capital cost estimate.

5.3. Civil/Earthwork

5.3.1. Site Clearing – N/A

5.3.2. Foundation Preparation – N/A

5.3.3. Piles – N/A

5.3.4. Other – N/A

5.4. Buildings

Buildings are not included in the capital cost estimate for the biomass feed system. Building structures to house and support biomass feed equipment are included in the gasifier cost estimates.

5.5. Equipment Foundations and Supports

Equipment foundations are not included in the capital cost estimate for the biomass feed system. Equipment foundations to support biomass feed equipment are included in the gasifier cost estimates.

5.6. Piping

Expansion joints are included in the equipment section of the estimate. The remaining process piping, manual and check valves are included in the piping estimate.

An allowance for piping was made for required sizes of carbon steel piping. These allowances are meant to account for process items such as potable water and nitrogen.

The unit price and the labor hours per unit for the installation of the piping was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

No structures or bridges are included to support interconnecting piping between the gasifier island and any other process areas. Piping is assumed to terminate at the gasifier island structure boundary. All piping supports within the gasifier island boundary are included in the estimate.

The following piping items are not included in the capital cost estimate:

- Any piping outside the gasifier island boundary.
- Piping related to storm water runoff systems.
- Piping related to process and/or sanitary sewer systems.
- Fire water systems (piping, hydrants, sprinklers etc.).

5.7. Electrical

5.7.1. Allowances for 5, 10, 25, 50, 100, 200 and 250 horsepower motors are included as needed.

5.7.2. The unit price and the labor hours per unit for the installation of the motors was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.7.3. The following “Electrical” items are NOT included in the capital cost estimate:

- MCC’s
- Control systems’ uninterrupted power supplies (UPS).
- Lightning protection.
- Lighting.
- Grounding.
- High voltage feeder and breaker.
- Unit substations (transformers/primary switch/secondary switch gear).
- Medium voltage feeder (this feeder will feed a single substation or loop feed multiple unit substations).
- Cable and conduit for the power distribution feeders between the transformers and the indoor switchgear, and between the switchgear and the MCCs.

5.8. Instrumentation

The estimate includes one allowance for all of the instrumentation and controls equipment and installation, based on a percentage of the project direct costs. Field instruments and transducers are 4-20mA type with twisted shield pair wiring and discrete devices are normally 120VAC.

5.8.1. Items Included in Instrumentation Allowance

- All field instruments for the measurement and control of such parameters as pressure, temperature and flow. The wiring, termination, and installation costs are also included.
- A programmable logic controller (PLC) based control system with a human machine interface (HMI).

- The necessary computer software and hardware to operate the control system.
- Control system I/O racks.
- Actuated valves and valve hook up.

5.8.2. Items Not Included in Instrumentation Allowance

- Special instruments such as various gas analysis devices and special reactor bed level control devices and their installation.
- Any continuous emissions monitoring system (CEMS) to monitor air emissions.

5.9. Process Insulation and Painting

No insulation is included.

Labor and materials related to painting are included in the estimate.

The unit price and the labor hours per unit for painting were taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.10. Equipment

5.10.1. Hoppers and Bins

Equipment installation is included based on vendor information.

5.10.2. Miscellaneous Equipment Not Included

- Process water treatment system (filters, pumps, tanks, etc.).
- Potable water system (pumps, tanks, etc.).
- Cooling water system (cooling tower, pumps, etc.).
- Fire water system (pumps, tanks, etc.).
- Waste water treatment facility.

5.11. Demolition

It is assumed that the gasifier system is erected on a greenfield site, thus no demolition is included in any of the estimates.

6. BASIS OF ESTIMATE – INDIRECT AND OTHER COSTS

6.1. Contractor indirect costs included in the labor rate:

6.1.1. Home office job management costs.

6.1.2. Statutory taxes and insurance.

6.1.3. Welfare and fringes.

6.1.4. Workers compensation.

6.1.5. Contractor's general liability insurance.

6.1.6. Small tools / consumables.

6.1.7. Field office job management costs.

6.1.8. Support craft - fire watch, snorkel watch, cleanup, warehousing.

6.1.9. Scaffolding.

6.1.10. Temporary construction – power, air, ice, water, toilets, barricades.

6.1.11. Rental of construction equipment and required supplies and services.

6.1.12. Field office and miscellaneous expenses.

6.1.13. Supervision (above first level 'pusher' foreman).

6.1.14. Casual overtime premium pay (i.e., not scheduled).

6.1.15. Contractor markup.

6.2. Indirect Costs

Direct costs and contractor's indirect costs are combined in the estimates and result in the total construction cost, otherwise known as total installed cost (TIC). To this were added the following indirect costs:

6.2.1. Engineering (Consultant)

Engineering costs are included at a rate of 10.0% of the total direct cost. This rate includes both feasibility and detailed design engineering.

6.2.2. Owner Engineering

Owner engineering costs are included at a rate of 2.0% of the total direct cost. This includes the owners engineering and oversight efforts.

6.2.3. Pre-Project Cost

Pre-project costs such as those associated with surveying, soil testing, ecological studies, etc. are included at a rate of 0.5% of the total construction cost.

6.2.4. Construction Management

Construction Management costs are included at a rate of 2.0% of the total construction cost.

6.2.5. Environmental or Legislative Costs

Environmental or legislative costs such as those associated with environmental permitting are included at a rate of 1.0% of the total construction cost.

6.2.6. Capitalized Spares

The costs of recommended spare parts are included at a rate of 3.0% of the total construction cost.

6.2.7. Sales Taxes

Sales taxes are included for owner and contractor furnished materials, including equipment, consumables and rentals. Sales taxes are included at a rate of 3.5% of the total construction cost, which approximates a 7.0% sales tax on the sum of the owner and contractor furnished materials.

6.2.8. Freight

Freight costs are included at a rate of 3.0% of the owner direct cost of equipment and materials.

6.3. Contingency

This category covers unforeseen costs that are expected but not identified at the time of the estimate. Contingency costs are included at a rate of 15% of the total direct and indirect costs. The percentage is based on HGI experience and the class of the estimate. Contingency is used to cover unanticipated additional costs that may develop during detailed engineering and construction such as:

6.3.1. Higher than anticipated labor rates that are caused by changes in local conditions but not caused by extended strikes.

6.3.2. Minor changes in equipment and material specifications and pricing.

6.3.3. Minor changes in construction that are agreed to be within the scope of the estimate.

6.3.4. Items encountered during design or constructions that were unaccounted for or not determinable at the time the estimate was prepared.

6.3.5. It is expected that contingency funds will be used. Contingency is not intended to cover escalation of major, unanticipated costs nor does it cover increases in project costs due to scope changes.

6.3.6. The contingency factor is applied to the sum of the total construction cost and indirect costs, and the combined total is called the Process Plant & Equipment (PP&E) cost.

6.4. Additional Indirect Costs

The following indirect costs are added to the PP&E cost to produce the grand total, otherwise known as the total project investment (TPI) for the estimates:

6.4.1. Escalation - Escalation costs are not included.

6.4.2. Capitalized Interest - Capitalized interest costs are not included.

6.4.3. Deferred Start-Up Costs - Deferred start-up costs are not included.

6.4.4. Working Capital - Working capital is not included.

6.4.5. Operator Training and Start-Up - Operator training and startup and commissioning costs are included at a rate of 2.0% of the total construction cost.

6.5. Cost Exclusions

The following costs are not included in this estimate:

6.5.1. Any costs beyond startup.

6.5.2. Costs for lost production.

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SECTION 9
DETAILED CAPITAL COST ESTIMATE – LOW PRESSURE BIOMASS FEED

1. TECHNOLOGY DESCRIPTION

1.1. General

The Low Pressure Biomass Feed System Model (HP biomass feed model) is used to design biomass feed systems feeding gasifiers operating at pressures up to 150 psig. The number of feed lines is a function of the gasifier reactor vessel diameter and the diameter of the biomass feed augers; however, the number is independent of the biomass feed rate. The HP biomass feed model produces a detailed capital cost estimate for purchasing and installing a single line biomass feed system and can be multiplied by the number of required feed lines to determine the cost of a complete system. The cost estimate does not include building/support structure costs as these are included in the gasifier models.

1.2. Biomass Transport to Biomass Feed System

Single or multiple (up to four) biomass feed system lines are to be fed by a bucket elevator and conveyor system which will transport biomass to the metering bin inlet chutes of each feed system line. The cost of the bucket elevator and conveyor is not a part of the HP biomass feed model.

1.3. Biomass Pressurization and Metering System Equipment

Biomass from the metering bin inlet chute feeds an atmospheric cylindrical metering bin. A rotating/traveling screw reclaim device at the bottom of the metering bin is used to move biomass to a center discharge nozzle. The metering bin is to be mounted high enough in the gasifier support building to allow biomass to free fall through a vertical chute into an atmospheric transfer screw conveyor. The horizontal transfer screw conveyor discharges biomass to a vertically oriented chute feeding the gasifier feed auger. The chute between the transfer screw conveyor and the gasifier feed auger is equipped with a rotary valve designed to meter biomass to the gasifier feed auger and provide a seal between the atmospheric pressure in the transfer screw conveyor and the gasifier pressure in the gasifier feed auger.

The chute between the transfer screw conveyor and the gasifier feed auger is also equipped with a knife gate block valve to isolate the bulk of a single feed system line from its dedicated gasifier feed auger, thus permitting maintenance of an individual biomass feed line while the gasifier continues operating with feed from one of the other feed lines.

2. MODEL BASIS AND ASSUMPTIONS

2.1. The HP biomass feed model requires inputs for scheduled and unscheduled downtime, from which the total annual operating hours are calculated.

2.2. Not all the input values in the 05-Design Criteria spreadsheet are used in calculations. Some values (e.g. biomass temperature) are provided for information only.

2.3. The LP biomass feed model provides an input in the 05-Design Criteria spreadsheet for gasifier reactor pressure. The LP biomass feed model is designed for a gasifier reactor pressure input in the range of 20-150 PSIG.

2.4. The LP biomass feed model provides an input in the 05-Design Criteria spreadsheet for gasifier reactor temperature. The gasifier reactor is designed for a maximum temperature of 1,900 °F.

2.5. The LP biomass feed model provides cells in the 05-Design Criteria spreadsheet for the design of each piece of equipment (metering bin, screw reclaim devices and screw conveyors).

2.6. The LP biomass feed model designs the metering bins from three basic shapes: cylinders, cones (or frustums of a cone) and flat plates. The vessels are designed in sections and a cost and weight is automatically calculated for each section using data from the material balance and lookup tables containing unit weights and costs. The design includes nozzles and support lugs. The total cost is broken into a material cost and a fabrication cost.

2.7. The LP biomass feed model provides inputs in the 05-Design Criteria spreadsheet for fourteen nozzles on the bins.

2.8. The LP biomass feed model includes one expansion joint in the chute between the transfer screw conveyor and the gasifier feed auger.

2.9. All the biomass feed system equipment is to be located in a multi-story gasifier building. The LP biomass feed model does not include any costs for a building or support structure. The building or support structure costs are included in the gasifier models.

3. EXCEL WORKBOOK MODEL OPERATION

The LP biomass feed model is an Excel workbook containing 23 Excel spreadsheet tabs that interact to produce a detailed capital cost estimate for a single line biomass feed system. The LP biomass feed model includes an equipment list and capital cost estimate, and it produces an equipment drawing for the metering bin.

3.1. Excel Options

Before manipulating the LP biomass feed model, the “Excel Options” entry screen must be accessed. Under the “Formulas” selection, the “Enable iterative calculation” box must be selected and set for 100 Maximum Iterations and 0.001 Maximum Change. Under the “Advanced” selection, the “Allow editing directly in cells” box must be deselected. With “Allow editing directly in cells” turned off, the operator is able to jump from a cell containing a formula to the referenced cell by double clicking on the cell with the formula. This is important in navigating the Excel workbook.

3.2. Cell Colors

3.2.1. Bright Yellow - Cells backlighted in bright yellow are input cells containing values that can be altered.

3.2.2. Light Yellow - Cells backlighted in light yellow are input cells containing values that can be altered but which normally remain the same.

3.2.3. Bright Green - Cells backlighted in bright green contain constants that are not to be altered.

3.2.4. Pink - Cells backlighted in pink contain a reference to cells in another spreadsheet(s) within the model and may display the referenced cell or use it in a calculation.

3.2.5. Lavender - Cells backlighted in lavender are used in the materials spreadsheets (e.g. spreadsheets 07-Plate Steel) to display material values and prices obtained from vendors.

3.2.6. White – Cells backlighted in white contain calculations that reference cells only within the same spreadsheet.

3.2.7. Light Green - Cells backlighted in light green contain text used for line item headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.8. Medium Blue - Cells backlighted in medium blue contain text used for column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.9. Light Blue - Cells backlighted in light blue contain text used for sub-column headings that do not normally need to be changed. However, this text may be changed without affecting any calculations in the model.

3.2.10. Dark Blue (With White Text) - Cells backlighted in dark blue contain references to other cells in the workbook and are only used for navigating (double clicking) to jump to other points in the workbook.

3.3. Individual Spreadsheet Descriptions

3.3.1. 00-Color Codes & Tab Index: This spreadsheet contains descriptions for each cell color used in the spreadsheets and provides a tab index with descriptions.

3.3.2. 01–Contact List: This spreadsheet contains a list of NREL, HGI and equipment vendor contacts who participated in this project.

3.3.3. 02-Dwg List: This spreadsheet is the control document for assigning drawing numbers and names to equipment drawings (EQ-4-XX).

3.3.4. 03-Cost Est: This spreadsheet contains the capital cost estimate summary and cost estimate details.

- Inputs are made for quantities of materials, unit prices and labor rates for site preparation (civil earthwork) equipment foundations, non refractory lined pipe (e.g. steam, natural gas, water), electrical equipment and wiring (motors are included with equipment), insulation and painting, and demolition.
- Inputs are made for the gasifier building footprint and factors for calculating structural steel quantities as a function of the total weight of all equipment and refractory lined ducts and pipe.

- Inputs are made for calculating factored costs (e.g. instrumentation, engineering, contingency, etc.) as a percentage of capital costs.

3.3.5. 04-Equip List: This spreadsheet is the control document for assigning equipment names and equipment numbers. Also, the spreadsheet provides cells for inputting the biomass feed system costs and weights.

3.3.6. 05-Design Criteria: This spreadsheet is the primary document for entering/changing data inputs.

3.3.7. 06-Plate Steel: This spreadsheet contains a lookup table which lists plate steel cost as a function of plate thickness for plate steel manufactured from ASME SA-516, Grade 70 carbon steel. All vessels (reactors, cyclones and tanks) are priced based on this grade of steel. The table also shows the maximum allowable stress for the steel plate at various temperatures.

3.3.8. 07-Fab Cost: This spreadsheet contains a lookup table which lists vessel fabrication cost as a function of total vessel weight for vessels fabricated with ASME SA-516, Grade 70 carbon steel.

3.3.9. 08-900# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.10. 09-150# Nozzles & Flanges: This spreadsheet contains a lookup table which lists nozzle and flange dimensions and properties as a function of diameter.

3.3.11. 10-900# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½″ to 24″ the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26″ to 96″ the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.12. 11-150# Pipe & Duct: This spreadsheet contains a lookup table which lists pipe and duct dimensions and properties as a function of diameter. For diameters from ½″ to 24″ the pipe and duct are manufactured from ASME SA-106, Grade B carbon steel. For diameters from 26″ to 96″ the pipe and duct are manufactured from ASME SA-516, Grade 70 carbon steel. All refractory lined pipes and ducts are priced based on this grade of steel.

3.3.13. 12-Exp Joints: This spreadsheet contains a lookup table which lists expansion joint properties and cost as a function of diameter.

3.3.14. 13-Screw Conv: This spreadsheet contains a lookup table for determining the weight, cost and horsepower for pressurized screw conveyors as a function of screw diameter and trough shell thickness.

3.3.15. 14-Motors: This spreadsheet contains lookup table for determining weight and cost of motors as a function of horsepower.

3.3.16. 15-Spare: Not Used

3.3.17. 16-Sheet Steel Allowable Stress: This spreadsheet contains a lookup table for determining the maximum allowable stress in tension for carbon and low alloy steel.

3.3.18. 17-Weld Joint Eff: This spreadsheet contains a lookup table that lists the weld efficiency for steel subjected to various degrees of radiographic examination.

3.3.19. 18-Steel Info: This spreadsheet contains a list of acceptable materials of construction for various components of fabricated vessels, ducts and lines.

3.3.20. 19-Columns: This spreadsheet contains a lookup table for assigning an identification number to columns in other lookup tables.

3.3.21. 20-Excel Help: This spreadsheet contains examples of a number of formulas used in the workbook.

3.3.22. 21-Scratch Sheet: This spreadsheet is to be used for making temporary calculations.

3.3.23. EQ-4-01: This spreadsheet contains an equipment drawing for the metering bin.

4. CAPITAL COST SUMMARY

The detailed capital cost estimate in the LP biomass feed model is considered a Class 3 budgetary estimate according to The Association for the Advancement of Cost Engineering (AACE) guidelines.

The detailed capital cost estimate is produced by the LP biomass feed model. Pricing and pricing guidelines were obtained from vendors in order to populate the material pricing lookup tables in the model. The costs of all the major equipment are calculated in the model. The remaining cost inputs are factored from the major equipment pricing and are shown in the 03-Cost Est spreadsheet tab in the model.

Cost estimates produced by the model are stated in 2012 dollars. According to AACE, the expected level of accuracy for a Class 3 estimate should average +40%/-20%.

The capital cost estimate from the LP biomass feed system model is shown in Appendix H for installation of a 500 oven dry metric tons per day single line.

5. BASIS OF ESTIMATE – DIRECT COSTS

Below is a summary of the methods and assumptions that were used in preparing the detailed capital cost estimate.

5.1. Labor

Total direct labor costs were determined by applying hourly labor rates to work hour estimates. Note that the estimate assumes an average hourly labor rate of $85 for most of the installation, erection and construction activities. The estimated labor rate is loosely based on union wage rates for the Southeastern United States. It is understood that most crafts and disciplines charge differing rates, however to simplify the estimate a single average rate was used. The labor rate is modifiable by the user to represent a location of higher or lower labor rates.

No added labor costs for overtime work were taken into account in the estimate. The labor rates are fully loaded rates, thus all contractor premium pay, indirects and markups are included in the base rate.

5.2. Land

The cost of land is not included in the capital cost estimate.

5.3. Civil/Earthwork

5.3.1. Site Clearing – N/A

5.3.2. Foundation Preparation – N/A

5.3.3. Piles – N/A

5.3.4. Other – N/A

5.4. Buildings

Buildings are not included in the capital cost estimate for the biomass feed system. Building structures to house and support biomass feed equipment are included in the gasifier cost estimates.

5.5. Equipment Foundations and Supports

Equipment foundations are not included in the capital cost estimate for the biomass feed system. Equipment foundations to support biomass feed equipment are included in the gasifier cost estimates.

5.6. Piping

Expansion joints are included in the equipment section of the estimate. The remaining process piping, manual and check valves are included in the piping estimate.

An allowance for piping was made for required sizes of carbon steel piping. These allowances are meant to account for process items such as potable water and nitrogen.

The unit price and the labor hours per unit for the installation of the piping was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

No structures or bridges are included to support interconnecting piping between the gasifier island and any other process areas. Piping is assumed to terminate at the gasifier island structure boundary. All piping supports within the gasifier island boundary are included in the estimate.

The following piping items are not included in the capital cost estimate:

- Any piping outside the gasifier island boundary.
- Piping related to storm water runoff systems.
- Piping related to process and/or sanitary sewer systems.
- Fire water systems (piping, hydrants, sprinklers etc.).

5.7. Electrical

5.7.1. Allowances for 5, 10, 25, 50, 100, 200 and 250 horsepower motors are included as needed.

5.7.2. The unit price and the labor hours per unit for the installation of the motors was taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.7.3. The following "Electrical" items are NOT included in the capital cost estimate:

- MCC's
- Control systems' uninterrupted power supplies (UPS).
- Lightning protection.
- Lighting.
- Grounding.
- High voltage feeder and breaker.
- Unit substations (transformers/primary switch/secondary switch gear).
- Medium voltage feeder (this feeder will feed a single substation or loop feed multiple unit substations).
- Cable and conduit for the power distribution feeders between the transformers and the indoor switchgear, and between the switchgear and the MCCs.

5.8. Instrumentation

The estimate includes one allowance for all of the instrumentation and controls equipment and installation, based on a percentage of the project direct costs. Field instruments and transducers are 4-20mA type with twisted shield pair wiring and discrete devices are normally 120VAC.

5.8.1. Items Included in Instrumentation Allowance

- All field instruments for the measurement and control of such parameters as pressure, temperature and flow. The wiring, termination, and installation costs are also included.
- A programmable logic controller (PLC) based control system with a human machine interface (HMI).

- The necessary computer software and hardware to operate the control system.
- Control system I/O racks.
- Actuated valves and valve hook up.

5.8.2. Items Not Included in Instrumentation Allowance

- Special instruments such as various gas analysis devices and special reactor bed level control devices and their installation.
- Any continuous emissions monitoring system (CEMS) to monitor air emissions.

5.9. Process Insulation and Painting

No insulation is included.

Labor and materials related to painting are included in the estimate.

The unit price and the labor hours per unit for painting were taken from the Harris Group estimating database which is based on typical industry practices and pricing.

5.10. Equipment

5.10.1. Hoppers and Bins

Equipment installation is included based on vendor information.

5.10.2. Miscellaneous Equipment Not Included

- Process water treatment system (filters, pumps, tanks, etc.).
- Potable water system (pumps, tanks, etc.).
- Cooling water system (cooling tower, pumps, etc.).
- Fire water system (pumps, tanks, etc.).
- Waste water treatment facility.

5.11. Demolition

It is assumed that the gasifier system is erected on a greenfield site, thus no demolition is included in any of the estimates.

6. BASIS OF ESTIMATE – INDIRECT AND OTHER COSTS

6.1. Contractor indirect costs included in the labor rate:

6.1.1. Home office job management costs.

6.1.2. Statutory taxes and insurance.

6.1.3. Welfare and fringes.

6.1.4. Workers compensation.

6.1.5. Contractor's general liability insurance.

6.1.6. Small tools / consumables.

6.1.7. Field office job management costs.

6.1.8. Support craft - fire watch, snorkel watch, cleanup, warehousing.

6.1.9. Scaffolding.

6.1.10. Temporary construction – power, air, ice, water, toilets, barricades.

6.1.11. Rental of construction equipment and required supplies and services.

6.1.12. Field office and miscellaneous expenses.

6.1.13. Supervision (above first level 'pusher' foreman).

6.1.14. Casual overtime premium pay (i.e., not scheduled).

6.1.15. Contractor markup.

6.2. Indirect Costs

Direct costs and contractor's indirect costs are combined in the estimates and result in the total construction cost, otherwise known as total installed cost (TIC). To this were added the following indirect costs:

6.2.1. Engineering (Consultant)

Engineering costs are included at a rate of 10.0% of the total direct cost. This rate includes both feasibility and detailed design engineering.

6.2.2. Owner Engineering

Owner engineering costs are included at a rate of 2.0% of the total direct cost. This includes the owners engineering and oversight efforts.

6.2.3. Pre-Project Cost

Pre-project costs such as those associated with surveying, soil testing, ecological studies, etc. are included at a rate of 0.5% of the total construction cost.

6.2.4. Construction Management

Construction Management costs are included at a rate of 2.0% of the total construction cost.

6.2.5. Environmental or Legislative Costs

Environmental or legislative costs such as those associated with environmental permitting are included at a rate of 1.0% of the total construction cost.

6.2.6. Capitalized Spares

The costs of recommended spare parts are included at a rate of 3.0% of the total construction cost.

6.2.7. Sales Taxes

Sales taxes are included for owner and contractor furnished materials, including equipment, consumables and rentals. Sales taxes are included at a rate of 3.5% of the total construction cost, which approximates a 7.0% sales tax on the sum of the owner and contractor furnished materials.

6.2.8. Freight

Freight costs are included at a rate of 3.0% of the owner direct cost of equipment and materials.

6.3. Contingency

This category covers unforeseen costs that are expected but not identified at the time of the estimate. Contingency costs are included at a rate of 15% of the total direct and indirect costs. The percentage is based on HGI experience and the class of the estimate. Contingency is used to cover unanticipated additional costs that may develop during detailed engineering and construction such as:

6.3.1. Higher than anticipated labor rates that are caused by changes in local conditions but not caused by extended strikes.

6.3.2. Minor changes in equipment and material specifications and pricing.

6.3.3. Minor changes in construction that are agreed to be within the scope of the estimate.

6.3.4. Items encountered during design or constructions that were unaccounted for or not determinable at the time the estimate was prepared.

6.3.5. It is expected that contingency funds will be used. Contingency is not intended to cover escalation of major, unanticipated costs nor does it cover increases in project costs due to scope changes.

6.3.6. The contingency factor is applied to the sum of the total construction cost and indirect costs, and the combined total is called the Process Plant & Equipment (PP&E) cost.

6.4. Additional Indirect Costs

The following indirect costs are added to the PP&E cost to produce the grand total, otherwise known as the total project investment (TPI) for the estimates:

6.4.1. Escalation - Escalation costs are not included.

6.4.2. Capitalized Interest - Capitalized interest costs are not included.

6.4.3. Deferred Start-Up Costs - Deferred start-up costs are not included.

6.4.4. Working Capital - Working capital is not included.

6.4.5. Operator Training and Start-Up - Operator training and startup and commissioning costs are included at a rate of 2.0% of the total construction cost.

6.5. Cost Exclusions

The following costs are not included in this estimate:

6.5.1. Any costs beyond startup.

6.5.2. Costs for lost production.

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SECTION 10
GASIFICATION COST COMPARISONS

1. GENERAL

An analysis was conducted comparing the order of magnitude capital cost estimates shown in Appendix D for the three gasification technologies with the Excel gasification and biomass feed model budgetary capital cost estimates shown in Appendix H. The comparisons are presented in the spreadsheet shown in Appendix I. The capital cost comparison spreadsheet includes a column for each of the following systems:

1.1. Technology #2 – CFB System

1.2. Excel Model – CFB System

1.3. Technology #1 – BFB Oxygen Blown System

1.4. Technology #3 – BFB Oxygen Blown System

1.5. Excel Model – BFB System (Without Air Separator, Reformer or Biomass Feed Lines)

1.6. Composite System – BFB System (With Air Separator, Reformer and (4) Biomass Feed Lines)

1.7. Excel Model – High Pressure Biomass Feed System (Single Line)

2. COMPOSITE BFB GASIFIER COST ESTIMATE

In order to compare the Excel BFB model cost estimate to the cost estimates for Technologies #1 and #3 (both BFB systems), a composite BFB system (Item-1.6 above) was created by combining the Excel BFB model with other components to create a BFB system comparable to Technologies #1 & #3. This composite BFB system is composed of the following:

2.1. The equipment costs for four HP biomass feed lines (Item-1.7 above) were used as was included in Technologies #1 and #3.

2.2. Because the BFB gasifier model in Item 1.5 above does not include a tar reforming system, a cost estimate was needed for the tar reforming equipment. The gasifier equipment (gasifier, cyclone, bed media feed system and ash system) was estimated to be similar to the equipment required for a tar reforming system; therefore, the BFB gasifier model (Item 1.5 above) equipment cost was used twice to account for both the gasifier system and the tar reformer system in the BFB composite system in Item 1.6 above.

2.3. Air separation plant equipment from Item-1.4 above.

2.4. Process air system equipment from Item-1.4 above.

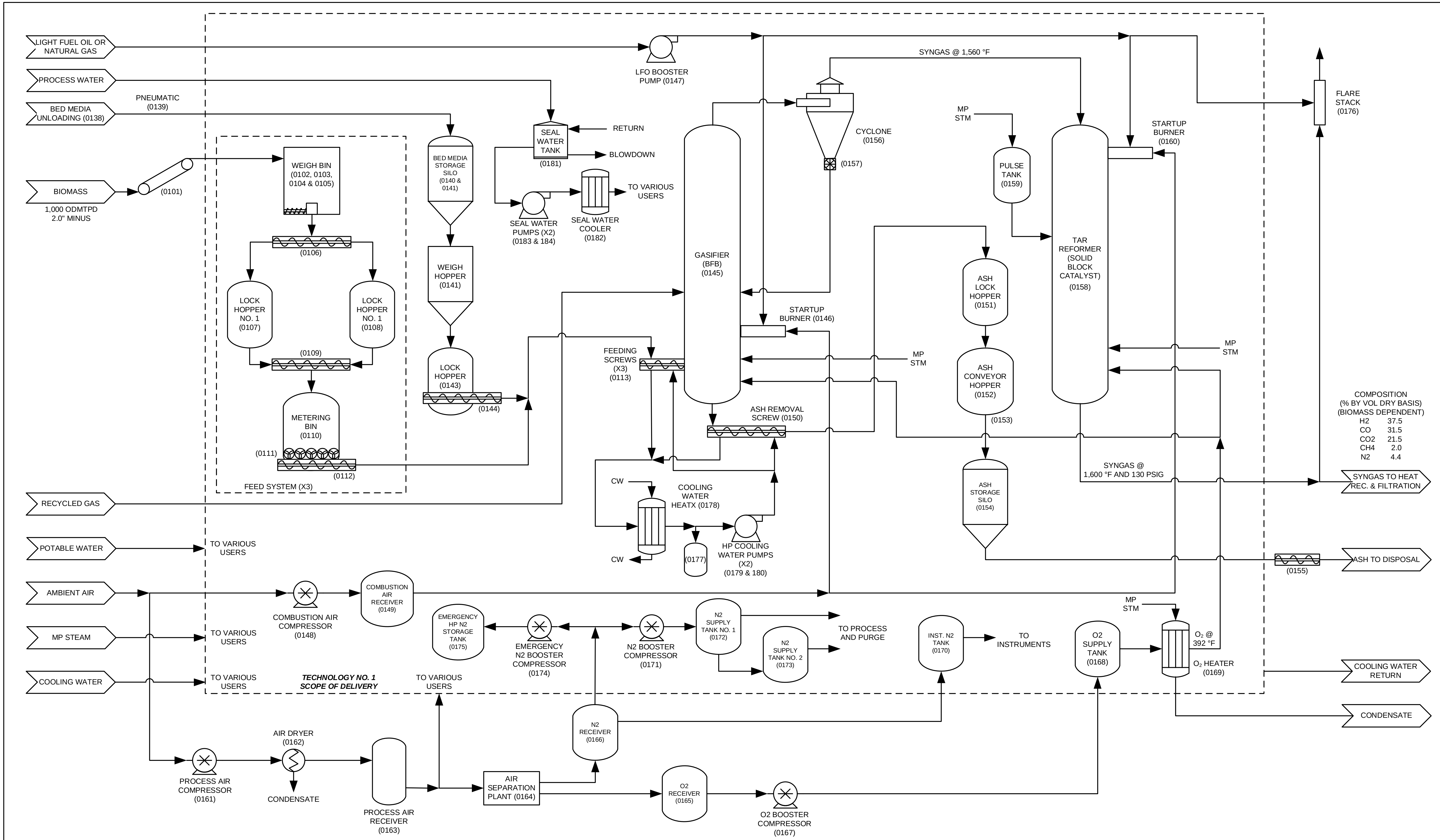
2.5. Oxygen system equipment from Item-1.4 above.

2.6. Nitrogen system equipment from Item-1.4 above.

2.7. Flare stack equipment from Item-1.3 above).

2.8. Individually identified ducts from Item-1.5 above, were entered a second time to cover the costs for the reformer system ducts.

APPENDIX A
ORDER OF MAGNITUDE ESTIMATES
FLOW DIAGRAMS



Reference Drawings		Revisions				Revisions			
Drawing No.	Title	Rev	Date	By	Description	Rev	Date	By	Description
		A	12/29/10	MWW	INITIAL CONCEPT FOR CLIENT REVIEW				
		B	01/12/11	MWW	ISSUED FOR FINAL REPORT				

Harris Group Inc.
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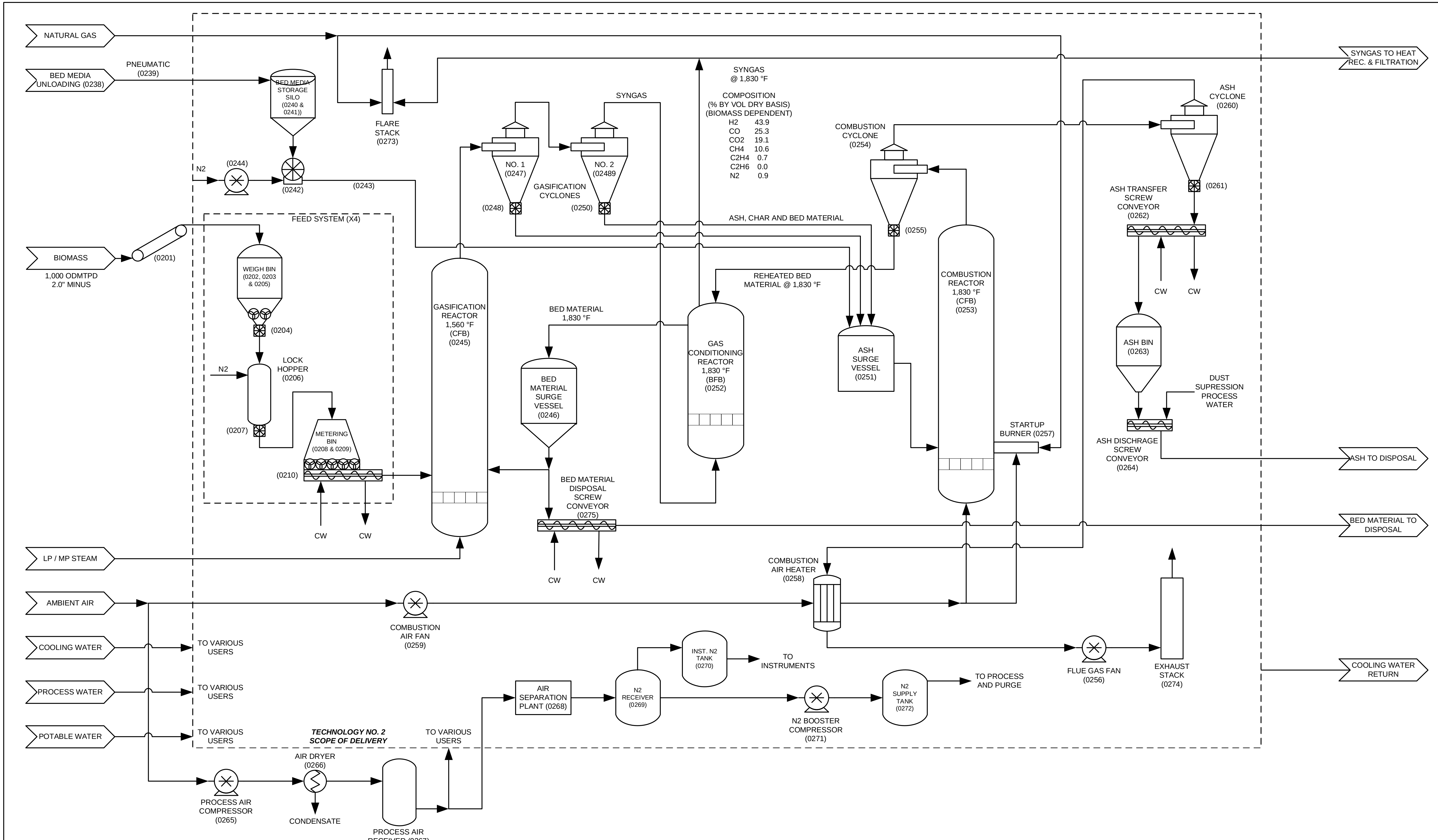
Subconsultant: -
Drawn: MWW Check: -
Engr: - Check: -
Appr: - PMgr: -

GASIFIER ASSESSMENT STUDY

GASIFIER ISLAND - TECHNOLOGY #1
PROCESS FLOW DIAGRAM

Project No: 30074.00 Drawing: F-100 Rev: B



Reference Drawings		Revisions				Revisions			
Drawing No.	Title	Rev	Date	By	Description	Rev	Date	By	Description
		A	12/29/10	MWW	INITIAL CONCEPT FOR CLIENT REVIEW				
		B	01/12/11	MWW	ISSUED FOR FINAL REPORT				

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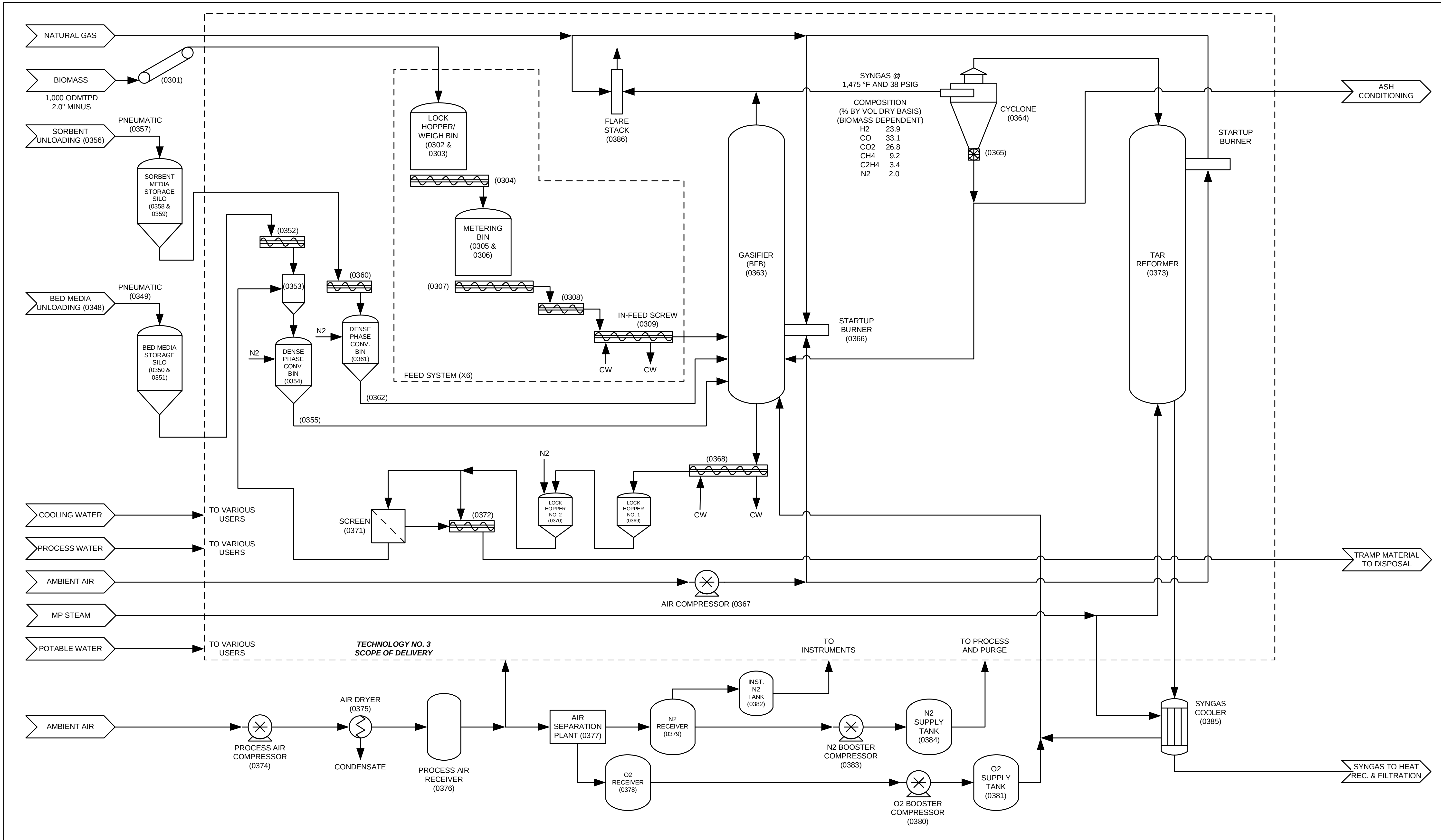
Drawn: MWW - Check: -
Engr: - Check: -
Appr: - PMgr: -

GASIFIER ASSESSMENT STUDY

GASIFIER ISLAND - TECHNOLOGY #2
PROCESS FLOW DIAGRAM

Project No: 30074.00 | Drawing: F-200 | Rev: B



Reference Drawings		Rev	Date	By	Description	Revisions			
Drawing No.	Title	Rev	Date	By	Description	Rev	Date	By	Description
		A	12/29/10	MWW	INITIAL CONCEPT FOR CLIENT REVIEW				
		B	01/12/11	MWW	ISSUED FOR FINAL REPORT				

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Engr: - Check: -
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GASIFIER ASSESSMENT STUDY

GASIFIER ISLAND - TECHNOLOGY #3
PROCESS FLOW DIAGRAM

Project No:	Drawing:	Rev:
30074.00	F-300	B

APPENDIX B
ORDER OF MAGNITUDE ESTIMATES
GASIFIER OPERATING CONDITIONS

OPERATING CONDITIONS - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
9	**BIOMASS TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
10	Biomass - Consumption Rate - Wet	metric tons wet biomass / day	1,134	
11		metric tons wet biomass / hr	47.3	
12		short tons wet biomass / day	1,250.0	
13		short tons wet biomass / hr	52.1	
14		lbs wet biomass / hr	104,168	
15				
16	Biomass - LHV - Wet	BTU / lb wet biomass	6,333	
17	Biomass - HHV - Wet	BTU / lb wet biomass	6,766	
18				
19	Biomass - Consumption Rate - Dry	metric tons dry biomass / day	907	
20		metric tons dry biomass / hr	37.8	
21		short tons dry biomass / day	1,000	
22		short tons dry biomass / hr	41.7	
23		lbs dry biomass / day	2,000,034	
24		lbs dry biomass / hr	83,335	
25				
26	Biomass - LHV - Dry	BTU / lb dry biomass	7,916	
27	Biomass - HHV - Dry	BTU / lb dry biomass	8,458	
28				
29	Biomass - Moisture Content	wt% water / wet biomass	20.0	
30	Biomass - Temperature	°F	77.0	
31	Biomass - Feed Pressure	psig	130.0	
32	Biomass - Bulk Density	lb/ft3	14.98	
33	Biomass - Size Distribution		80% < 1.3"	
34				
35	Biomass - Type		Souther Pine chip and bark mixture	
36	Biomass - Ultimate Analysis			
37	Carbon	% wt. (dry basis)	49.72	
38	Hydrogen	% wt. (dry basis)	5.67	
39	Nitrogen	% wt. (dry basis)	0.20	
40	Sulfur	% wt. (dry basis)	0.02	
41	Oxygen	% wt. (dry basis)	42.31	
42	Chlorine	% wt. (dry basis)	0.000122	
43	Ash	% wt. (dry basis)	2.08	
44				
45	**BED MATERIAL TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
46	Bed Material - Consumption Rate - As is	lb / hr	934	24.7 lb bed material / metric ton of dry biomass
47		short tons / day	11.2	
48	Bed Material - Temperature	°F	77.0	
49	Bed Material - Feed Pressure	psig	130.0	
50				
51	Bulk Density (Uncompacted Dolomite)	kg/m3	1,300.0	
52		lb/ft3	81.2	
53				
54	Bed Media Storage Silo	hr	200.3	w/ bin vent
55		day	8.3	

OPERATING CONDITIONS - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00
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8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
56		ft3	2,305.8	
57		m3	65.3	based on tech #1 vendor quote
58				
59	Height	ft	20.0	
60	Diameter	ft	12.1	
61				
62				
63	Bed Media Weigh Hopper	ft3	166.0	
64		m3	4.7	based on tech #1 vendor quote
65				
66	Bed Media Lock/Surge Hopper	ft3	14.0	
67		m3	0.4	based on tech #1 vendor quote
68				
69	**STEAM TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
70	Steam - Flow	lb/hr	13,175	348.5 lb steam / metric ton of dry biomass
71	Steam - Temperature	°F	392.0	
72	Steam - Temperature	°C	200.0	
73	Steam - Pressure	psig	203.0	
74				
75	**STANDARD CONDITIONS**			
76	Standard Conditions - Temperature	°F	60.0	
77	Standard Conditions - Pressure	psia	14.696	
78				
79	Normal Conditions - Temperature	°F	32.0	
80	Normal Conditions - Pressure	psia	14.696	
81				
82	**OXYGEN REQUIREMENTS TO GASIFIER**			
83	Oxygen Required by Gasifier	lbs O^2 / hr	25,633	678.1 lb 100% O2 / metric ton of dry biomass
84	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
85	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	27,862	
86	Oxygen - Temperature	°F	392.0	
87	Oxygen - Temperature	°C	200.0	
88	Oxygen - Pressure	psig	203.0	
89				
90	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
91	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	870.7	
92	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	312,614	At Normal Conditions
93	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	5,210	At Normal Conditions
94	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	330,417	At Standard Conditions
95	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	5,507	At Standard Conditions
96				
97	Oxygen Required by Gasifier	short tons O^2 / day	307.6	@ 100% purity
98	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	334.3	
99				
100	**RECYCLE GAS TO GASIFIER**			

OPERATING CONDITIONS - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
101				unknown
102				
103	**NITROGEN USAGE**			
104				unknown
105				
106	**GASIFIER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
107	Syngas - Clean Gas - Production Rate	lbs syngas / hr	156,055	4128.4 lb syngas / metric ton of dry biomass
108	Syngas - Pressure	psig	130.0	
109	Syngas - Temperature	°C	850	
110	Syngas - Temperature	°F	1,562	
111	Syngas - LHV - Dry	BTU / lb dry syngas		
112	Syngas - HHV - Dry	BTU / lb dry syngas		
113				
114	Syngas - Composition			
115	CO	% (by vol. wet)	19.90	
116		% (by vol. dry)	25.41	
117	CO2	% (by vol. wet)	21.85	
118		% (by vol. dry)	27.90	
119	H2	% (by vol. wet)	25.83	
120		% (by vol. dry)	32.98	
121	H2O	% (by vol. wet)	21.68	
122		% (by vol. dry)	0.00	
123	N2	% (by vol. wet)	3.60	
124		% (by vol. dry)	4.60	
125	CH4 (methane)	% (by vol. wet)	6.41	
126		% (by vol. dry)	8.18	
127	C2H4 (ethylene)	% (by vol. wet)	0.15	
128		% (by vol. dry)	0.19	
129	C2H6 (ethane)	% (by vol. wet)	0.19	
130		% (by vol. dry)	0.25	
131	C6H6 (benzene)	% (by vol. wet)	0.19	
132		% (by vol. dry)	0.25	
133	CxHy (tars)	% (by vol. wet)	0.0531	
134		% (by vol. dry)	0.07	
135	H2S+COS	% (by vol. wet)	0.0068	
136		% (by vol. dry)	0.01	
137	NH3+HCN	% (by vol. wet)	0.14	
138		% (by vol. dry)	0.18	
139	HCl	% (by vol. wet)	0.0008	
140		% (by vol. dry)	0.00	
141	Total	% (by vol. wet)	100.01	
142				
143	H2/CO ratio		1.30	
144				
145	**ASH PRODUCTION**	**UNITS**	**VALUE**	**REMARKS**
146	Bottom Ash Discharge	lb / hr	962	25.5 lb ash / metric ton of dry biomass

OPERATING CONDITIONS - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
147		short tons / day	11.5	
148	Bottom Ash - Temperature	°F	77.0	
149				
150	Filter Ash Discharge	lb / hr	2,819	74.6 lb ash / metric ton of dry biomass
151		short tons / day	33.8	
152	Filter Ash - Temperature	°F	77.0	
153				
154	Total Ash	lb / hr	3,781	
155		short tons / day	45.4	
156				
157	**STEAM TO TAR REFORMER**	**UNITS**	**VALUE**	**REMARKS**
158	Steam - Flow	lb/hr	4,600	121.7 lb steam / metric ton of dry biomass
159	Steam - Temperature	°F	203.0	
160	Steam - Temperature	°C	95.0	
161	Steam - Pressure	psig	392.0	
162				
163	**OXYGEN REQUIREMENTS TO TAR REFORMER**			
164	Oxygen Required by Tar Reformer	lbs O^2 / hr	7,261	192.1 lb 100% O2 / metric ton of dry biomass
165	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
166	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	7,893	
167	Oxygen - Temperature	°F	392.0	
168	Oxygen - Temperature	°C	200.0	
169	Oxygen - Pressure	psig	203.0	
170				
171	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
172	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	246.6	
173	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	88,558	At Normal Conditions
174	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	1,476	At Normal Conditions
175	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	93,601	At Standard Conditions
176	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	1,560	At Standard Conditions
177				
178	Oxygen Required by Gasifier	short tons O^2 / day	87.1	@ 100% purity
179	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	94.7	
180				
181	**TAR REFORMER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
182	Syngas - Clean Gas - Production Rate	lbs syngas / hr	168,723	4463.6 lb syngas / metric ton of dry biomass
183				
184	Syngas - Pressure	psig	130.0	
185	Syngas - Temperature	°C	871	
186	Syngas - Temperature	°F	1,600	
187	Syngas - LHV - Dry	BTU / lb dry syngas		
188	Syngas - HHV - Dry	BTU / lb dry syngas		
189				
190	Syngas - Composition			
191	CO	% (by vol. wet)	24.64	
192		% (by vol. dry)	31.46	

OPERATING CONDITIONS - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
193	CO2	% (by vol. wet)	16.86	
194		% (by vol. dry)	21.53	
195	H2	% (by vol. wet)	29.39	
196		% (by vol. dry)	37.52	
197	H2O	% (by vol. wet)	24.00	
198		% (by vol. dry)	0.00	
199	N2	% (by vol. wet)	3.48	
200		% (by vol. dry)	4.44	
201	CH4 (methane)	% (by vol. wet)	1.54	
202		% (by vol. dry)	1.97	
203	C2H4 (ethylene)	% (by vol. wet)	0.022	
204		% (by vol. dry)	0.03	
205	C2H6 (ethane)	% (by vol. wet)	0.005	
206		% (by vol. dry)	0.01	
207	C6H6 (benzene)	% (by vol. wet)	0.050	
208		% (by vol. dry)	0.06	
209	CxHy (tars)	% (by vol. wet)	0.0041	
210		% (by vol. dry)	0.01	
211	H2S+COS	% (by vol. wet)	0.0059	
212		% (by vol. dry)	0.01	
213	NH3+HCN	% (by vol. wet)	0.0095	
214		% (by vol. dry)	0.01	
215	HCl	% (by vol. wet)	0.0007	
216		% (by vol. dry)	0.00	
217	Total	% (by vol. wet)	100.01	
218				
219	H2/CO ratio		1.19	
220				
221	**OTHER**	**UNITS**	**VALUE**	**REMARKS**
222	Parasitic Load	MW		unknown
223		hp		
224				

OPERATING CONDITIONS - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
9	**BIOMASS TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
10	Biomass - Consumption Rate - Wet	metric tons wet biomass / day	1,111	
11		metric tons wet biomass / hr	46.3	
12		short tons wet biomass / day	1,224.8	
13		short tons wet biomass / hr	51.0	
14		lbs wet biomass / hr	102,066	
15				
16	Biomass - LHV - Wet	BTU / lb wet biomass	7,254	
17	Biomass - HHV - Wet	BTU / lb wet biomass	7,804	
18				
19	Biomass - Consumption Rate - Dry	metric tons dry biomass / day	1,000	
20		metric tons dry biomass / hr	41.7	
21		short tons dry biomass / day	1,102	
22		short tons dry biomass / hr	45.9	
23		lbs dry biomass / day	2,204,623	
24		lbs dry biomass / hr	91,859	
25				
26	Biomass - LHV - Dry	BTU / lb dry biomass	8,060	
27	Biomass - HHV - Dry	BTU / lb dry biomass	8,671	
28				
29	Biomass - Moisture Content	wt% water / wet biomass	10.0	
30	Biomass - Temperature	°F		
31	Biomass - Feed Pressure	psig		
32	Biomass - Bulk Density	lb/ft3		
33	Biomass - Size Distribution		2.0" minus	
34				
35	Biomass - Type		Hybrid Poplar	
36	Biomass - Ultimate Analysis			
37	Carbon	% wt. (dry basis)	50.88	
38	Hydrogen	% wt. (dry basis)	6.04	
39	Nitrogen	% wt. (dry basis)	0.17	
40	Sulfur	% wt. (dry basis)	0.09	
41	Oxygen	% wt. (dry basis)	41.90	
42	Chlorine	% wt. (dry basis)		unknown
43	Ash	% wt. (dry basis)	0.92	
44				
45	**BED MATERIAL TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
46	Bed Material - Consumption Rate - As is	lb / hr		unknown
47		short tons / day		
48	Bed Material - Temperature	°F		
49	Bed Material - Feed Pressure	psig		
50				
51	Bulk Density (Uncompacted Dolomite)	kg/m3	1,300.0	
52		lb/ft3	81.2	
53				
54	Bed Media Storage Silo	hr	200.3	w/ bin vent, based on tech #1 quote
55		day	8.3	

OPERATING CONDITIONS - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
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8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
56		ft3		unknown
57		m3		
58				
59	Height	ft	20.0	
60	Diameter	ft		unknown
61				
62				
63	Bed Media Weigh Hopper	ft3		unknown
64		m3		
65				
66	Bed Media Lock/Surge Hopper	ft3		unknown
67		m3		
68				
69	**STEAM TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
70	Steam - Flow	lb/hr	12,000	288.0 lb steam / metric ton of dry biomass
71	Steam - Temperature	°F	366.0	
72	Steam - Temperature	°C	185.6	
73	Steam - Pressure	psig	150.0	
74				
75	**STANDARD CONDITIONS**			
76	Standard Conditions - Temperature	°F	60.0	
77	Standard Conditions - Pressure	psia	14.696	
78				
79	Normal Conditions - Temperature	°F	32.0	
80	Normal Conditions - Pressure	psia	14.696	
81				
82	**OXYGEN REQUIREMENTS TO GASIFIER**			
83	Oxygen Required by Gasifier	lbs O^2 / hr	0	
84	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
85	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	0	
86	Oxygen - Temperature	°F		
87	Oxygen - Temperature	°C		
88	Oxygen - Pressure	psig		
89				
90	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
91	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	0.0	
92	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	0	At Normal Conditions
93	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	0	At Normal Conditions
94	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	0	At Standard Conditions
95	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	0	At Standard Conditions
96				
97	Oxygen Required by Gasifier	short tons O^2 / day	0.0	@ 100% purity
98	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	0.0	
99				
100	**RECYCLE GAS TO GASIFIER**			

OPERATING CONDITIONS - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
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8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
101				unknown
102				
103	**NITROGEN USAGE**			
104				unknown
105				
106	**GASIFIER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
107	Syngas - Clean Gas - Production Rate	scfh		unknown
108		scfm		
109		lbs syngas / hr		
110	Syngas - Pressure	psig		
111	Syngas - Temperature	°C	850	
112	Syngas - Temperature	°F	1,562	
113				
114	Syngas Calorific Value	MJ/Nm3		unknown
115		Btu/scf		N = 0°C & 1 atm or 101.325 kPa, S = 60 °F & 1 atm
116				
117	Syngas - Composition			unknown
118	CO	% (by vol. dry)		
119	CO2	% (by vol. dry)		
120	H2	% (by vol. dry)		
121	H2O	% (by vol. dry)		
122	N2	% (by vol. dry)		
123	CH4 (methane)	% (by vol. dry)		
124	C2H4 (ethylene)	% (by vol. dry)		
125	C2H6 (ethane)	% (by vol. dry)		
126	C6H6 (benzene)	% (by vol. dry)		
127	CxHy (tars)	% (by vol. dry)		
128	H2S+COS	% (by vol. dry)		
129	NH3+HCN	% (by vol. dry)		
130	HCl	% (by vol. dry)		
131	Total		0.00	
132				
133	H2/CO ratio			unknown
134				
135	**STEAM TO TAR REFORMER**	**UNITS**	**VALUE**	**REMARKS**
136	Steam - Flow	lb/hr	0	
137	Steam - Temperature	°F		
138	Steam - Temperature	°C		
139	Steam - Pressure	psig		
140				
141	**OXYGEN REQUIREMENTS TO TAR REFORMER**			
142	Oxygen Required by Tar Reformer	lbs O^2 / hr	0	
143	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
144	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	0	
145	Oxygen - Temperature	°F		
146	Oxygen - Temperature	°C		

OPERATING CONDITIONS - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
147	Oxygen - Pressure	psig		
148				
149	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
150	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	0.0	
151	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	0	At Normal Conditions
152	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	0	At Normal Conditions
153	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	0	At Standard Conditions
154	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	0	At Standard Conditions
155				
156	Oxygen Required by Gasifier	short tons O^2 / day	0.0	@ 100% purity
157	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	0.0	
158				
159	**TAR REFORMER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
160	Syngas - Clean Gas - Production Rate	scfh	1,580,000	37920 scf syngas / metric ton of dry biomass
161		scfm	26,333	
162				
163	Syngas - Pressure	psig	1.0	
164	Syngas - Temperature	°C	1,000	
165	Syngas - Temperature	°F	1,832	
166				
167	Syngas Calorific Value	MJ/Nm3	15.5	14-17 range from vendor
168		Btu/scf	393.6	N = 0°C & 1 atm or 101.325 kPa, S = 60 °F & 1 atm
169				
170	Syngas - Composition			
171	CO	% (by vol. dry)	25.30	
172	CO2	% (by vol. dry)	19.10	
173	H2	% (by vol. dry)	43.90	
174	H2O	% (by vol. dry)	0.00	
175	N2	% (by vol. dry)	0.90	
176	CH4 (methane)	% (by vol. dry)	10.60	
177	C2H4 (ethylene)	% (by vol. dry)	0.70	
178	C2H6 (ethane)	% (by vol. dry)	0.00	
179	C6H6 (benzene)	% (by vol. dry)	0.00	
180	CxHy (tars)	% (by vol. dry)	0.00	
181	H2S+COS	% (by vol. dry)	0.00	
182	NH3+HCN	% (by vol. dry)	0.00	
183	HCl	% (by vol. dry)	0.00	
184	Total		100.50	
185				
186	H2/CO ratio		1.74	
187				
188	**CHAR COMBUSTOR**	**UNITS**	**VALUE**	**REMARKS**
189	Bed Material Temperature from Combustion Reactor	°C	850	Same as tar reformation temp. from vendor
190		°F	1,562	
191				
192	Combustion Air Flow Rate	lb/hr	200,000	4800 lb air / metric ton of dry biomass

OPERATING CONDITIONS - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
193		scfh		
194		scfm	0	
195	Combustion Air Temperature	°F	1,000	from vendor
196		°C	538	
197				
198	Flue Gas Flow Rate	scfh	2,800,000	67200 scf syngas / metric ton of dry biomass
199		scfm	46,667	
200	Flue Gas Temperature	°C	1,000	from vendor
201		°F	1,832	
202				
203	**OTHER**	**UNITS**	**VALUE**	**REMARKS**
204	Parasitic Load	MW	4.0	96.0 kW / metric ton of dry biomass
205		hp	5,364	
206				

OPERATING CONDITIONS - TECHNOLOGY #3

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
9	**BIOMASS TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
10	Biomass - Consumption Rate - Wet	metric tons wet biomass / day	1,176	
11		metric tons wet biomass / hr	49.0	
12		short tons wet biomass / day	1,296.8	
13		short tons wet biomass / hr	54.0	
14		lbs wet biomass / hr	108,070	
15				
16	Biomass - LHV - Wet	BTU / lb wet biomass	6,851	
17	Biomass - HHV - Wet	BTU / lb wet biomass	7,370	
18				
19	Biomass - Consumption Rate - Dry	metric tons dry biomass / day	1,000	
20		metric tons dry biomass / hr	41.7	
21		short tons dry biomass / day	1,102	
22		short tons dry biomass / hr	45.9	
23		lbs dry biomass / day	2,204,623	
24		lbs dry biomass / hr	91,859	
25				
26	Biomass - LHV - Dry	BTU / lb dry biomass	8,060	
27	Biomass - HHV - Dry	BTU / lb dry biomass	8,671	
28				
29	Biomass - Moisture Content	wt% water / wet biomass	15.0	
30	Biomass - Temperature	°F		
31	Biomass - Feed Pressure	psig	38.0	
32	Biomass - Bulk Density	lb/ft3	9.60	
33	Biomass - Size Distribution		2.0" minus	
34				
35	Biomass - Type		Hybrid Poplar	
36	Biomass - Ultimate Analysis			
37	Carbon	% wt. (dry basis)	50.88	
38	Hydrogen	% wt. (dry basis)	6.04	
39	Nitrogen	% wt. (dry basis)	0.17	
40	Sulfur	% wt. (dry basis)	0.09	
41	Oxygen	% wt. (dry basis)	41.90	
42	Chlorine	% wt. (dry basis)		unknown
43	Ash	% wt. (dry basis)	0.92	
44				
45	**BED MATERIAL TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
46	Bed Material - Consumption Rate - As is	lb / hr	230	5.5 lb bed material / metric ton of dry biomass
47		short tons / day	2.8	
48	Bed Material - Temperature	°F		
49	Bed Material - Feed Pressure	psig	38.0	
50				
51	Bulk Density (Uncompacted Dolomite)	kg/m3	1,300.0	
52		lb/ft3	81.2	
53				
54	Bed Media Storage Silo	hr	200.3	w/ bin vent
55		day	8.3	

OPERATING CONDITIONS - TECHNOLOGY #3

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Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
56		ft3	566.9	
57		m3	16.1	based on tech #1 vendor quote
58				
59	Height	ft	15.0	
60	Diameter	ft	6.9	
61				
62				
63	Bed Media Weigh Hopper	ft3	166.0	
64		m3	4.7	based on tech #1 vendor quote
65				
66	Bed Media Lock/Surge Hopper	ft3	14.0	
67		m3	0.4	based on tech #1 vendor quote
68				
69	**STEAM TO GASIFIER**	**UNITS**	**VALUE**	**REMARKS**
70	Steam - Flow	lb/hr	16,337	392.1 lb steam / metric ton of dry biomass
71	Steam - Temperature	°F	489.0	
72		°C	253.9	
73	Steam - Superheated Temperature	°F	1,000.0	
74		°C	537.8	
75	Steam - Pressure	psig	125.0	
76				
77	**STANDARD CONDITIONS**			
78	Standard Conditions - Temperature	°F	60.0	
79	Standard Conditions - Pressure	psia	14.696	
80				
81	Normal Conditions - Temperature	°F	32.0	
82	Normal Conditions - Pressure	psia	14.696	
83				
84	**OXYGEN REQUIREMENTS TO GASIFIER**			
85	Oxygen Required by Gasifier	lbs O^2 / hr	29,043	697.0 lb 100% O2 / metric ton of dry biomass
86	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
87	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	31,568	
88	Oxygen - Temperature	°F		unknown
89	Oxygen - Temperature	°C		
90	Oxygen - Pressure	psig		
91				
92	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
93	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	986.5	
94	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	354,199	At Normal Conditions
95	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	5,903	At Normal Conditions
96	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	374,371	At Standard Conditions
97	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	6,240	At Standard Conditions
98				
99	Oxygen Required by Gasifier	short tons O^2 / day	348.5	@ 100% purity
100	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	378.8	
101				

OPERATING CONDITIONS - TECHNOLOGY #3

HARRIS GROUP PROJECT NO.: 30074.00
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DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
102	**RECYCLE GAS TO GASIFIER**			
103				unknown
104				
105	**NITROGEN USAGE**			
106				unknown
107				
108	**GASIFIER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
109	Syngas - Clean Gas - Production Rate	lbs syngas / hr	152,799	3667.2 lb syngas / metric ton of dry biomass
110	Syngas - Pressure	psig	38.0	
111	Syngas - Temperature	°C	802	
112	Syngas - Temperature	°F	1,475	
113				
114	Syngas - HHV - Dry	BTU / scf	362	@ 60 °F & 14.73 psi
115				
116	Syngas - Composition			
117	CO	% (by vol. wet)	23.90	
118		% (by vol. dry)	33.17	
119	CO2	% (by vol. wet)	19.30	
120		% (by vol. dry)	26.79	
121	H2	% (by vol. wet)	17.20	
122		% (by vol. dry)	23.87	
123	H2O	% (by vol. wet)	27.90	
124		% (by vol. dry)	0.00	
125	N2	% (by vol. wet)	1.50	
126		% (by vol. dry)	2.08	
127	CH4 (methane)	% (by vol. wet)	6.70	
128		% (by vol. dry)	9.30	
129	C2H4 (ethylene)	% (by vol. wet)	2.40	
130		% (by vol. dry)	3.33	
131	C2H6 (ethane)	% (by vol. wet)	0.50	
132		% (by vol. dry)	0.69	
133	C6H6 (benzene)	% (by vol. wet)	0.00	
134		% (by vol. dry)	0.00	
135	CxHy (tars)	% (by vol. wet)	0.4900	
136		% (by vol. dry)	0.68	
137	H2S+COS	% (by vol. wet)	0.0000	
138		% (by vol. dry)	0.00	
139	NH3+HCN	% (by vol. wet)	0.06	
140		% (by vol. dry)	0.08	
141	HCl	% (by vol. wet)	0.0008	
142		% (by vol. dry)	0.00	
143	Total	% (by vol. wet)	99.95	
144				
145	H2/CO ratio		0.72	
146				
147	**STEAM TO TAR REFORMER**	**UNITS**	**VALUE**	**REMARKS**

OPERATING CONDITIONS - TECHNOLOGY #3

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
148	Syngas - Clean Gas - Production Rate (from Gasifier)	lbs syngas / hr	152,799	1st column is tech #1 flow
149	Steam - Flow	lb/hr	4,504	29.5 lb steam / klb syngas
150	Steam - Temperature	°F		unknown
151	Steam - Temperature	°C		
152	Steam - Pressure	psig		
153				
154	**OXYGEN REQUIREMENTS TO TAR REFORMER**			
155	Syngas - Clean Gas - Production Rate (from Gasifier)	lbs syngas / hr	152,799	1st column is tech #1 flow
156	Oxygen Required by Tar Reformer	lbs O^2 / hr	7,110	46.5 lb 100% O2 / klb syngas
157		lbs O^2 / hr	7,110	
158	Oxygen Gas - Oxygen Composition	wt% O^2 / oxygen gas	92.00	
159	Oxygen Gas - Mass Required by Gasifier	lbs oxygen gas / hr	7,728	
160	Oxygen - Temperature	°F		unknown
161	Oxygen - Temperature	°C		
162	Oxygen - Pressure	psig		
163				
164	Oxygen Gas - Average Molecular Weight	lbs oxygen gas / lb-mole	32.0	The average molecular weight will change if oxygen gas composition changes.
165	Oxygen Gas - Moles Required by Gasifier	lb-moles oxygen gas / hr	241.5	
166	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	86,711	At Normal Conditions
167	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	1,445	At Normal Conditions
168	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / hr	91,649	At Standard Conditions
169	Oxygen Gas - Volume Required by Gasifier	ft^3 oxygen gas / min	1,527	At Standard Conditions
170				
171	Oxygen Required by Gasifier	short tons O^2 / day	96.0	@ 100% purity
172	Oxygen Gas - Required by Gasifier	short tons oxygen gas / day	92.7	
173				
174	**TAR REFORMER OUTPUT**	**UNITS**	**VALUE**	**REMARKS**
175	Syngas - Clean Gas - Production Rate	lbs syngas / hr	164,413	Estimate
176	Syngas - Pressure	psig		
177	Syngas - Temperature	°C		unknown
178	Syngas - Temperature	°F		
179	Syngas - LHV - Dry	BTU / lb dry syngas		
180	Syngas - HHV - Dry	BTU / lb dry syngas		
181				
182	Syngas - Composition			unknown
183	CO	% (by vol. wet)		
184		% (by vol. dry)	0.00	
185	CO2	% (by vol. wet)		
186		% (by vol. dry)	0.00	
187	H2	% (by vol. wet)		
188		% (by vol. dry)	0.00	
189	H2O	% (by vol. wet)		
190		% (by vol. dry)	0.00	
191	N2	% (by vol. wet)		
192		% (by vol. dry)	0.00	
193	CH4 (methane)	% (by vol. wet)		

OPERATING CONDITIONS - TECHNOLOGY #3

HARRIS GROUP PROJECT NO.: 30074.00
PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 02/28/2011

8	DESCRIPTION	UNITS	VALUE (at 1,000 ODMTPD)	REMARKS
194		% (by vol. dry)	0.00	
195	C2H4 (ethylene)	% (by vol. wet)		
196		% (by vol. dry)	0.00	
197	C2H6 (ethane)	% (by vol. wet)		
198		% (by vol. dry)	0.00	
199	C6H6 (benzene)	% (by vol. wet)		
200		% (by vol. dry)	0.00	
201	CxHy (tars)	% (by vol. wet)		
202		% (by vol. dry)	0.00	
203	H2S+COS	% (by vol. wet)		
204		% (by vol. dry)	0.00	
205	NH3+HCN	% (by vol. wet)		
206		% (by vol. dry)	0.00	
207	HCl	% (by vol. wet)		
208		% (by vol. dry)	0.00	
209	Total	% (by vol. wet)	0.00	
210				
211	H2/CO ratio			unknown
212				
213	**OTHER**	**UNITS**	**VALUE**	**REMARKS**
214	Gasifier Compressor Load	MW	0.52	12.4 kW / metric ton of dry biomass
215		hp	695	
216				
217	Other Gasifier Island Equipment Load	MW	2.26	54.2 kW / metric ton of dry biomass
218		hp	3,030	
219				

APPENDIX C
ORDER OF MAGNITUDE ESTIMATES
GASIFIER ISLAND EQUIPMENT LISTS

Harris Group Inc.
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REV	DATE	BY
A	1/14/2011	JRY

NREL Gasifier Technology Assessment - Technology - #1

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011 | PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN			ELECTRICAL			MATERIAL	RFP No.	QUOTE INFO	FOB SHOP	REMARKS
									SIZE (EA)	CAPACITY	HEAD/PRESS	HP (total)	RPM	VOLTS			NO/DATE/VALID	$	
BIOMASS FUEL HANDLING & STORAGE SYSTEM DISTRIBUTION CONVEYOR																			
A	-	- E -	0101	Biomass Delivery Conveyor	F-100	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	Drag chain conveyor, , , ,
A	-	- M -	0101	Biomass Delivery Conveyor Motor	F-100	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1																			
A	-	- E -	0102	Biomass Line-1 - Weigh Bin Inlet Distribution Spreader	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Rotation Spreader, , , ,
A	-	- M -	0102	Biomass Line-1 - Weigh Bin Inlet Distribution Spreader Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0103	Biomass Line-1 - Weigh Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	-	- E -	0104	Biomass Line-1 - Weigh Bin Bottom Screw Discharger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer / discharger screw conveyor, , , ,
A	-	- M1 -	0104	Biomass Line-1 - Weigh Bin Bottom Screw Discharger Rotation Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- M2 -	0104	Biomass Line-1 - Weigh Bin Bottom Screw Discharger Travel Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0105	Biomass Line-1 -Weigh Bin Vent Filter	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	-	- E -	0106	Biomass Line-1 - Lock Hopper Reversing Feed Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	-	- M -	0106	Biomass Line-1 - Lock Hopper Reversing Feed Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0107	Biomass Line-1 - Lock Hopper No.1	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	-	- E -	0108	Biomass Line-1 - Lock Hopper No.2	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	-	- E -	0109	Biomass Line-1 - Lock Hopper Discharge Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	-	- M -	0109	Biomass Line-1 - Lock Hopper Discharge Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0110	Biomass Line-1 -Metering Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	-	- E -	0111	Biomass Line-1 - Metering Bin Live Bottom Discharge Screws	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	-	- M -	0111	Biomass Line-1 - Metering Bin Live Bottom Discharge Screws Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	-	- E -	0112	Biomass Line-1 - Metering Bin Discharge Screw Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw, Pressurized , , ,
A	-	- M -	0112	Biomass Line-1 - Metering Bin Discharge Screw Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0113	Biomass Line-1 - Gasifier Feed Screw	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	-	- M -	0113	Biomass Line-1 - Gasifier Feed Screw Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2																			
A	-	- E -	0114	Biomass Line-2 - Weigh Bin Inlet Distribution Spreader	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Rotation Spreader, , , ,
A	-	- M -	0114	Biomass Line-2 - Weigh Bin Inlet Distribution Spreader Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	-	- E -	0115	Biomass Line-2 - Weigh Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,

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REV	DATE	BY
A	1/14/2011	JRY

NREL Gasifier Technology Assessment - Technology - #1

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	E -	0116	Biomass Line-2 - Weigh Bin Bottom Screw Discharger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer / discharger screw conveyor, , , ,
A	- -	M1 -	0116	Biomass Line-2 - Weigh Bin Bottom Screw Discharger Rotation Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	M2 -	0116	Biomass Line-2 - Weigh Bin Bottom Screw Discharger Travel Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0117	Biomass Line-2 -Weigh Bin Vent Filter	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0118	Biomass Line-2 - Lock Hopper Reversing Feed Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0118	Biomass Line-2 - Lock Hopper Reversing Feed Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0119	Biomass Line-2 - Lock Hopper No.1	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	- -	E -	0120	Biomass Line-2 - Lock Hopper No.2	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	- -	E -	0121	Biomass Line-2 - Lock Hopper Discharge Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0121	Biomass Line-2 - Lock Hopper Discharge Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0122	Biomass Line-2 -Metering Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0123	Biomass Line-2 - Metering Bin Live Bottom Discharge Screws	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0123	Biomass Line-2 - Metering Bin Live Bottom Discharge Screws Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0124	Biomass Line-2 - Metering Bin Discharge Screw Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw, Pressurized , , ,
A	- -	M -	0124	Biomass Line-2 - Metering Bin Discharge Screw Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0125	Biomass Line-2 - Gasifier Feed Screw	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	- -	M -	0125	Biomass Line-2 - Gasifier Feed Screw Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3																			
A	- -	E -	0126	Biomass Line-3 - Weigh Bin Inlet Distribution Spreader	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Rotation Spreader, , , ,
A	- -	M -	0126	Biomass Line-3 - Weigh Bin Inlet Distribution Spreader Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0127	Biomass Line-3 - Weigh Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	- -	E -	0128	Biomass Line-3 - Weigh Bin Bottom Screw Discharger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer / discharger screw conveyor, , , ,
A	- -	M1 -	0128	Biomass Line-3 - Weigh Bin Bottom Screw Discharger Rotation Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	M2 -	0128	Biomass Line-3 - Weigh Bin Bottom Screw Discharger Travel Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0129	Biomass Line-3 -Weigh Bin Vent Filter	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0130	Biomass Line-3 - Lock Hopper Reversing Feed Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0130	Biomass Line-3 - Lock Hopper Reversing Feed Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0131	Biomass Line-3 - Lock Hopper No.1	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,

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NREL Gasifier Technology Assessment - Technology - #1

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN			ELECTRICAL			MATERIAL	RFP No.	QUOTE INFO	FOB SHOP	REMARKS
									SIZE (EA)	CAPACITY	HEAD/PRESS	HP (total)	RPM	VOLTS			NO/DATE/VALID	$	
A	- -	E -	0132	Biomass Line-3 - Lock Hopper No.2	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	- -	E -	0133	Biomass Line-3 - Lock Hopper Discharge Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0133	Biomass Line-3 - Lock Hopper Discharge Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0134	Biomass Line-3 -Metering Bin	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0135	Biomass Line-3 - Metering Bin Live Bottom Discharge Screws	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0135	Biomass Line-3 - Metering Bin Live Bottom Discharge Screws Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0136	Biomass Line-3 - Metering Bin Discharge Screw Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw, Pressurized , , ,
A	- -	M -	0136	Biomass Line-3 - Metering Bin Discharge Screw Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0137	Biomass Line-3 - Gasifier Feed Screw	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	- -	M -	0137	Biomass Line-3 - Gasifier Feed Screw Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BED MEDIA STORAGE & HANDLING																		
A	- -	E -	0138	Bed Media - Recieving Station	F-100	Vendor-07	-	1	-	-	-	-	-	-	-	-	-	$38,800	Truck unloading station, Dolomite material, , ,
A	- -	E -	0139	Bed Media - Pneumatic Unloading Conveyor	F-100	Vendor-06	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized air is the motive power source, , , ,
A	- -	E -	0140	Bed Media - Storage Silo	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, Bottom discharge fluidizing air system, Outlet shutoff valve, ,
A	- -	E -	0141	Bed Media - Storage Silo Vent Filter	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0142	Bed Media - Weigh Hopper	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, Bottom discharge fluidizing air system, , ,
A	- -	E -	0143	Bed Media - Lock Hopper	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Inlet shutoff valve, Outlet shutoff valve, ,
A	- -	E -	0144	Bed Media - Lock Hopper Discharge Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw conveyor, Pressurized , Outlet shutoff valve, ,
A	- -	M -	0144	Bed Media - Lock Hopper Discharge Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	GASIFIER																		
A	- -	E -	0145	Gasifier	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	$14,528,047	Fluidized bed auto thermal gasifier, Pressure vessel, Refractory lined, Fired with biomass fuel & oxygen, Fluidizing bed composed of dolomite, medium pressure steam, recycled syngas & ash
A	- -	E -	0146	Gasifier - Startup Burner	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Horizontal pressure vessel fire box, Natural gas or light fuel oil burner, Refractory lined, ,
A	- -	E -	0147	Gasifier - Startup Burner - Light Fuel Oil Booster Pump	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Oil pump, , , ,
A	- -	M -	0147	Gasifier - Startup Burner - Light Fuel Oil Booster Pump Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0148	Gasifier - Combustuon Air Compressor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0148	Gasifier - Combustuon Air Compressor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0149	Gasifier - Combustuon Air Receiver	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,

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REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
	GASIFIER ASH REMOVAL SYSTEM																		
A	- -	E -	0150	Gasifier Ash Removal - Screw Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized, Water cooled, Discharge shutoff valave,
A	- -	M -	0150	Gasifier Ash Removal - Screw Conveyor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0151	Gasifier Ash Removal - Lock Hopper	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0152	Gasifier Ash Removal - Conveyor Hopper	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, Nitrogen gas pneumatic discharge, , ,
A	- -	E -	0153	Gasifier Ash Removal - Pneumatic Conveyor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized nitrogen gas motive power source, , , ,
A	- -	E -	0154	Gasifier Ash Removal - Ash Storage Silo	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0155	Gasifier Ash Removal - Ash Transfer Conveyor	F-100	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	$40,000	Screw conveyor, , , ,
A	- -	M -	0155	Gasifier Ash Removal - Ash Transfer Conveyor Motor	F-100	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	SYNGAS ASH REMOVAL SYSTEM																		
A	- -	E -	0156	Syngas Ash Removal - Cyclone	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Refractory lined, , ,
A	- -	E -	0157	Syngas Ash Removal - Cyclone Rotary Discharger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Metering device, Pressurized , , ,
A	- -	M -	0157	Syngas Ash Removal - Cyclone Rotary Discharger Motor	F-100	Vendor-01	-	-	-	-	-	-	-	-	-	-	-	included	, , , ,
	SYNGAS TAR REFORMER																		
A	- -	E -	0158	Tar Reformer	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Refractory lined, Internal catalyst support trays, Packed with catalyst blocks,
A	- -	E -	0159	Tar Reformer - Pulse Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Steam receiver tank for periodic back flow pulsing of catalyst blocks to clean catalyst, , ,
A	- -	E -	0160	Tar Reformer - Burner	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Horizontal pressure vessel fire box, Natural gas or light fuel oil burner, Refractory lined, ,
	PROCESS AIR SYSTEM																		
A	- -	E -	0161	Process Air - Compressor	F-100	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	$50,000	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0161	Process Air - Compressor Motor	F-100	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0162	Process Air - Dryer	F-100	Vendor-11	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0163	Process Air - Receiver Tank	F-100	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
	AIR SEPARATION SYSTEM																		
A	- -	E -	0164	Air Separation Plant - Oxygen / Nitrogen Separator	F-100	Vendor-04	-	1	-	-	-	-	-	-	-	-	-	$7,198,807	Pressure vessel, , , ,
A	- -	E -	0165	Air Separation Plant - Oxygen Gas Receiver Tank	F-100	Vendor-04	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0166	Air Separation Plant - Nitrogen Gas Receiver Tank	F-100	Vendor-04	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
	OXYGEN SYSTEM																		
A	- -	E -	0167	Oxygen System - Booster Compressor	F-100	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	$50,000	Screw compressor, Air cooled, Oil free operation, ,

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NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	M -	0167	Oxygen System - Booster Compressor Motor	F-100	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0168	Oxygen System - Oxygen Gas Supply Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Oxygen supply for gasifier & tar remover combustion, , ,
A	- -	E -	0169	Oxygen System - Oxygen Heater	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Indirect heat supplied by medium pressure steam, , , ,
	NITROGEN SYSTEM																		
A	- -	E -	0170	Nitrogen System - Instrument Nitrogen Gas Supply Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Nitrogen supply for instrumentation operation, , ,
A	- -	E -	0171	Nitrogen System - Booster Compressor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0171	Nitrogen System - Booster Compressor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0172	Nitrogen System - Process Nitrogen Gas Supply Tank No.1	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, High pressure nitrogen, Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements, ,
A	- -	E -	0173	Nitrogen System - Process Nitrogen Gas Supply Tank No.2	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Low pressure nitrogen, Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements, ,
A	- -	E -	0174	Nitrogen System - Emergency Booster Compressor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0174	Nitrogen System - Emergeny Booster Compressor Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0175	Nitrogen System - Emergency Nitrogen Gas Storage Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, High pressure nitrogen, Nitrogen supply for emergency shutdowns to prevent fires and explosions, ,
	FLARE STACK																		
A	- -	E -	0176	Syngas Flare Stack	F-100	Vendor-12	-	1	-	-	-	-	-	-	-	-	-	$25,000	Screw compressor, , , ,
	ASH SCREW COOLING WATER SYSTEM																		
A	- -	E -	0177	Ash Screw Cooling Water - Storage Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0178	Ash Screw Cooling Water - Heat Exchanger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Indirect heat exchanger with clean ash screw cooling water on one side being cooled by cold mill water on
A	- -	E -	0179	Ash Screw Cooling Water - No.1 Pump	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Centrifugal pump, , , ,
A	- -	M -	0179	Ash Screw Cooling Water - No.1 Pump Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0180	Ash Screw Cooling Water - No.2 Pump	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Centrifugal pump, , , ,
A	- -	M -	0180	Ash Screw Cooling Water - No.2 Pump Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	SEAL WATER SYSTEM																		
A	- -	E -	0181	Seal Water - Storage Tank	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0182	Seal Water - Heat Exchanger	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Indirect heat exchanger with clean seal water on one side being cooled by cold mill water on the other side,
A	- -	E -	0183	Seal Water Water - No.1 Pump	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Centrifugal pump, , , ,
A	- -	M -	0183	Seal Water Water - No.1 Pump Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0184	Seal Water Water - No.2 Pump	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	Centrifugal pump, , , ,

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REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	M -	0184	Seal Water Water - No.2 Pump Motor	F-100	Vendor-01	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,

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NREL Gasifier Technology Assessment - Technology - #2

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
BIOMASS FUEL HANDLING & STORAGE SYSTEM DISTRIBUTION CONVEYOR																			
A	- -	E -	0201	Biomass Delivery Conveyor	F-200	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	Drag chain conveyor, , , ,
A	- -	M -	0201	Biomass Delivery Conveyor Motor	F-200	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1																			
A	- -	E -	0202	Biomass Line-1 - Weigh Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	- -	E -	0203	Biomass Line-1 - Weigh Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0203	Biomass Line-1 - Weigh Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0204	Biomass Line-1 - Weigh Bin Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0204	Biomass Line-1 - Weigh Bin Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0205	Biomass Line-1 - Weigh Bin Vent Filter	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0206	Biomass Line-1 - Lock Hopper	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0207	Biomass Line-1 - Lock Hopper Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0207	Biomass Line-1 - Lock Hopper Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0208	Biomass Line-1 - Metering Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0209	Biomass Line-1 - Metering Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0209	Biomass Line-1 - Metering Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0210	Biomass Line-1 - Gasifier Fuel Metering Screw Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0210	Biomass Line-1 - Gasifier Fuel Metering Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2																			
A	- -	E -	0211	Biomass Line-2 - Weigh Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	- -	E -	0212	Biomass Line-2 - Weigh Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0212	Biomass Line-2 - Weigh Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0213	Biomass Line-2 - Weigh Bin Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0213	Biomass Line-2 - Weigh Bin Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0214	Biomass Line-2 - Weigh Bin Vent Filter	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0215	Biomass Line-2 - Lock Hopper	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0216	Biomass Line-2 - Lock Hopper Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0216	Biomass Line-2 - Lock Hopper Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,

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NREL Gasifier Technology Assessment - Technology - #2

NATIONAL RENEWABLE ENERGY LABORATORY

REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	E -	0217	Biomass Line-2 - Metering Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0218	Biomass Line-2 - Metering Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0218	Biomass Line-2 - Metering Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0219	Biomass Line-2 - Gasifier Fuel MeteringScrew Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0219	Biomass Line-2 - Gasifier Fuel Metering Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3																		
A	- -	E -	0220	Biomass Line-3 - Weigh Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	- -	E -	0221	Biomass Line-3 - Weigh Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0221	Biomass Line-3 - Weigh Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0222	Biomass Line-3 - Weigh Bin Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0222	Biomass Line-3 - Weigh Bin Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0223	Biomass Line-3 - Weigh Bin Vent Filter	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0224	Biomass Line-3 - Lock Hopper	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0225	Biomass Line-3 - Lock Hopper Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0225	Biomass Line-3 - Lock Hopper Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0226	Biomass Line-3 - Metering Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0227	Biomass Line-3 - Metering Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0227	Biomass Line-3 - Metering Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0228	Biomass Line-3 - Gasifier Fuel Metering Screw Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0228	Biomass Line-3 - Gasifier Fuel Metering Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-4																		
A	- -	E -	0229	Biomass Line-4 - Weigh Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Weighing hopper, Atmospheric vessel, , ,
A	- -	E -	0230	Biomass Line-4 - Weigh Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0230	Biomass Line-4 - Weigh Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0231	Biomass Line-4 - Weigh Bin Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0231	Biomass Line-4 - Weigh Bin Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0232	Biomass Line-4 - Weigh Bin Vent Filter	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0233	Biomass Line-4 - Lock Hopper	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,

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NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	E -	0234	Biomass Line-4 - Lock Hopper Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0234	Biomass Line-4 - Lock Hopper Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0235	Biomass Line-4 - Metering Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0236	Biomass Line-4 - Metering Bin Live Bottom Discharge Screws	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Reclaimer with multiple screws discharging to a screw conveyor, , , ,
A	- -	M -	0236	Biomass Line-4 - Metering Bin Live Bottom Discharge Screws Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Single motor and drive mechanism used to drive multiple screws , , , ,
A	- -	E -	0237	Biomass Line-4 - Gasifier Fuel MeteringScrew Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, , , ,
A	- -	M -	0237	Biomass Line-4 - Gasifier Fuel Metering Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BED MEDIA STORAGE & HANDLING																		
A	- -	E -	0238	Bed Media - Recieving Station	F-200	Vendor-07	-	1	-	-	-	-	-	-	-	-	-	$38,800	Truck unloading station, Typically silica material, , ,
A	- -	E -	0239	Bed Media - Pneumatic Unloading Conveyor	F-200	Vendor-06	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized air is the motive power source, , , ,
A	- -	E -	0240	Bed Media - Storage Silo	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0241	Bed Media - Storage Silo Vent Filter	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0242	Bed Media - Nitrogen Gas Pneumatic Conveyor - Rotary Feeder	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized nitrogen gas motive power source, , , ,
A	- -	M -	0242	Bed Media - Nitrogen Gas Pneumatic Conveyor - Rotary Feeder Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0243	Bed Media - Nitrogen Gas Pneumatic Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Material is routed through a closed pipe , , , ,
A	- -	E -	0244	Bed Media - Nitrogen Gas Pneumatic Conveyor - Blower	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized nitrogen gas motive force, , , ,
A	- -	M -	0244	Bed Media - Nitrogen Gas Pneumatic Conveyor - Blower Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	GASIFICATION																		
A	- -	E -	0245	Gasification Reactor - Vessel	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	$14,330,003	Circulating fluidized bed allo thermal gasifier, Fluidized bed composed of biomass, externally heated bed
A	- -	E -	0246	Gasification Reactor - Heated Bed Material Surge Vessel	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Cone shaped bottom, , , ,
A	- -	E -	0247	Gasification Reactor - Cyclone No.1	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Cone shaped bottom, , , ,
A	- -	E -	0248	Gasification Reactor - Cyclone No.1 - Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0248	Gasification Reactor - Cyclone No.1 - Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0249	Gasification Reactor - Cyclone No.2	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Cone shaped bottom, , , ,
A	- -	E -	0250	Gasification Reactor - Cyclone No.2 - Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0250	Gasification Reactor - Cyclone No.2 - Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0251	Gasification Reactor - Ash Surge Vessel	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	TAR REFORMING																		

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NATIONAL RENEWABLE ENERGY LABORATORY

REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	E -	0252	Gas Conditioning Reactor - Vessel	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Bubbling fluidized bed tar reformer, Fluidized bed composed of externally heated bed material & clean
	COMBUSTION																		
A	- -	E -	0253	Combustion Reactor - Vessel	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Circulating fluidized bed combustion reactor, Fluidized bed composed of of ash, char, bed material &
A	- -	E -	0254	Combustion Reactor - Cyclone	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Cone shaped bottom, , , ,
A	- -	E -	0255	Combustion Reactor - Cyclone - Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0255	Combustion Reactor - Cyclone - Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0256	Combustion Reactor - Flue Gas Fan	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	M -	0256	Combustion Reactor - Flue Gas Fan Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0257	Combustion Reactor - Startup Burner	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Horizontal pressure vessel fire box, Refractory lined, Natural gas burner, ,
	COMBUSTION AIR SYSTEM																		
A	- -	E -	0258	Combustion Air - Heater	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	- -	E -	0259	Combustion Air - Fan	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	M -	0259	Combustion Air - Fan Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	ASH REMOVAL SYSTEM																		
A	- -	E -	0260	Ash - Cyclone	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Refractory lined, , ,
A	- -	E -	0261	Ash - Cyclone Rotary Discharger	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	M -	0261	Ash - Cyclone Rotary Discharger Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0262	Ash - Transfer Screw Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	- -	M -	0262	Ash - Transfer Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0263	Ash - Ash Storage Bin	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, , , ,
A	- -	E -	0264	Ash - Storage Bin Discharge Screw Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Process water added to supress dust , Ash discharged as a moist solid suitable for soil
A	- -	M -	0264	Ash - Storage Bin DischargeScrew Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0275	Bed Material Disposal - Screw Conveyor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Water cooled, , ,
A	- -	M -	0275	Bed Material Disposal - Screw Conveyor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	PROCESS AIR SYSTEM																		
A	- -	E -	0265	Process Air - Compressor	F-200	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	$50,000	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0265	Process Air - Compressor Motor	F-200	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0266	Process Air - Dryer	F-200	Vendor-11	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,

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NREL Gasifier Technology Assessment - Technology - #2

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN			ELECTRICAL			MATERIAL	RFP No.	QUOTE INFO	FOB SHOP	REMARKS
									SIZE (EA)	CAPACITY	HEAD/PRESS	HP (total)	RPM	VOLTS			NO/DATE/VALID	$	
A	- -	E -	0267	Process Air - Receiver Tank	F-200	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
	AIR SEPARATION SYSTEM																		
A	- -	E -	0268	Air Separation Plant - Oxygen / Nitrogen Separator	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, Oxygen is vented to atmosphere,
A	- -	E -	0269	Air Separation Plant - Nitrogen Gas Receiver Tank	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
	NITROGEN SYSTEM																		
A	- -	E -	0270	Nitrogen System - Instrument Nitrogen Gas Supply Tank	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Nitrogen supply for instrumentation operation, , ,
A	- -	E -	0271	Nitrogen System - Booster Compressor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0271	Nitrogen System - Booster Compressor Motor	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0272	Nitrogen System - Process Nitrogen Gas Supply Tank	F-200	Vendor-02	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, High pressure nitrogen, Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements
	STACKS																		

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NREL Thermochemical Ethanol Production - Technology - #3

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
BIOMASS FUEL HANDLING & STORAGE SYSTEM DISTRIBUTION CONVEYOR																			
A	- -	E -	0301	Biomass Distribution Conveyor	F-300	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	Drag chain conveyor, , , ,
A	- -	M -	0301	Biomass Distribution Conveyor Motor	F-300	Vendor-05	-	1	-	-	-	-	-	-	-	-	-	TBD	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1																			
A	- -	E -	0302	Biomass Line-1 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0303	Biomass Line-1 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0303	Biomass Line-1 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0304	Biomass Line-1 - Lock Hopper Weigh Bin Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0304	Biomass Line-1 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0305	Biomass Line-1 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0306	Biomass Line-1 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0306	Biomass Line-1 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0307	Biomass Line-1 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0307	Biomass Line-1 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0308	Biomass Line-1 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0308	Biomass Line-1 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0309	Biomass Line-1 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0309	Biomass Line-1 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2																			
A	- -	E -	0310	Biomass Line-2 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0311	Biomass Line-2 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0311	Biomass Line-2 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0312	Biomass Line-2 - Lock Hopper Weigh Bin Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0312	Biomass Line-2 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0313	Biomass Line-2 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0314	Biomass Line-2 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0314	Biomass Line-2 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0315	Biomass Line-2 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,

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NREL Thermochemical Ethanol Production - Technology - #3

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	M -	0315	Biomass Line-2 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0316	Biomass Line-2 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0316	Biomass Line-2 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0317	Biomass Line-2 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0317	Biomass Line-2 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3																			
A	- -	E -	0318	Biomass Line-3 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0319	Biomass Line-3 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0319	Biomass Line-3 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0320	Biomass Line-3 - Lock Hopper Weigh Bin Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0320	Biomass Line-3 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0321	Biomass Line-3 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0322	Biomass Line-3 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0322	Biomass Line-3 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0323	Biomass Line-3 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0323	Biomass Line-3 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0324	Biomass Line-3 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0324	Biomass Line-3 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0325	Biomass Line-3 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0325	Biomass Line-3 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-4																			
A	- -	E -	0326	Biomass Line-4 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0327	Biomass Line-4 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0327	Biomass Line-4 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0328	Biomass Line-4 - Lock Hopper Weigh Bin DischargeScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0328	Biomass Line-4 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0329	Biomass Line-4 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0330	Biomass Line-4 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,

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NREL Thermochemical Ethanol Production - Technology - #3

REV A PROJECT: 30074.00 DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	M -	0330	Biomass Line-4 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0331	Biomass Line-4 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0331	Biomass Line-4 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0332	Biomass Line-4 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0332	Biomass Line-4 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0333	Biomass Line-4 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0333	Biomass Line-4 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-5																		
A	- -	E -	0334	Biomass Line-5 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0335	Biomass Line-5 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0335	Biomass Line-5 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0336	Biomass Line-5 - Lock Hopper Weigh Bin Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0336	Biomass Line-5 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0337	Biomass Line-5 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0338	Biomass Line-5 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0338	Biomass Line-5 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0339	Biomass Line-5 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0339	Biomass Line-5 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0340	Biomass Line-5 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0340	Biomass Line-5 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0341	Biomass Line-5 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0341	Biomass Line-5 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-6																		
A	- -	E -	0342	Biomass Line-6 - Lock Hopper Weigh Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0343	Biomass Line-6 - Lock Hopper Weigh Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0343	Biomass Line-6 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0344	Biomass Line-6 - Lock Hopper Weigh Bin Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0344	Biomass Line-6 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,

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NREL Thermochemical Ethanol Production - Technology - #3

NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV: A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
A	- -	E -	0345	Biomass Line-6 - Metering Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, Inlet and outlet pneumatic slide gates, ,
A	- -	E -	0346	Biomass Line-6 - Metering Bin Live Bottom Discharge Device	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Proprietary, , , ,
A	- -	M -	0346	Biomass Line-6 - Metering Bin Live Bottom Discharge Device Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0347	Biomass Line-6 - Metering Bin Discharge Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0347	Biomass Line-6 - Metering Bin Discharge Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0348	Biomass Line-6 - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, , ,
A	- -	M -	0348	Biomass Line-6 - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0349	Biomass Line-6 - Gasifier Fuel MeteringScrew Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized with nitrogen, Water cooled, ,
A	- -	M -	0349	Biomass Line-6 - Gasifier Fuel Metering Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	BED MEDIA STORAGE & HANDLING																		
A	- -	E -	0348	Bed Media - Recieving Station	F-300	Vendor-07	-	1	-	-	-	-	-	-	-	-	-	$38,800	Truck unloading station, Typically silica material, , ,
A	- -	E -	0349	Bed Media - Pneumatic Unloading Conveyor	F-300	Vendor-06	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized air is the motive power source, , , ,
A	- -	E -	0350	Bed Media - Storage Silo	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	$116,300	Atmospheric vessel, Bottom discharge, , ,
A	- -	E -	0351	Bed Media - Storage Silo Vent Filter	F-300	Vendor-08	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0352	Bed Media - Transfer Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw conveyor, Pressurized , , ,
A	- -	M -	0352	Bed Media - Transfer Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0353	Bed Media - Recycled Media Mixing Hopper	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric vessel, Bottom discharge , , ,
A	- -	E -	0354	Bed Media - Dense Phase Conveyor Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0355	Bed Media - Pneumatic Metering Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Bed material and recycled char, Pressurized nitrogen is the motive power source, , ,
	SORBENT MEDIA STORAGE & HANDLING																		
A	- -	E -	0356	Sorbent Media - Recieving Station	F-300	Vendor-07	-	1	-	-	-	-	-	-	-	-	-	$58,750	Truck unloading station, Typically limestone for removal of chlorine and sulfur, , ,
A	- -	E -	0357	Sorbent Media - Pneumatic Unloading Conveyor	F-300	Vendor-06	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized air is the motive power source, , , ,
A	- -	E -	0358	Sorbent Media - Storage Silo	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	$176,250	Atmospheric vessel, Bottom discharge, , ,
A	- -	E -	0359	Sorbent Media - Storage Silo Vent Filter	F-300	Vendor-08	-	1	-	-	-	-	-	-	-	-	-	included	Fabric filter, , , ,
A	- -	E -	0360	Sorbent Media - Transfer Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Metering screw conveyor, Pressurized , , ,
A	- -	M -	0360	Sorbent Media - Transfer Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0361	Sorbent Media - Dense Phase Conveyor Bin	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0362	Sorbent Media - Pneumatic Metering Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressurized nitrogen is the motive power source, , , ,

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NREL NATIONAL RENEWABLE ENERGY LABORATORY

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
	GASIFIER																		
A	- -	E -	0363	Gasifier	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	$14,248,916	Bubbling fluid bed auto thermal gasifier, Pressure vessel, Refractory lined, Fired with biomass, oxygen & steam, Fluidized bed composed of bed media, sorbent media, & biomass
A	- -	E -	0364	Gasifier - Cyclone	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Cone shaped bottom, , , ,
A	- -	E -	0365	Gasifier - Cyclone - Rotary Discharger	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Rotary pocket feeder discharge device, , , ,
A	- -	M -	0365	Gasifier - Cyclone - Rotary Discharger Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0366	Gasifier - Startup Burner	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Horizontal pressure vessel fire box, Natural gas burner, Refractory lined, ,
A	- -	E -	0367	Gasifier - Startup Burner - Air Compressor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0367	Gasifier - Startup Burner - Air Compressor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	GASIFIER BED MEDIA CLEANING SYSTEM																		
A	- -	E -	0368	Gasifier Bed - Discharge Screw Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Screw conveyor, Pressurized, Water cooled, ,
A	- -	M -	0368	Gasifier Bed - Discharge Screw Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0369	Gasifier Bed Cleaning - Lock Hopper No.1	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, , ,
A	- -	E -	0370	Gasifier Bed Cleaning - Lock Hopper No.2	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Pressurized with nitrogen, , ,
A	- -	E -	0371	Gasifier Bed Cleaning - Screen	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric, , , ,
A	- -	E -	0372	Gasifier Bed Cleaning - Rejects Conveyor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Atmospheric, , , ,
A	- -	M -	0372	Gasifier Bed Cleaning - Rejects Conveyor Motor	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
	TAR REFORMER																		
A	- -	E -	0373	Tar Reformer	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Refractory lined, , ,
	PROCESS AIR SYSTEM																		
A	- -	E -	0374	Process Air - Compressor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	$50,000	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0374	Process Air - Compressor Motor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0375	Process Air - Dryer	F-300	Vendor-11	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,
A	- -	E -	0376	Process Air - Receiver Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
	AIR SEPARATION SYSTEM																		
A	- -	E -	0377	Air Separation Plant - Oxygen / Nitrogen Separator	F-300	Vendor-04	-	1	-	-	-	-	-	-	-	-	-	$7,186,112	, , , ,
A	- -	E -	0378	Air Separation Plant - Oxygen Gas Receiver Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,
A	- -	E -	0379	Air Separation Plant - Nitrogen Gas Receiver Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, , , ,

Harris Group Inc.
Engineering for Optimum Performance®

REV	DATE	BY
A	1/14/2011	JRY

NREL Thermochemical Ethanol Production - Technology - #3

REV A | PROJECT: 30074.00 | DATE: 1/14/2011

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

Mechanical Equipment List

REV	Area	- Type -	Eq No	DESCRIPTION	PFD	VENDOR	MODEL	QUANT.	DESIGN SIZE (EA)	DESIGN CAPACITY	DESIGN HEAD/PRESS	ELECTRICAL HP (total)	ELECTRICAL RPM	ELECTRICAL VOLTS	MATERIAL	RFP No.	QUOTE INFO NO/DATE/VALID	FOB SHOP $	REMARKS
	OXYGEN SYSTEM																		
A	- -	E -	0380	Oxygen System - Booster Compressor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	$50,000	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0380	Oxygen System - Booster Compressor Motor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0381	Oxygen System - Oxygen Gas Supply Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Oxygen supply for gasifier & tar remover combustion, , ,
	NITROGEN SYSTEM																		
A	- -	E -	0382	Nitrogen System - Instrument Nitrogen Gas Supply Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	$75,000	Pressure vessel, Nitrogen supply for instrumentation operation, , ,
A	- -	E -	0383	Nitrogen System - Booster Compressor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Screw compressor, Air cooled, Oil free operation, ,
A	- -	M -	0383	Nitrogen System - Booster Compressor Motor	F-300	Vendor-10	-	1	-	-	-	-	-	-	-	-	-	included	Variable frequeny drive, , , ,
A	- -	E -	0384	Nitrogen System - Process Nitrogen Gas Supply Tank	F-300	Vendor-09	-	1	-	-	-	-	-	-	-	-	-	included	Pressure vessel, Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements, , ,
	SYNGAS COOLER																		
A	- -	E -	0385	Ash Screw Cooling Water - Heat Exchanger	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	Indirect heat exchanger with hot syngas on one side being used to superheat steam on the other side, , , ,
	FLARE STACK																		
A	- -	E -	0386	Syngas Flare Stack	F-300	Vendor-03	-	1	-	-	-	-	-	-	-	-	-	included	, , , ,

APPENDIX D
ORDER OF MAGNITUDE ESTIMATES
CAPITAL COST ESTIMATE DETAILS

CLASS 4 COST ESTIMATE - TECHNOLOGY #1

HARRIS GROUP PROJECT NO.: 30074.00

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 01/14/2011

SEQUENCE	AREA	CATEGORY	PURCHASER	EQUIP. NO.	DESCRIPTION	MATERIAL % / QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H./ UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
11					**Summary By Work Category**											
12		1			Civil / Earthwork	2.0%			-	487,300		3,630	73.25	265,898	170,500	923,698
13		2			Buildings	2.3%			-	460,000		7,000	52.00	364,000	274,000	1,098,000
14		3			Equipment Foundations/Supports	13.2%			-	3,124,000		39,050	73.50	2,870,175	210,650	6,204,825
15		4			Piping	7.6%			-	2,010,000		27,900	56.00	1,562,400	-	3,572,400
16		5			Electrical	9.0%			-	2,116,692		33,598	63.00	2,116,692	-	4,233,383
17		6			Instrumentation	5.0%			-	1,175,940		19,599	60.00	1,175,940	-	2,351,880
18		7			Process Insulation / Painting	2.0%			-	470,376		9,698	48.50	470,376	-	940,752
19		8			Equipment	58.9%			21,930,654	-		91,000	62.00	5,642,000	140,000	27,712,654
20		9			Demolition	0.0%			-	-		-	-	-	-	-
21					**Total Direct Cost**				21,930,654	9,844,307		231,476	62.50	14,467,480	795,150	47,037,591
22					Contractor Premium Pay (% of Total Labor)	included in rate								-		-
23					Contractor's Indirects (% of Total Labor)	included in rate								-		-
24					Contractor's Markup (% of Materials & Sub Contracts)	included in rate								-		-
25					**Total Construction Cost (aka Total Installed Cost)**				21,930,654	9,844,307		231,476	62.50	14,467,480	795,150	47,037,591
26					Engineering Consultant (% of Direct Cost)	10.0%										4,703,759
27					Owner Engineering (% of Direct Cost)	2.0%										940,752
28					Pre-Project Cost (% of Construction Cost)	0.5%										235,188
29					Construction Management (% of Construction Cost)	2.0%										940,752
30					Environmental or Legislative Costs (% of Construction Cost)	1.0%										470,376
31					Capitalized Spares (% of Construction Cost)	3.0%										1,411,128
32					Sales Taxes (% of Construction Cost)	3.5%										1,646,316
33					Freight (% of Owner Material Direst Cost)	3.0%										657,920
34					**Total Indirects**											11,006,190
35					**Sub-Total Direct and Indirects**											58,043,781
36					Contingency (% of Sub-Total Direct and Indirects)	20.0%										11,608,756
37					**Total Process Plant & Equipment (PP&E)**											69,652,537
38					Escalation (% of Sub-Total Direct and Indirects)	excluded										-
39					Capitalized Interest (% of Sub-Total Direct and Indirects)	excluded										-
40					Deferred Start-Up Costs (% of Sub-Total Direct and Indirects)	excluded										-
41					Working Capital (% of Sub-Total Direct and Indirects)	excluded										-
42					Operator Training (% of Construction Cost)	1.0%										470,376
43					Start-Up (% of Construction Cost)	1.0%										470,376
44					**Grand Total (aka Total Project Investment)**											70,593,289
45																

CLASS 4 COST ESTIMATE - TECHNOLOGY #2

HARRIS GROUP PROJECT NO.: 30074.00

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 01/14/2011

SEQUENCE	AREA	CATEGORY	PURCHASER	EQUIP. NO.	DESCRIPTION	MATERIAL: % / QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR: L.H./ UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
11					**Summary By Work Category**											
12		1			Civil / Earthwork	1.7%			-	354,400		2,640	73.25	193,380	124,000	671,780
13		2			Buildings	2.8%			-	460,000		7,000	52.00	364,000	274,000	1,098,000
14		3			Equipment Foundations/Supports	12.7%			-	2,556,000		31,950	73.50	2,348,325	172,350	5,076,675
15		4			Piping	9.0%			-	2,010,000		27,900	56.00	1,562,400	-	3,572,400
16		5			Electrical	9.0%			-	1,791,996		28,444	63.00	1,791,996	-	3,583,992
17		6			Instrumentation	5.0%			-	995,553		16,593	60.00	995,553	-	1,991,106
18		7			Process Insulation / Painting	2.0%			-	398,221		8,211	48.50	398,221	-	796,443
19		8			Equipment	57.8%			16,836,734	-		97,500	62.00	6,045,000	150,000	23,031,734
20		9			Demolition	0.0%			-	-		-	-	-	-	-
21					**Total Direct Cost**				16,836,734	8,566,170		220,238	62.20	13,698,875	720,350	39,822,129
22					Contractor Premium Pay (% of Total Labor)	included in rate								-		-
23					Contractor's Indirects (% of Total Labor)	included in rate								-		-
24					Contractor's Markup (% of Materials & Sub Contracts)	included in rate								-		-
25					**Total Construction Cost (aka Total Installed Cost)**				16,836,734	8,566,170		220,238	62.20	13,698,875	720,350	39,822,129
26					Engineering Consultant (% of Direct Cost)	10.0%										3,982,213
27					Owner Engineering (% of Direct Cost)	2.0%										796,443
28					Pre-Project Cost (% of Construction Cost)	0.5%										199,111
29					Construction Management (% of Construction Cost)	2.0%										796,443
30					Environmental or Legislative Costs (% of Construction Cost)	1.0%										398,221
31					Capitalized Spares (% of Construction Cost)	3.0%										1,194,664
32					Sales Taxes (% of Construction Cost)	3.5%										1,393,775
33					Freight (% of Owner Material Direst Cost)	3.0%										505,102
34					**Total Indirects**											9,265,970
35					**Sub-Total Direct and Indirects**											49,088,100
36					Contingency (% of Sub-Total Direct and Indirects)	20.0%										9,817,620
37					**Total Process Plant & Equipment (PP&E)**											58,905,720
38					Escalation (% of Sub-Total Direct and Indirects)	excluded										-
39					Capitalized Interest (% of Sub-Total Direct and Indirects)	excluded										-
40					Deferred Start-Up Costs (% of Sub-Total Direct and Indirects)	excluded										-
41					Working Capital (% of Sub-Total Direct and Indirects)	excluded										-
42					Operator Training (% of Construction Cost)	1.0%										398,221
43					Start-Up (% of Construction Cost)	1.0%										398,221
44					**Grand Total (aka Total Project Investment)**											59,702,162
45																

CLASS 4 COST ESTIMATE - TECHNOLOGY #3

HARRIS GROUP PROJECT NO.: 30074.00

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 01/14/2011

SEQUENCE	AREA	CATEGORY	PURCHASER	EQUIP. NO.	DESCRIPTION	MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
						% / QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H./ UNIT	LABOR HOURS	RATE	TOTAL		
11					**Summary By Work Category**											
12		1			Civil / Earthwork	2.0%			-	487,300		3,630	73.25	265,898	170,500	923,698
13		2			Buildings	2.3%			-	460,000		7,000	52.00	364,000	274,000	1,098,000
14		3			Equipment Foundations/Supports	13.2%			-	3,124,000		39,050	73.50	2,870,175	210,650	6,204,825
15		4			Piping	7.6%			-	2,010,000		27,900	56.00	1,562,400	-	3,572,400
16		5			Electrical	9.0%			-	2,120,413		33,657	63.00	2,120,413	-	4,240,827
17		6			Instrumentation	5.0%			-	1,178,007		19,633	60.00	1,178,007	-	2,356,015
18		7			Process Insulation / Painting	2.0%			-	471,203		9,716	48.50	471,203	-	942,406
19		8			Equipment	59.0%			22,000,128	-		91,000	62.00	5,642,000	140,000	27,782,128
20		9			Demolition	0.0%			-	-		-	-	-	-	-
21					**Total Direct Cost**				22,000,128	9,850,924		231,586	62.50	14,474,096	795,150	47,120,298
22					Contractor Premium Pay (% of Total Labor)	included in rate								-		-
23					Contractor's Indirects (% of Total Labor)	included in rate								-		-
24					Contractor's Markup (% of Materials & Sub Contracts)	included in rate								-		-
25					**Total Construction Cost (aka Total Installed Cost)**				22,000,128	9,850,924		231,586	62.50	14,474,096	795,150	47,120,298
26					Engineering Consultant (% of Direct Cost)	10.0%										4,712,030
27					Owner Engineering (% of Direct Cost)	2.0%										942,406
28					Pre-Project Cost (% of Construction Cost)	0.5%										235,601
29					Construction Management (% of Construction Cost)	2.0%										942,406
30					Environmental or Legislative Costs (% of Construction Cost)	1.0%										471,203
31					Capitalized Spares (% of Construction Cost)	3.0%										1,413,609
32					Sales Taxes (% of Construction Cost)	3.5%										1,649,210
33					Freight (% of Owner Material Direst Cost)	3.0%										660,004
34					**Total Indirects**											11,026,470
35					**Sub-Total Direct and Indirects**											58,146,768
36					Contingency (% of Sub-Total Direct and Indirects)	20.0%										11,629,354
37					**Total Process Plant & Equipment (PP&E)**											69,776,122
38					Escalation (% of Sub-Total Direct and Indirects)	excluded										-
39					Capitalized Interest (% of Sub-Total Direct and Indirects)	excluded										-
40					Deferred Start-Up Costs (% of Sub-Total Direct and Indirects)	excluded										-
41					Working Capital (% of Sub-Total Direct and Indirects)	excluded										-
42					Operator Training (% of Construction Cost)	1.0%										471,203
43					Start-Up (% of Construction Cost)	1.0%										471,203
44					**Grand Total (aka Total Project Investment)**											70,718,528
45																

CLASS 4 COST ESTIMATE COMPARISON

HARRIS GROUP PROJECT NO.: 30074.00

PROJECT NAME: GASIFIER TECHNOLOGY ASSESSMENT

CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 01/14/2010

SEQUENCE	AREA	CATEGORY	PURCHASER	EQUIP. NO.	DESCRIPTION	Technology #1		Technology #2		Technology #3	
						OWNER FURNISHED	GRAND TOTAL	OWNER FURNISHED	GRAND TOTAL	OWNER FURNISHED	GRAND TOTAL
11					**Summary By Work Category**						
12		1			Civil / Earthwork		923,698		671,780		923,698
13		2			Buildings		1,098,000		1,098,000		1,098,000
14		3			Equipment Foundations/Supports		6,204,825		5,076,675		6,204,825
15		4			Piping		3,572,400		3,572,400		3,572,400
16		5			Electrical		4,233,383		3,583,992		4,240,827
17		6			Instrumentation		2,351,880		1,991,106		2,356,015
18		7			Process Insulation / Painting		940,752		796,443		942,406
19		8			Equipment	**21,930,654**	27,712,654	**16,836,734**	23,031,734	**22,000,128**	27,782,128
20		9			Demolition		-		-		-
21					**Total Direct Cost**		47,037,591		39,822,129		47,120,298
22					Contractor Premium Pay (% of Total Labor)		included		included		included
23					Contractor's Indirects (% of Total Labor)		included		included		included
24					Contractor's Markup (% of Materials & Sub Contracts)		included		included		included
25					**Total Construction Cost (aka Total Installed Cost)**		47,037,591		39,822,129		47,120,298
26					Engineering Consultant (% of Direct Cost)		4,703,759		3,982,213		4,712,030
27					Owner Engineering (% of Direct Cost)		940,752		796,443		942,406
28					Pre-Project Cost (% of Construction Cost)		235,188		199,111		235,601
29					Construction Management (% of Construction Cost)		940,752		796,443		942,406
30					Environmental or Legislative Costs (% of Construction Cost)		470,376		398,221		471,203
31					Capitalized Spares (% of Construction Cost)		1,411,128		1,194,664		1,413,609
32					Sales Taxes (% of Construction Cost)		1,646,316		1,393,775		1,649,210
33					Freight (% of Owner Material Direst Cost)		657,920		505,102		660,004
34					**Total Indirects**		11,006,190		9,265,970		11,026,470
35					**Sub-Total Direct and Indirects**		58,043,781		49,088,100		58,146,768
36					Contingency (% of Sub-Total Direct and Indirects)		11,608,756		9,817,620		11,629,354
37					**Total Process Plant & Equipment (PP&E)**		69,652,537		58,905,720		69,776,122
38					Escalation (% of Sub-Total Direct and Indirects)		excluded		excluded		excluded
39					Capitalized Interest (% of Sub-Total Direct and Indirects)		excluded		excluded		excluded
40					Deferred Start-Up Costs (% of Sub-Total Direct and Indirects)		excluded		excluded		excluded
41					Working Capital (% of Sub-Total Direct and Indirects)		excluded		excluded		excluded
42					Operator Training (% of Construction Cost)		470,376		398,221		471,203
43					Start-Up (% of Construction Cost)		470,376		398,221		471,203
44					**Grand Total (aka Total Project Investment)**		70,593,289		59,702,162		70,718,528
45											

APPENDIX E-1
DETAILED ESTIMATE
EQUIPMENT LIST
CFB GASIFIER MODEL

2	EQUIPMENT LIST INPUT - CFB											
3	HARRIS GROUP PROJECT NO.: 30300.00											Harris Group Inc. Engineering for Optimum Performance.®
4	PROJECT NAME: CFB GASIFICATION MODEL											
5	CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY											
6	LOCATION: GOLDEN, COLORADO											DATE: 08/03/2012
7												
8-10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
11												
12	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1											
13	101	Biomass Line-1 - Weigh Bin	1	tank	E	$210,000	80,000					Based on Process Baron quote
14	102	Biomass Line-1 - Weigh Bin No.1 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
15	102-M	Biomass Line-1 - Weigh Bin No.1 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
16	103	Biomass Line-1 - Weigh Bin No.2 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
17	103-M	Biomass Line-1 - Weigh Bin No.2 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
18	104	Biomass Line-1 - Weigh Bin Vent Filter	1	filter	E	Incl	Incl					Based on Process Baron quote
19	105	Biomass Line-1 - Lock Hopper	1	tank	E	$75,000	18,000					Based on Process Carbona quote
20	106	Biomass Line-1 - Lock Hopper Inlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
21	107	Biomass Line-1 - Lock Hopper Outlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
22	108	Biomass Line-1 - Pressurized Metering Bin	1	tank	E	$120,000	40,000					Based on Process Carbona quote
23	109	Biomass Line-1 - Pressurized Metering Bin Live Bottom Screws	1	discharger	E	Incl	Incl					Based on Process Carbona quote
24	109-M	Biomass Line-1 - Pressurized Metering Bin Live Bottom Screws Motor	1	motor	M	Incl	Incl					Based on Process Carbona quote
25	110	Biomass Line-1 - Transfer Screw	1	discharger	E	$17,000	15,000					Price based on Buckeye project/Bill Atwood
26	110-M	Biomass Line-1 - Transfer Screw Motor	1	motor	M	Incl	Incl					Price based on Buckeye project/Bill Atwood
27	111	Biomass Line-1 - Gasifier Injection Screw	1	conveyor	E	$34,000	20,000					Water cooled
28	111-M	Biomass Line-1 - Gasifier Injection Screw Motor	1	motor	M	Incl	Incl					
29	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2											
30	112	Biomass Line-2 - Weigh Bin	1	tank	E	$210,000	80,000					Based on Process Baron quote
31	113	Biomass Line-2 - Weigh Bin No.1 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
32	113-M	Biomass Line-2 - Weigh Bin No.1 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
33	114	Biomass Line-2 - Weigh Bin No.2 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote

2	**EQUIPMENT LIST INPUT - CFB**	Harris Group Inc. *Engineering for Optimum Performance.®*
3	**HARRIS GROUP PROJECT NO.: 30300.00**	
4	**PROJECT NAME: CFB GASIFICATION MODEL**	
5	**CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**	
6	**LOCATION: GOLDEN, COLORADO**	**DATE: 08/03/2012**
7		

8 / 9 / 10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
34	114-M	Biomass Line-2 - Weigh Bin No.2 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
35	115	Biomass Line-2 - Weigh Bin Vent Filter	1	filter	E	Incl	Incl					Based on Process Baron quote
36	116	Biomass Line-2 - Lock Hopper	1	tank	E	$75,000	18,000					Based on Process Carbona quote
37	117	Biomass Line-2 - Lock Hopper Inlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
38	118	Biomass Line-2 - Lock Hopper Outlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
39	119	Biomass Line-2 - Pressurized Metering Bin	1	tank	E	$120,000	40,000					Based on Process Carbona quote
40	120	Biomass Line-2 - Pressurized Metering Bin Live Bottom Screws	1	discharger	E	Incl	Incl					Based on Process Carbona quote
41	120-M	Biomass Line-2 - Pressurized Metering Bin Live Bottom Screws Motor	1	motor	M	Incl	Incl					Based on Process Carbona quote
42	121	Biomass Line-2 - Transfer Screw	1	discharger	E	$17,000	15,000					Price based on Buckeye project/Bill Atwood
43	121-M	Biomass Line-2 - Transfer Screw Motor	1	motor	M	Incl	Incl					Price based on Buckeye project/Bill Atwood
44	122	Biomass Line-2 - Gasifier Injection Screw	1	conveyor	E	$34,000	20,000					Water cooled
45	122-M	Biomass Line-2 - Gasifier Injection Screw Motor	1	motor	M	Incl	Incl					
46	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3**											
47	123	Biomass Line-3 - Weigh Bin	1	tank	E	$210,000	80,000					Based on Process Baron quote
48	124	Biomass Line-3 - Weigh Bin No.1 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
49	124-M	Biomass Line-3 - Weigh Bin No.1 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
50	125	Biomass Line-3 - Weigh Bin No.2 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
51	125-M	Biomass Line-3 - Weigh Bin No.2 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
52	126	Biomass Line-3 - Weigh Bin Vent Filter	1	filter	E	Incl	Incl					Based on Process Baron quote
53	127	Biomass Line-3 - Lock Hopper	1	tank	E	$75,000	18,000					Based on Process Carbona quote
54	128	Biomass Line-3 - Lock Hopper Inlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
55	129	Biomass Line-3 - Lock Hopper Outlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote

EQUIPMENT LIST INPUT - CFB

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: CFB GASIFICATION MODEL
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 08/03/2012

	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
56	130	Biomass Line-3 - Pressurized Metering Bin	1	tank	E	$120,000	40,000					Based on Process Carbona quote
57	131	Biomass Line-3 - Pressurized Metering Bin Live Bottom Screws	1	discharger	E	Incl	Incl					Based on Process Carbona quote
58	131-M	Biomass Line-3 - Pressurized Metering Bin Live Bottom Screws Motor	1	motor	M	Incl	Incl					Based on Process Carbona quote
59	132	Biomass Line-3 - Transfer Screw	1	discharger	E	$17,000	15,000					Price based on Buckeye project/Bill Atwood
60	132-M	Biomass Line-3 - Transfer Screw Motor	1	motor	M	Incl	Incl					Price based on Buckeye project/Bill Atwood
61	133	Biomass Line-3 - Gasifier Injection Screw	1	conveyor	E	$34,000	20,000					Water cooled
62	133-M	Biomass Line-3 - Gasifier Injection Screw Motor	1	motor	M	Incl	Incl					
	BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-4											
64	134	Biomass Line-4 - Weigh Bin	1	tank	E	$210,000	80,000					Based on Process Baron quote
65	135	Biomass Line-4 - Weigh Bin No.1 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
66	135-M	Biomass Line-4 - Weigh Bin No.1 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
67	136	Biomass Line-4 - Weigh Bin No.2 Outfeed Screw	1	conveyor	E	Incl	Incl					Based on Process Baron quote
68	136-M	Biomass Line-4 - Weigh Bin No.2 Outfeed Screw Motor	1	motor	M	Incl	Incl					Based on Process Baron quote
69	137	Biomass Line-4 - Weigh Bin Vent Filter	1	filter	E	Incl	Incl					Based on Process Baron quote
70	138	Biomass Line-4 - Lock Hopper	1	tank	E	$75,000	18,000					Based on Process Carbona quote
71	139	Biomass Line-4 - Lock Hopper Inlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
72	140	Biomass Line-4 - Lock Hopper Outlet Shutoff Valve	1	tank	E	Incl	Incl					Based on Process Carbona quote
73	141	Biomass Line-4 - Pressurized Metering Bin	1	tank	E	$120,000	40,000					Based on Process Carbona quote
74	142	Biomass Line-4 - Pressurized Metering Bin Live Bottom Screws	1	discharger	E	Incl	Incl					Based on Process Carbona quote
75	142-M	Biomass Line-4 - Pressurized Metering Bin Live Bottom Screws Motor	1	motor	M	Incl	Incl					Based on Process Carbona quote
76	143	Biomass Line-4 - Transfer Screw	1	discharger	E	$17,000	15,000					Price based on Buckeye project/Bill Atwood
77	143-M	Biomass Line-4 - Transfer Screw Motor	1	motor	M	Incl	Incl					Price based on Buckeye project/Bill Atwood

2	EQUIPMENT LIST INPUT - CFB
3	HARRIS GROUP PROJECT NO.: 30300.00
4	PROJECT NAME: CFB GASIFICATION MODEL
5	CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
6	LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 08/03/2012

	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
78	144	Biomass Line-4 - Gasifier Injection Screw	1	conveyor	E	$34,000	20,000					Water cooled
79	144-M	Biomass Line-4 - Gasifier Injection Screw Motor	1	motor	M	Incl	Incl					
80	GASIFIER REACTOR & CYCLONES											
81	145	Gasifier Reactor	1	tank	R	$821,963	410,824					
82	146	Gasifier Reactor Startup Burner	1	burner	E	$50,000	8,000					
83	147	Duct-01 - From Gasifier Reactor To Gasifier Reactor No.1 Cyclone	1	duct	D	$649,975	169,495					
84	148	Gasifier Reactor No.1 Cyclone	1	tank	C	$511,015	486,741					
85	149	Line-01 - From Gasifier Reactor No.1 Cyclone To Gasifier Reactor Cyclones Solids Collection Bin	1	line	L	$124,188	33,143					
86	150	Gasifier Reactor Cyclones Solids Collection Bin	1	tank	T	$496,632	81,940					
87	151	Duct-02 - From Gasifier Reactor No.1 Cyclone To Gasifier Reactor No.2 Cyclone	1	duct	D	$562,066	142,145					
88	152	Gasifier Reactor No.2 Cyclone	1	tank	C	$504,655	479,285					
89	153	Line-05 - From Gasifier Reactor No.2 Cyclone To Gasifier Reactor Cyclones Solids Collection Bin	1	line	L	$200,579	61,684					
90	154	Duct-03 - From Gasifier Reactor No.2 Cyclone To Duct-14 - From Duct-03 & Duct-13 To Syngas Reformer Reactor	1	duct	D	$1,235,358	486,255					
91	155	Line-06 - From Gasifier Reactor Cyclones Solids Collection Bin To Char Combustion Reactor	1	line	L	$279,658	108,486					
92	156	Duct-17 - From Duct-15 - From Char Conbustion Reactor Air Blower To Char Combustion Reactor Startup Burner To Gasifier Reactor Startup Burner	1	duct	D	$306,772	226,014					
93	GASIFIER LOOP BED MEDIA MAKEUP SYSTEM											
94	157	Gasifier Loop Bed Media Truck Unloading Station	1	truck unloading station	E	$5,000	250					
95	158	Line-02 - From Gasifier Loop Bed Media Truck Unloading Station To Gasifier Loop Bed Media Feed Bin	1	line	L	$31,196	13,377					
96	159	Gasifier Loop Bed Media Feed Bin	1	tank	T	$109,246	22,046					

2	EQUIPMENT LIST INPUT - CFB												Harris Group Inc. Engineering for Optimum Performance®
3	HARRIS GROUP PROJECT NO.: 30300.00												
4	PROJECT NAME: CFB GASIFICATION MODEL												
5	CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY												
6	LOCATION: GOLDEN, COLORADO												DATE: 08/03/2012
7													
8, 9, 10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK	
97	160	Gasifier Loop Bed Media Makeup Blower	1	blower	E	$35,000	3,000						
98	160-M	Gasifier Loop Bed Media Makeup Blower Motor	1	motor	M	Incl	400						
99	161	Line-03 - From Gasifier Loop Bed Media Makeup Blower To Char Combustion Reactor	1	line	L	$41,937	20,342						
100	CHAR COMBUSTION REACTOR												
101	162	Char Combustion Reactor	1	tank	R	$896,893	379,343						
102	163	Char Combustion Reactor Air Heater	1	heat exchanger	E	$159,000	25,000						
103	164	Char Conbustion Reactor Air Blower	1	blower	E	$262,500	20,000						
104	164-M	Char Conbustion Reactor Air Blower Motor	1	motor	M	Incl	350						
105	165	Char Combustion Reactor Startup Burner	1	burner	E	$50,000	8,000						
106	166	Duct-15 - From Char Conbustion Reactor Air Blower To Char Combustion Reactor Startup Burner	1	duct	D	$484,442	118,328						
107	CHAR COMBUSTION CYCLONES												
108	167	Duct-04 - From Char Combustion Reactor To Char Combustion Reactor No.1 Cyclone	1	duct	D	$768,435	178,471						
109	168	Char Combustion Reactor No.1 Cyclone	1	tank	C	$785,028	758,731						
110	169	Line-07 - From Char Combustion Reactor No.1 Cyclone To Char Combustion Reactor No.1 Cyclone Solids Collection Bin	1	line	L	$246,648	73,857						
111	170	Char Combustion Reactor No.1 Cyclone Solids Collection Bin	1	tank	T	$490,073	81,022						
112	171	Line-08 - From Char Combustion Reactor No.1 Cyclone Solids Collection Bin To Gasifier Reactor	1	line	L	$279,658	108,486						
113	172	Duct-05 - From Char Combustion Reactor No.1 Cyclone To Char Combustion Reactor No.2 Cyclone	1	duct	D	$718,530	160,420						
114	173	Char Combustion Reactor No.2 Cyclone	1	tank	C	$780,928	752,354						

2	**EQUIPMENT LIST INPUT - CFB**											Harris Group Inc. *Engineering for Optimum Performance®*
3	**HARRIS GROUP PROJECT NO.: 30300.00**											
4	**PROJECT NAME: CFB GASIFICATION MODEL**											
5	**CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**											
6	**LOCATION: GOLDEN, COLORADO**											**DATE: 08/03/2012**
7												
8-10	**EQ. NO.**	**DESCRIPTION**	**QTY**	**SHORT DESCRIPTION**	**E=EQUIP M=MOTOR**	**COST**	**SHIPPING WEIGHT LBS**	**SIZE / CAPACITY**	**HEAD/PRESS**	**MOTOR HP**	**MOTOR RPM**	**REMARK**
115	174	Line-09 - From Char Combustion Reactor No.2 Cyclone To Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor	1	line	L	$189,828	67,502					
116	175	Duct-06 - From Char Combustion Reactor No.2 Cyclone To Battery Limit (Flue Gas)	1	duct	D	$644,279	144,076					
117	**CHAR COMBUSTION BED MEDIA & ASH DISPOSAL**											
118	176	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor	1	conveyor	E	$20,000	5000					
119	176-M	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Motor	1	motor	M	Incl	400					
120	177	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder	1	conveyor	E	$7,000	900					
121	177-M	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder Motor	1	motor	M	Incl	400					
122	178	Line-19 - From Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor To Gasifier Loop Depleted Bed Media & Ash Storage Bin	1	line	L	$14,367	2,308					
123	179	Gasifier Loop Depleted Bed Media & Ash Storage Bin	1	tank	T	$109,246	22,046					
124	**SYNGAS REFORMER & CYCLONES**											
125	180	Duct-13 - From Supplemental Gas Battery Limits To Syngas Reformer Reactor	1	duct	D	$541,728	132,263					
126	181	Duct-14 - From Duct-03 & Duct-13 To Syngas Reformer Reactor	1	duct	D	$702,848	161,594					
127	182	Syngas Reformer Reactor	1	tank	R	$1,522,654	600,175					
128	183	Duct-07 - From Syngas Reformer Reactor To Syngas Reformer Reactor No.1 Cyclone	1	duct	D	$1,199,771	353,009					
129	184	Syngas Reformer Reactor No.1 Cyclone	1	tank	C	$992,813	966,290					
130	185	Line-10 - From Syngas Reformer Reactor No.1 Cyclone To Syngas Reformer Reactor Cyclones Solids Collection Bin	1	line	L	$179,003	43,104					
131	186	Syngas Reformer Reactor Cyclones Solids Collection Bin	1	tank	T	$498,006	82,129					
132	187	Duct-08 - From Syngas Reformer Reactor No.1 Cyclone To Syngas Reformer Reactor No.2 Cyclone	1	duct	D	$1,199,771	353,009					

2 # EQUIPMENT LIST INPUT - CFB

3 **HARRIS GROUP PROJECT NO.: 30300.00**

4 **PROJECT NAME: CFB GASIFICATION MODEL**

5 **CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**

6 **LOCATION: GOLDEN, COLORADO**

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 08/03/2012

7

8 / 9 / 10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
133	188	Syngas Reformer Reactor No.2 Cyclone	1	tank	C	$992,813	966,290					
134	189	Line-14 - From Syngas Reformer Reactor No.2 Cyclone To Syngas Reformer Reactor Cyclones Solids Collection Bin	1	line	L	$183,783	57,426					
135	190	Duct-09 - From Syngas Reformer Reactor No.2 Cyclone To Battery Limit (Reformed Syngas)	1	duct	D	$1,199,771	353,009					
136	191	Line-15 - From Syngas Reformer Reactor Cyclones Solids Collection Bin To Reformer Bed Media Heating Reactor	1	line	L	$326,966	125,189					
137	**REFORMER LOOP BED MEDIA MAKEUP SYSTEM**											
138	192	Reformer Loop Bed Media Truck Unloading Station	1	truck unloading station	E	$5,000	250					
139	193	Line-11 - From Reformer Loop Bed Media Truck Unloading Station To Reformer Loop Bed Media Feed Bin	1	line	L	$33,835	13,377					
140	194	Reformer Loop Bed Media Feed Bin	1	tank	T	$109,246	22,046					
141	195	Reformer Loop Bed Media Makeup Blower	1	blower	E	$35,000	3,000					
142	195-M	Reformer Loop Bed Media Makeup Blower Motor	1	motor	M	Incl	400					
143	196	Line-12 - From Reformer Loop Bed Media Makeup Blower To Reformer Bed Media Heating Reactor	1	line	L	$44,576	20,342					
144	**REFORMER BED MEDIA HEATING REACTOR**											
145	197	Reformer Bed Media Heating Reactor	1	tank	R	$593,440	269,725					
146	198	Reformer Bed Media Heating Reactor Air Heater	1	heat exchanger	E	$159,000	25,000					
147	199	Reformer Bed Media Heating Reactor Air Blower	1	blower	E	$262,500	20,000					
148	199-M	Reformer Bed Media Heating Reactor Air Blower Motor	1	motor	M	Incl	350					
149	200	Reformer Bed Media Heating Reactor Burner	1	burner	E	$75,000	10,000					
150	201	Duct-16 - From Reformer Bed Media Heating Reactor Air Heater To Reformer Bed Media Heating Reactor	1	duct	D	$208,339	59,120					

2	**EQUIPMENT LIST INPUT - CFB**
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6	**LOCATION: GOLDEN, COLORADO**
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Harris Group Inc.
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DATE: 08/03/2012

8 / 9 / 10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
151	**REFORMER BED MEDIA HEATING CYCLONES**											
152	202	Duct-10 - From Reformer Bed Media Heating Reactor To Reformer Bed Media Heating Reactor No.1 Cyclone	1	duct	D	$438,507	157,602					
153	203	Reformer Bed Media Heating Reactor No.1 Cyclone	1	tank	C	$193,670	174,580					
154	204	Line-16 - From Reformer Bed Media Heating Reactor No.1 Cyclone To Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin	1	line	L	$183,783	57,426					
155	205	Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin	1	tank	T	$491,894	81,276					
156	206	Line-17 - From Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin To Syngas Reformer Reactor	1	line	L	$326,966	125,189					
157	207	Duct-11 - From Reformer Bed Media Heating Reactor No.1 Cyclone To Reformer Bed Media Heating Reactor No.2 Cyclone	1	duct	D	$438,507	157,602					
158	208	Reformer Bed Media Heating Reactor No.2 Cyclone	1	tank	C	$193,670	174,580					
159	209	Line-18 - From Reformer Bed Media Heating Reactor No.2 Cyclone To Reformer Loop Depleted Bed Media Cooling Screw Conveyor	1	line	L	$218,098	86,412					
160	210	Duct-12 - From Reformer Bed Media Heating Reactor No.2 Cyclone To Battery Limit (Flue Gas)	1	duct	D	$438,507	157,602					
161	**REFORMER HEATER BED MEDIA & ASH DISPOSAL**											
162	211	Reformer Loop Depleted Bed Media Cooling Screw Conveyor	1	conveyor	E	$20,000	5000					
163	211-M	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Motor	1	motor	M	Incl	400					
164	212	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder	1	feeder	E	$7,000	900					
165	212-M	Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder Motor	1	motor	M	Incl	400					
166	213	Line-20 - From Reformer Loop Depleted Bed Media Cooling Screw Conveyor To Reformer Loop Depleted Bed Media Storage Bin	1	line	L	$17,006	2,308					
167	214	Reformer Loop Depleted Bed Media Storage Bin	1	tank	T	$109,246	22,046					

EQUIPMENT LIST INPUT - CFB

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: CFB GASIFICATION MODEL
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 08/03/2012

	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	E=EQUIP M=MOTOR	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
168	FLARE SYSTEM											
169	215	Stack Flare Burner	1	burner	E	$6,000	1500					

APPENDIX E-2
DETAILED ESTIMATE
EQUIPMENT LIST
BFB GASIFIER MODEL

EQUIPMENT LIST INPUT - BFB

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: BFB BIOMASS GASIFICATION SYSTEM
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 08/03/2012

	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	D = DUCT E = EQUIP L = LINE M = MOTOR V = VESSEL	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
12	**GASIFIER REACTOR & CYCLONE**											
13	101	Gasifier Reactor	1	reactor	V	$546,361	227,776	6.3' Dia X 9.1' Dia X 35.9 Hi				
14	102	Gasifier Reactor Startup Burner	1	burner	E	$150,000	3,000					Includes refractory lined combustion chamber, burner & burner management system.
15	103	Duct-01 (Refractory Lined) - From Gasifier Reactor To Gasifier Cyclone	1	duct	D	$161,893	18,169					
16	104	Gasifier Cyclone	1	tank	V	$160,924	77,227	5.3' Dia X 13.7 Hi				
17	105	Line-01 (Refractory Lined) - From Gasifier Cyclone To Gasifier Reactor	1	line	L	$191,879	46,161					
18	106	Duct-02 (Refractory Lined) - From Gasifier Cyclone To Battery Limit	1	duct	D	$201,035	32,952					
19	107	Line-02 (Refractory Lined) - From Gasifier Reactor To Ash Cooling Screw Conveyor	1	line	L	$130,945	19,760					
20	**BED MEDIA MAKEUP SYSTEM**											
21	108	Bed Media Truck Unloading Station	1	truck unloading station	E	$8,500	750					The unloading station cost is a function of the speed at which a truck is to be unloaded. All trucks will be the same size, therefore this is a fixed cost estimated as shown.
22	109	Piping - From Bed Media Truck Unloading Station To Bed Media Storage Bin	1	line	L	Incl	Incl					
23	110	Bed Media Storage Bin	1	tank	V	$105,819	15,575	12.0' Dia X 22.5 Hi				
24	111	Bed Media Nitrogen Tank	1	tank	V	$83,111	14,200	6.0' Dia X 11.0 Hi				
25	112	Piping - From Bed Media Nitrogen Tank To Bed Media Pneumatic Transporter	1	line	L	$2,500	350					This is estimated to be a fixed cost regardless of system capacity.
26	113	Bed Media Pneumatic Transporter	1	tank	E	$250,000	3,000					This is estimated to be a fixed cost regardless of system capacity.
27	114	Piping - From Bed Media Pneumatic Transporter To Gasifier Reactor	1	line	L	Incl	Incl					
28	**ASH REMOVAL SYSTEM**											
29	115	Ash Cooling Screw Conveyor	1	conveyor	E	$159,497	16,466	18.0" Dia X 5.0 Long				
30	115-M	Ash Cooling Screw Conveyor Motor	1	motor	M	Incl	Incl			30		

2	**EQUIPMENT LIST INPUT - BFB**											
3	**HARRIS GROUP PROJECT NO.: 30300.00**											Harris Group Inc. *Engineering for Optimum Performance.®*
4	**PROJECT NAME: BFB BIOMASS GASIFICATION SYSTEM**											
5	**CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**											
6	**LOCATION: GOLDEN, COLORADO**											**DATE: 08/03/2012**
7												
8 9 10	**EQ. NO.**	**DESCRIPTION**	**QTY**	**SHORT DESCRIPTION**	**D = DUCT E = EQUIP L = LINE M = MOTOR V = VESSEL**	**COST**	**SHIPPING WEIGHT LBS**	**SIZE / CAPACITY**	**HEAD/PRESS**	**MOTOR HP**	**MOTOR RPM**	**REMARK**
31	116	Piping - From Ash Cooling Screw Conveyor To Ash Discharge Hopper	1	line	L	$5,000	500					This is estimated to be a fixed cost regardless of system capacity.
32	117	Ash Discharge Hopper	1	tank	V	$165,732	27,288	9.0' Dia X 19.5 Hi				
33	118	Ash Lock Hopper Inlet Block Valve	1	valve	L	$15,000	2,000					This valve is estimated to be a 24" dome valve with a fixed cost regardless of system capacity.
34	119	Piping - From Ash Discharge Hopper To Ash Lock Hopper	1	line	L	$5,000	500					This is estimated to be a fixed cost regardless of system capacity.
35	120	Ash Lock Hopper	1	tank	V	$165,185	27,208	9.0' Dia X 19.5 Hi				
36	121	Ash Lock Hopper Discharge Screw Conveyor	1	conveyor	E	$310,935	31,714	18.0" Dia X 12.0 Long				
37	121-M	Ash Lock Hopper Discharge Screw Conveyor Motor	1	motor	M	Incl	400			65		
38	122	Ash Lock Hopper Outlet Block Valve	1	valve	L	$15,000	2,000					This valve is estimated to be a 24" dome valve with a fixed cost regardless of system capacity.
39	123	Piping - From Ash Lock Hopper To Battery Limit	1	line	L	$8,000	500					This is estimated to be a fixed cost regardless of system capacity.

APPENDIX E-3
DETAILED ESTIMATE
EQUIPMENT LIST
HP BIOMASS FEED SYSTEM MODEL

2 # EQUIPMENT LIST INPUT - HP BIOMASS FEED SYSTEM

Harris Group Inc.
Engineering for Optimum Performance®

3 **HARRIS GROUP PROJECT NO.: 30300.00**
4 **PROJECT NAME: HP BIOMASS FEED SYSTEM - SINGLE LINE**
5 **CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**
6 **LOCATION: GOLDEN, COLORADO**

DATE: 08/03/2012

7

8–10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	D = DUCT E = EQUIP L = LINE M = MOTOR V = VESSEL	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
11												
12	**BIOMASS FEED LINE**											
13	101	Biomass Lock Hopper Feed Equipment	1	conveyor	E	$250,000						Pricing for this equipment is a function of the biomass feed rate and an HGI estimated cost factor.
14	102	Biomass Lock Hopper Feed Chute	1	chute	C	$15,000	1,500					
15	103	Biomass Lock Hopper Inlet Block Valve	1	valve	I	$75,000	1,000					This is estimated to be a fixed cost regardless of system capacity.
16	104	Biomass Lock Hopper	1	vessel	V	$176,400	38,413	14.0' Dia X 28.0 Hi				
17	105	Biomass Lock Hopper Bottom Reclaimer	1	screw conveyor	SC	$232,100	23,676	24.5" Dia X 7.0 Long				Reclaimer with single rotating screw, which pivets around bottom of hopper to move biomass to a center discharge chute.
18	105-M	Biomass Lock Hopper Rotating Dischrage Screw Motor	1	motor	M	Incl	Incl			35		
19	106	Biomass Lock Hopper Outlet Block Valve	1	valve	I	$75,000	1,000					This is estimated to be a fixed cost regardless of system capacity.
20	107	Biomass Lock Hopper Vent Filter	1	vent	E	$15,000	750					
21	108	Biomass Lock Hopper Vent Filter Valve	1	valve	I	$15,000	600					
22	109	Biomass Metering Bin	1	vessel	V	$197,100	41,501	15.0' Dia X 30.0 Hi				
23	110	Biomass Metering Bin Rotating Dischrage Screw	1	screw conveyor	SC	$248,300	25,278	24.5" Dia X 7.5 Long				
24	110-M	Biomass Metering Bin Rotating Dischrage Screw Motor	1	motor	M	Incl	Incl			35		
25	111	Biomass Transfer Screw Conveyor	1	screw conveyor	SC	$764,300	76,423	24.5' 'Dia X 23.5 Long				
26	111-M	Biomass Transfer Screw Conveyor Motor	1	motor	M	Incl	Incl			25		
27	112	Biomass Transfer Screw Conveyor Discharge Expansion Joint	1	motor	E	$57,500	300					
28	113	Biomass Transfer Screw Conveyor Discharge Chute	1	chute	C	$15,000	1,500					This is estimated to be a fixed cost regardless of system capacity.
29	114	Biomass Transfer Screw Conveyor Discharge Chute Block Valve	1	valve	I	$75,000	1,000					This is estimated to be a fixed cost regardless of system capacity.
30	115	Gasifier Injection Auger	1	screw conveyor	SC	$244,300	24,618	24.5" Dia X 6.0 Long				

2	EQUIPMENT LIST INPUT - HP BIOMASS FEED SYSTEM
3	HARRIS GROUP PROJECT NO.: 30300.00
4	PROJECT NAME: HP BIOMASS FEED SYSTEM - SINGLE LINE
5	CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
6	LOCATION: GOLDEN, COLORADO
7	

Harris Group Inc.
Engineering for Optimum Performance.®

DATE: 08/03/2012

8 / 9 / 10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	D = DUCT E = EQUIP L = LINE M = MOTOR V = VESSEL	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
31	115-M	Gasifier Injection Auger Motor	1	motor	M	Incl	Incl			10		

APPENDIX E-4
DETAILED ESTIMATE
EQUIPMENT LIST
LP BIOMASS FEED SYSTEM MODEL

Harris Group Inc.
Engineering for Optimum Performance.®

2 # EQUIPMENT LIST INPUT - LP BIOMASS FEED SYSTEM

3 **HARRIS GROUP PROJECT NO.: 30300.00**

4 **PROJECT NAME: LP BIOMASS FEED SYSTEM - SINGLE LINE**

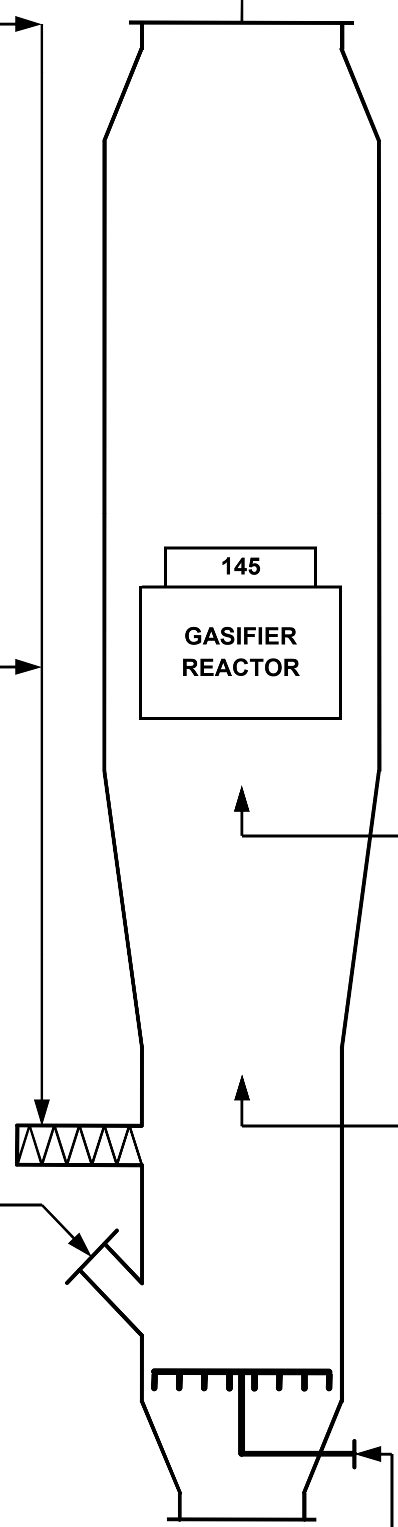
5 **CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY**

6 **LOCATION: GOLDEN, COLORADO** — **DATE: 08/03/2012**

7

8–10	EQ. NO.	DESCRIPTION	QTY	SHORT DESCRIPTION	D = DUCT E = EQUIP L = LINE M = MOTOR V = VESSEL	COST	SHIPPING WEIGHT LBS	SIZE / CAPACITY	HEAD/PRESS	MOTOR HP	MOTOR RPM	REMARK
11												
12	**BIOMASS FEED LINE**											
13	101	Biomass Metering Bin Distributor	1	conveyor	E	$250,000						Pricing for this equipment is a function of the biomass feed rate and an HGI estimated cost factor.
14	102	Biomass Metering Bin Feed Chute	1	chute	C	$15,000	1,500					
15	103	Biomass Metering Bin	1	vessel	V	$196,700	41,305	15.0' Dia X 30.0 Hi				
16	104	Biomass Metering Bin Reclaim Screw	1	screw conveyor	SC	$248,300	25,278	24.5" Dia X 7.5 Long				
17	104-M	Biomass Metering Bin Reclaim Screw Motor	1	motor	M	Incl	Incl			35		
18	105	Biomass Transfer Screw Conveyor	1	screw conveyor	SC	$764,300	76,423	24.5' 'Dia X 23.5 Long				
19	105-M	Biomass Transfer Screw Conveyor Motor	1	motor	M	Incl	Incl			25		
20	106	Biomass Transfer Chute	1	chute	C	$15,000	1,500					This is estimated to be a fixed cost regardless of system capacity.
21	107	Biomass Transfer Chute Expansion Joint	1	motor	E	$57,500	300					
22	108	Biomass Transfer Chute Rotary Valve	1	valve	I	$120,000	2,000					This is estimated to be a fixed cost regardless of system capacity.
23	108-M	Biomass Transfer Chute Rotary Valve Motor	1	motor	M	Incl	Incl					
24	109	Biomass Transfer Chute Block Valve	1	valve	I	$75,000	1,000					This is estimated to be a fixed cost regardless of system capacity.
25	110	Gasifier Injection Auger	1	screw conveyor	SC	$244,300	24,618	24.5" Dia X 6.0 Long				
26	110-M	Gasifier Injection Auger Motor	1	motor	M	Incl	Incl			10		

APPENDIX F-1
DETAILED ESTIMATE
MASS BALANCE FLOW DIAGRAMS
CFB GASIFIER MODEL



BATTERY LIMITS — X — NITROGEN
NITROGEN FROM BATTERY LIMITS TO GASIFIER REACTOR

0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
0	LBS/HR - TOTAL
0.00	% MOISTURE
80	°F
0	PSIG
15	PSIA
0	ACFM

BATTERY LIMITS — L — BIOMASS
BIOMASS FROM BIOMASS STORAGE TO GASIFIER

50,333	LBS/HR - CARBON
6,558	LBS/HR - HYDROGEN
46,074	LBS/HR - OXYGEN
168	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
910	LBS/HR - ASH
0	LBS/HR - BED MEDIA
104,132	LBS/HR - TOTAL
5.00	% MOISTURE
80	°F

BH — 147
CHAR FROM GASIFIER REACTOR TO SYNGAS ENTRAINMENT

14,093	LBS/HR - CARBON
1,038	LBS/HR - HYDROGEN
2,070	LBS/HR - OXYGEN
10	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
17,218	LBS/HR - TOTAL
0.00	% MOISTURE
1,562	°F

BN — 147
ASH FROM GASIFIER REACTOR TO SYNGAS ENTRAINMENT

0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
929	LBS/HR - ASH
0	LBS/HR - BED MEDIA
929	LBS/HR - TOTAL
0.00	% MOISTURE
1,562	°F

BT — 147
BED MEDIA FROM GASIFIER REACTOR TO SYNGAS ENTRAINMENT

0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,154,012	LBS/HR - TOTAL
0.00	% MOISTURE
1,562	°F

BZ — 147
CHAR, ASH & BED MEDIA IN SYNGAS FROM GASIFIER REACTOR TO GASIFIER REACTOR NO.1 CYCLONE

14,093	LBS/HR - CARBON
1,038	LBS/HR - HYDROGEN
2,070	LBS/HR - OXYGEN
10	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
929	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,172,159	LBS/HR - TOTAL
0.00	% MOISTURE
1,562	°F

CF — 147
DUST FREE SYNGAS FROM GASIFIER REACTOR TO GASIFIER REACTOR NO.1 CYCLONE

36,240	LBS/HR - CARBON
9,925	LBS/HR - HYDROGEN
78,970	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
125,376	LBS/HR - TOTAL
35.53	% MOISTURE
1,562	°F
25	PSIG
40	PSIA
56,143	ACFM

BB — 145
DUST FREE SYNGAS IN MIDDLE (ZONE-2) OF GASIFIER REACTOR

18,120	LBS/HR - CARBON
7,457	LBS/HR - HYDROGEN
59,280	LBS/HR - OXYGEN
79	LBS/HR - NITROGEN
41	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
84,977	LBS/HR - TOTAL
52.44	% MOISTURE
1,562	°F
25	PSIG
40	PSIA
39,342	ACFM

AV — 145
OXYGEN, STEAM & BIOMASS WATER VAPOR IN BOTTOM (ZONE-1) OF GASIFIER REACTOR

0	LBS/HR - CARBON
4,989	LBS/HR - HYDROGEN
39,590	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
44,579	LBS/HR - TOTAL
100.00	% MOISTURE
1,562	°F
25	PSIG
40	PSIA
22,540	ACFM

AP — OXY & STM
OXYGEN & STEAM FROM OXYGEN & STEAM HEADER TO GASIFIER REACTOR

0	LBS/HR - CARBON
4,406	LBS/HR - HYDROGEN
34,966	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
39,372	LBS/HR - TOTAL
100.00	% MOISTURE
392	°F
174	PSIG
189	PSIA
1,765	ACFM

BATTERY LIMITS — AD — OXYGEN
OXYGEN BLAST FROM OXYGEN HEADER TO GASIFIER REACTOR

0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
0	LBS/HR - TOTAL
0.00	% MOISTURE
172	°F
0	PSIG
15	PSIA
0	ACFM

BATTERY LIMITS — AJ — STEAM
STEAM FROM STEAM HEADER TO GASIFIER REACTOR

0	LBS/HR - CARBON
4,406	LBS/HR - HYDROGEN
34,966	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
39,372	LBS/HR - TOTAL
100.00	% MOISTURE
392	°F
174	PSIG
189	PSIA
1,765	ACFM

TO: MB-1-02 — CL — 147
SYNGAS FROM GASIFIER REACTOR TO GASIFIER REACTOR NO.1 CYCLONE

50,333	LBS/HR - CARBON
10,964	LBS/HR - HYDROGEN
81,040	LBS/HR - OXYGEN
168	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
929	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,297,535	LBS/HR - TOTAL
0.84	% MOISTURE
1,562	°F
25	PSIG
40	PSIA
56,143	ACFM

FROM: MB-1-03 — R — 171
SOLIDS FROM CHAR COMBUSTION REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN TO GASIFIER REACTOR

0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
19	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,154,031	LBS/HR - TOTAL
0.00	% MOISTURE
1,635	°F

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

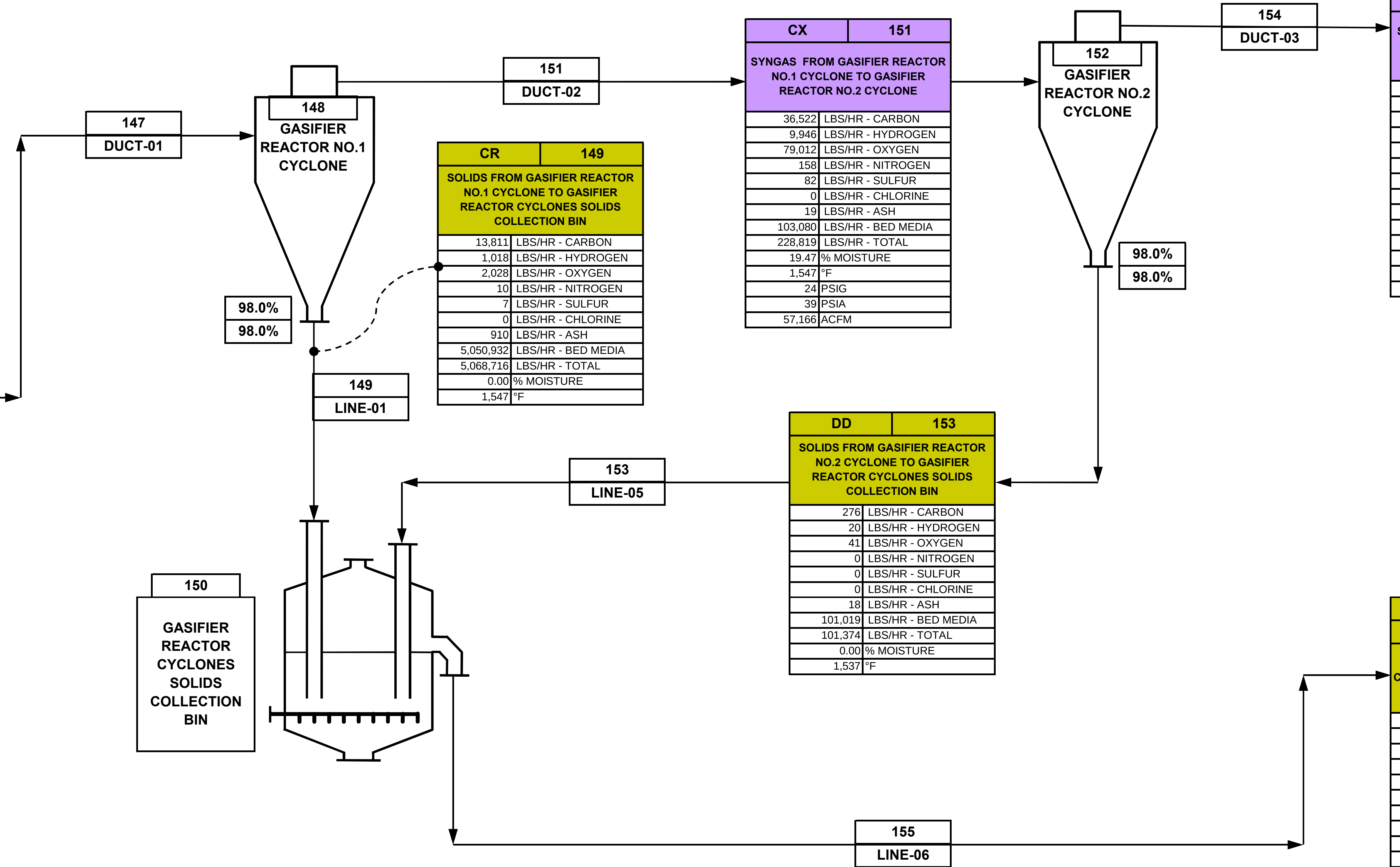
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group Inc. Engineering for Optimum Performance®

NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

MATERIAL BALANCE DRAWING
GASIFIER REACTOR

PROJ NO.: 30300.00
DWG NO.: MB-1-01
DATE: 08/03/12



FROM: MB-1-01

CL	147
SYNGAS FROM GASIFIER REACTOR TO GASIFIER REACTOR NO.1 CYCLONE	
50,333	LBS/HR - CARBON
10,964	LBS/HR - HYDROGEN
81,040	LBS/HR - OXYGEN
168	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
929	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,297,535	LBS/HR - TOTAL
0.84	% MOISTURE
1,562	°F
25	PSIG
40	PSIA
56,143	ACFM

CR	149
SOLIDS FROM GASIFIER REACTOR NO.1 CYCLONE TO GASIFIER REACTOR CYCLONES SOLIDS COLLECTION BIN	
13,811	LBS/HR - CARBON
1,018	LBS/HR - HYDROGEN
2,028	LBS/HR - OXYGEN
10	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
910	LBS/HR - ASH
5,050,932	LBS/HR - BED MEDIA
5,068,716	LBS/HR - TOTAL
0.00	% MOISTURE
1,547	°F

CX	151
SYNGAS FROM GASIFIER REACTOR NO.1 CYCLONE TO GASIFIER REACTOR NO.2 CYCLONE	
36,522	LBS/HR - CARBON
9,946	LBS/HR - HYDROGEN
79,012	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
19	LBS/HR - ASH
103,080	LBS/HR - BED MEDIA
228,819	LBS/HR - TOTAL
19.47	% MOISTURE
1,547	°F
24	PSIG
39	PSIA
57,166	ACFM

TO: MB-1-04

DJ	154
SYNGAS FROM GASIFIER REACTOR NO.2 CYCLONE TO SYNGAS REFORMER REACTOR	
36,246	LBS/HR - CARBON
9,926	LBS/HR - HYDROGEN
78,971	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
2,062	LBS/HR - BED MEDIA
127,445	LBS/HR - TOTAL
34.95	% MOISTURE
1,537	°F
23	PSIG
38	PSIA
58,391	ACFM

DD	153
SOLIDS FROM GASIFIER REACTOR NO.2 CYCLONE TO GASIFIER REACTOR CYCLONES SOLIDS COLLECTION BIN	
276	LBS/HR - CARBON
20	LBS/HR - HYDROGEN
41	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
18	LBS/HR - ASH
101,019	LBS/HR - BED MEDIA
101,374	LBS/HR - TOTAL
0.00	% MOISTURE
1,537	°F

TO: MB-1-03

DV	155
SOLIDS FROM GASIFIER REACTOR CYCLONES SOLIDS COLLECTION BIN TO CHAR COMBUSTION REACTOR	
14,088	LBS/HR - CARBON
1,038	LBS/HR - HYDROGEN
2,069	LBS/HR - OXYGEN
10	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
928	LBS/HR - ASH
5,151,950	LBS/HR - BED MEDIA
5,170,090	LBS/HR - TOTAL
0.00	% MOISTURE
1,547	°F

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

NREL

Harris Group Inc.
Engineering for Optimum Performance®

NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
MATERIAL BALANCE DRAWING
GASIFIER CYCLONES

PROJ NO.: 30300.00
DWG NO.: MB-1-02
DATE: 08/03/12

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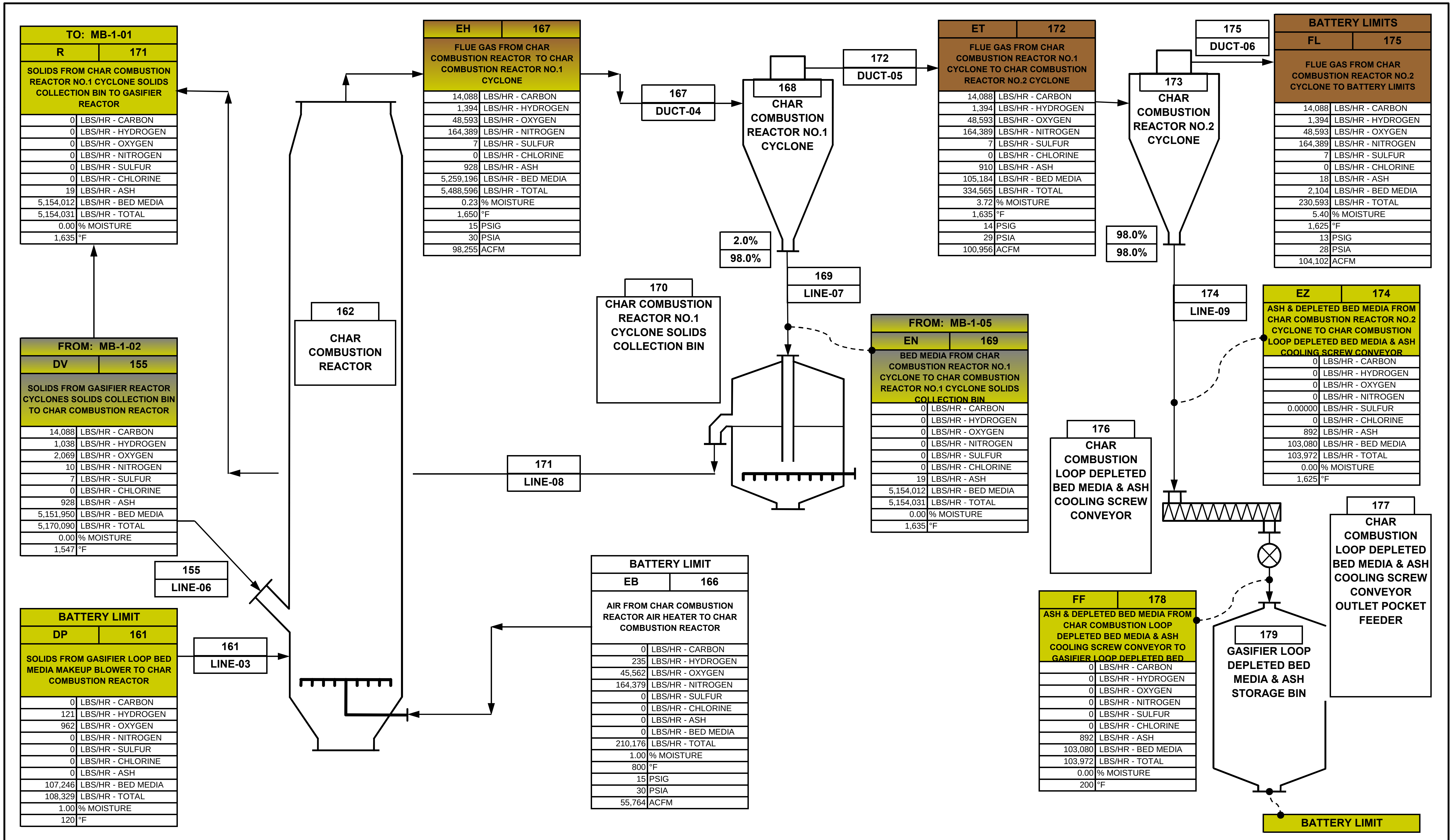
8/3/12 9:01 AM



TO: MB-1-01	
R	171
SOLIDS FROM CHAR COMBUSTION REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN TO GASIFIER REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
19	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,154,031	LBS/HR - TOTAL
0.00	% MOISTURE
1,635	°F

FROM: MB-1-02	
DV	155
SOLIDS FROM GASIFIER REACTOR CYCLONES SOLIDS COLLECTION BIN TO CHAR COMBUSTION REACTOR	
14,088	LBS/HR - CARBON
1,038	LBS/HR - HYDROGEN
2,069	LBS/HR - OXYGEN
10	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
928	LBS/HR - ASH
5,151,950	LBS/HR - BED MEDIA
5,170,090	LBS/HR - TOTAL
0.00	% MOISTURE
1,547	°F

BATTERY LIMIT	
DP	161
SOLIDS FROM GASIFIER LOOP BED MEDIA MAKEUP BLOWER TO CHAR COMBUSTION REACTOR	
0	LBS/HR - CARBON
121	LBS/HR - HYDROGEN
962	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
107,246	LBS/HR - BED MEDIA
108,329	LBS/HR - TOTAL
1.00	% MOISTURE
120	°F

EH	167
FLUE GAS FROM CHAR COMBUSTION REACTOR TO CHAR COMBUSTION REACTOR NO.1 CYCLONE	
14,088	LBS/HR - CARBON
1,394	LBS/HR - HYDROGEN
48,593	LBS/HR - OXYGEN
164,389	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
928	LBS/HR - ASH
5,259,196	LBS/HR - BED MEDIA
5,488,596	LBS/HR - TOTAL
0.23	% MOISTURE
1,650	°F
15	PSIG
30	PSIA
98,255	ACFM

BATTERY LIMIT	
EB	166
AIR FROM CHAR COMBUSTION REACTOR AIR HEATER TO CHAR COMBUSTION REACTOR	
0	LBS/HR - CARBON
235	LBS/HR - HYDROGEN
45,562	LBS/HR - OXYGEN
164,379	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
210,176	LBS/HR - TOTAL
1.00	% MOISTURE
800	°F
15	PSIG
30	PSIA
55,764	ACFM

ET	172
FLUE GAS FROM CHAR COMBUSTION REACTOR NO.1 CYCLONE TO CHAR COMBUSTION REACTOR NO.2 CYCLONE	
14,088	LBS/HR - CARBON
1,394	LBS/HR - HYDROGEN
48,593	LBS/HR - OXYGEN
164,389	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
910	LBS/HR - ASH
105,184	LBS/HR - BED MEDIA
334,565	LBS/HR - TOTAL
3.72	% MOISTURE
1,635	°F
14	PSIG
29	PSIA
100,956	ACFM

FROM: MB-1-05	
EN	169
BED MEDIA FROM CHAR COMBUSTION REACTOR NO.1 CYCLONE TO CHAR COMBUSTION REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
19	LBS/HR - ASH
5,154,012	LBS/HR - BED MEDIA
5,154,031	LBS/HR - TOTAL
0.00	% MOISTURE
1,635	°F

BATTERY LIMITS	
FL	175
FLUE GAS FROM CHAR COMBUSTION REACTOR NO.2 CYCLONE TO BATTERY LIMITS	
14,088	LBS/HR - CARBON
1,394	LBS/HR - HYDROGEN
48,593	LBS/HR - OXYGEN
164,389	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
18	LBS/HR - ASH
2,104	LBS/HR - BED MEDIA
230,593	LBS/HR - TOTAL
5.40	% MOISTURE
1,625	°F
13	PSIG
28	PSIA
104,102	ACFM

EZ	174
ASH & DEPLETED BED MEDIA FROM CHAR COMBUSTION REACTOR NO.2 CYCLONE TO CHAR COMBUSTION LOOP DEPLETED BED MEDIA & ASH COOLING SCREW CONVEYOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.00000	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
892	LBS/HR - ASH
103,080	LBS/HR - BED MEDIA
103,972	LBS/HR - TOTAL
0.00	% MOISTURE
1,625	°F

FF	178
ASH & DEPLETED BED MEDIA FROM CHAR COMBUSTION LOOP DEPLETED BED MEDIA & ASH COOLING SCREW CONVEYOR TO GASIFIER LOOP DEPLETED BED	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
892	LBS/HR - ASH
103,080	LBS/HR - BED MEDIA
103,972	LBS/HR - TOTAL
0.00	% MOISTURE
200	°F

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

MATERIAL BALANCE DRAWING
CHAR COMBUSTION REACTOR & CYCLONES

PROJ NO.: 30300.00
DWG NO.: MB-1-03
DATE: 08/03/12

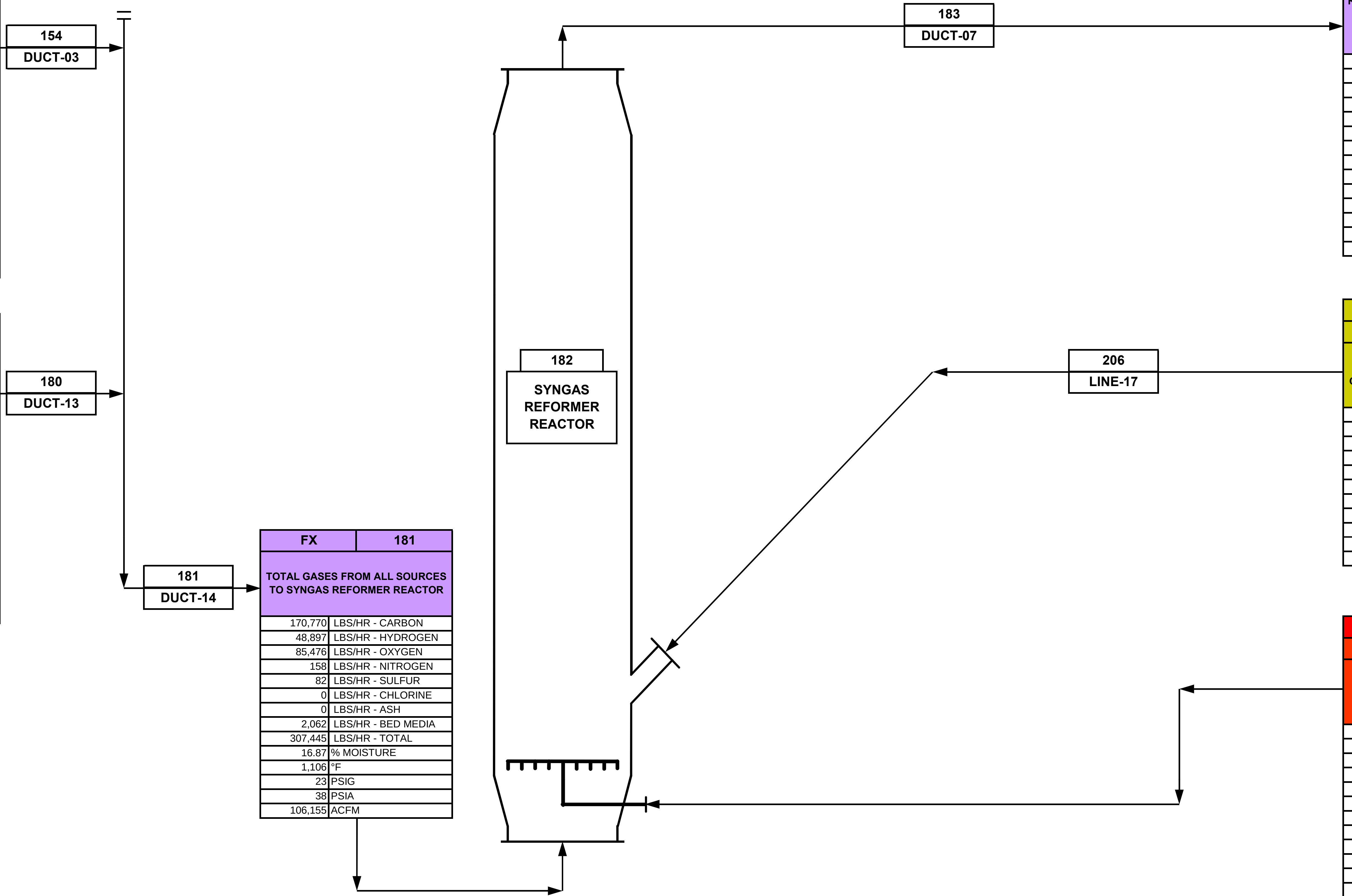
U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]MB-1-03

8/3/12 9:01 AM

FROM: MB-1-02	
DJ	154
SYNGAS FROM GASIFIER REACTOR NO.2 CYCLONE TO SYNGAS REFORMER REACTOR	
36,246	LBS/HR - CARBON
9,926	LBS/HR - HYDROGEN
78,971	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
2,062	LBS/HR - BED MEDIA
127,445	LBS/HR - TOTAL
34.95	% MOISTURE
1,537	°F
23	PSIG
38	PSIA
58,391	ACFM

BATTERY LIMITS	
FR	180
SUPPLEMENTAL GAS FROM OUTSIDE SOURCE TO SYNGAS REFORMER REACTOR	
134,525	LBS/HR - CARBON
38,971	LBS/HR - HYDROGEN
6,504	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
180,000	LBS/HR - TOTAL
4.07	% MOISTURE
800	°F
23	PSIG
38	PSIA
48,597	ACFM

FX	181
TOTAL GASES FROM ALL SOURCES TO SYNGAS REFORMER REACTOR	
170,770	LBS/HR - CARBON
48,897	LBS/HR - HYDROGEN
85,476	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
2,062	LBS/HR - BED MEDIA
307,445	LBS/HR - TOTAL
16.87	% MOISTURE
1,106	°F
23	PSIG
38	PSIA
106,155	ACFM



TO: MB-1-05	
GP	183
REFORMED SYNGAS FROM SYNGAS REFORMER REACTOR TO SYNGAS REFORMER REACTOR NO.1 CYCLONE	
170,770	LBS/HR - CARBON
67,714	LBS/HR - HYDROGEN
234,815	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,743,968	LBS/HR - BED MEDIA
14,217,508	LBS/HR - TOTAL
0.00	% MOISTURE
1,652	°F
21	PSIG
36	PSIA
505,760	ACFM

FROM: MB-1-06	
GD	206
SOLIDS FROM REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN TO SYNGAS REFORMER REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,741,907	LBS/HR - BED MEDIA
13,741,907	LBS/HR - TOTAL
0.00	% MOISTURE
1,735	°F

BATTERY LIMITS	
GJ	STEAM
STEAM FROM STEAM HEADER TO SYNGAS REFORMER REACTOR	
0	LBS/HR - CARBON
18,818	LBS/HR - HYDROGEN
149,340	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
168,157	LBS/HR - TOTAL
100.00	% MOISTURE
392	°F
174	PSIG
189	PSIA
7,539	ACFM

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

MATERIAL BALANCE DRAWING
SYNGAS REFORMER REACTOR

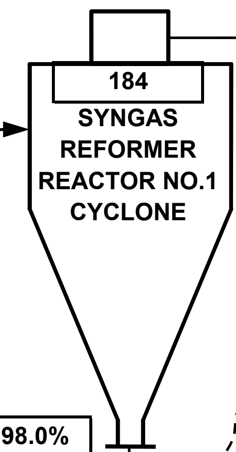
PROJ NO.: 30300.00
DWG NO.: MB-1-04
DATE: 08/03/12

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]MB-1-04

8/3/12 9:01 AM

FROM: MB-1-04	
GP	183
REFORMED SYNGAS FROM SYNGAS REFORMER REACTOR TO SYNGAS REFORMER REACTOR NO.1 CYCLONE	
170,770	LBS/HR - CARBON
67,714	LBS/HR - HYDROGEN
234,815	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,743,968	LBS/HR - BED MEDIA
14,217,508	LBS/HR - TOTAL
0.00	% MOISTURE
1,652	°F
21	PSIG
36	PSIA
505,760	ACFM

183
DUCT-07

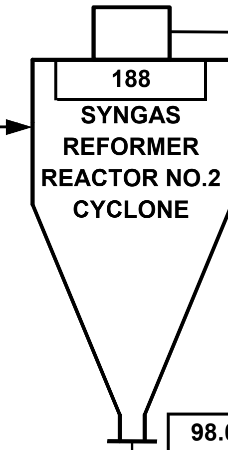


187
DUCT-08

GV	185
SOLIDS FROM SYNGAS REFORMER REACTOR NO.1 CYCLONE TO SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,469,089	LBS/HR - BED MEDIA
13,469,089	LBS/HR - TOTAL
0.00	% MOISTURE
1,627	°F

185
LINE-10

HB	187
REFORMED SYNGAS FROM SYNGAS REFORMER NO.1 CYCLONE TO SYNGAS REFORMER REACTOR NO.2 CYCLONE	
170,770	LBS/HR - CARBON
67,714	LBS/HR - HYDROGEN
234,815	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
274,879	LBS/HR - BED MEDIA
748,419	LBS/HR - TOTAL
0.00	% MOISTURE
1,637	°F
20	PSIG
35	PSIA
516,641	ACFM



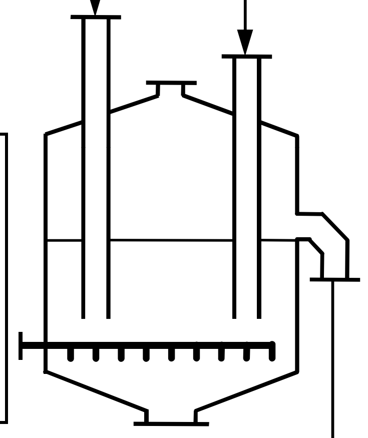
190
DUCT-09

BATTERY LIMITS	
HN	190
REFORMED SYNGAS FROM SYNGAS REFORMER REACTOR NO.2 CYCLONE TO BATTERY LIMITS	
170,765	LBS/HR - CARBON
67,714	LBS/HR - HYDROGEN
234,814	LBS/HR - OXYGEN
158	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
5,498	LBS/HR - BED MEDIA
479,031	LBS/HR - TOTAL
0.00	% MOISTURE
1,627	°F
19	PSIG
34	PSIA
529,436	ACFM

HH	189
SOLIDS FROM SYNGAS REFORMER REACTOR NO.2 CYCLONE TO SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN	
6	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
1	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
269,382	LBS/HR - BED MEDIA
269,389	LBS/HR - TOTAL
0.00	% MOISTURE
1,627	°F

189
LINE-14

186
SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN



191
LINE-15

TO: MB-1-06	
HZ	191
SOLIDS FROM SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN TO REFORMER BED MEDIA HEATING REACTOR	
6	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
1	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,738,471	LBS/HR - BED MEDIA
13,738,478	LBS/HR - TOTAL
0.00	% MOISTURE
1,627	°F

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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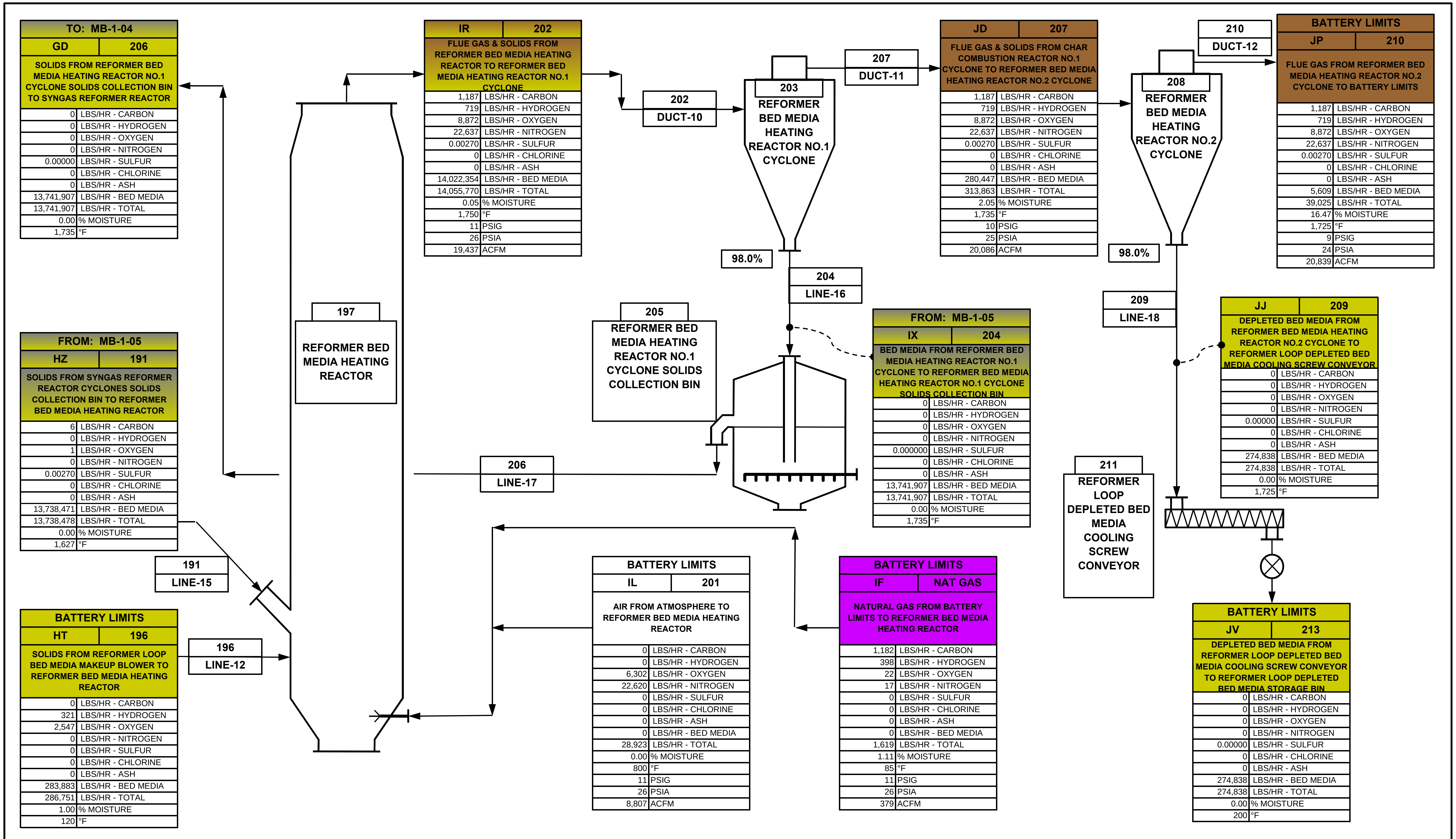
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
MATERIAL BALANCE DRAWING
SYNGAS REFORMER CYCLONES

PROJ NO.: 30300.00
DWG NO.: MB-1-05
DATE: 08/03/12



TO: MB-1-04

GD	206
SOLIDS FROM REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN TO SYNGAS REFORMER REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.00000	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,741,907	LBS/HR - BED MEDIA
13,741,907	LBS/HR - TOTAL
0.00	% MOISTURE
1,735	°F

IR	202
FLUE GAS & SOLIDS FROM REFORMER BED MEDIA HEATING REACTOR TO REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE	
1,187	LBS/HR - CARBON
719	LBS/HR - HYDROGEN
8,872	LBS/HR - OXYGEN
22,637	LBS/HR - NITROGEN
0.00270	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
14,022,354	LBS/HR - BED MEDIA
14,055,770	LBS/HR - TOTAL
0.05	% MOISTURE
1,750	°F
11	PSIG
26	PSIA
19,437	ACFM

JD	207
FLUE GAS & SOLIDS FROM CHAR COMBUSTION REACTOR NO.1 CYCLONE TO REFORMER BED MEDIA HEATING REACTOR NO.2 CYCLONE	
1,187	LBS/HR - CARBON
719	LBS/HR - HYDROGEN
8,872	LBS/HR - OXYGEN
22,637	LBS/HR - NITROGEN
0.00270	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
280,447	LBS/HR - BED MEDIA
313,863	LBS/HR - TOTAL
2.05	% MOISTURE
1,735	°F
10	PSIG
25	PSIA
20,086	ACFM

BATTERY LIMITS

JP	210
FLUE GAS FROM REFORMER BED MEDIA HEATING REACTOR NO.2 CYCLONE TO BATTERY LIMITS	
1,187	LBS/HR - CARBON
719	LBS/HR - HYDROGEN
8,872	LBS/HR - OXYGEN
22,637	LBS/HR - NITROGEN
0.00270	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
5,609	LBS/HR - BED MEDIA
39,025	LBS/HR - TOTAL
16.47	% MOISTURE
1,725	°F
9	PSIG
24	PSIA
20,839	ACFM

FROM: MB-1-05

HZ	191
SOLIDS FROM SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN TO REFORMER BED MEDIA HEATING REACTOR	
6	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
1	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.00270	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,738,471	LBS/HR - BED MEDIA
13,738,478	LBS/HR - TOTAL
0.00	% MOISTURE
1,627	°F

FROM: MB-1-05

IX	204
BED MEDIA FROM REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE TO REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.000000	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
13,741,907	LBS/HR - BED MEDIA
13,741,907	LBS/HR - TOTAL
0.00	% MOISTURE
1,735	°F

JJ	209
DEPLETED BED MEDIA FROM REFORMER BED MEDIA HEATING REACTOR NO.2 CYCLONE TO REFORMER LOOP DEPLETED BED MEDIA COOLING SCREW CONVEYOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.00000	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
274,838	LBS/HR - BED MEDIA
274,838	LBS/HR - TOTAL
0.00	% MOISTURE
1,725	°F

BATTERY LIMITS

HT	196
SOLIDS FROM REFORMER LOOP BED MEDIA MAKEUP BLOWER TO REFORMER BED MEDIA HEATING REACTOR	
0	LBS/HR - CARBON
321	LBS/HR - HYDROGEN
2,547	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
283,883	LBS/HR - BED MEDIA
286,751	LBS/HR - TOTAL
1.00	% MOISTURE
120	°F

BATTERY LIMITS

IL	201
AIR FROM ATMOSPHERE TO REFORMER BED MEDIA HEATING REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
6,302	LBS/HR - OXYGEN
22,620	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
28,923	LBS/HR - TOTAL
0.00	% MOISTURE
800	°F
11	PSIG
26	PSIA
8,807	ACFM

BATTERY LIMITS

IF	NAT GAS
NATURAL GAS FROM BATTERY LIMITS TO REFORMER BED MEDIA HEATING REACTOR	
1,182	LBS/HR - CARBON
398	LBS/HR - HYDROGEN
22	LBS/HR - OXYGEN
17	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
1,619	LBS/HR - TOTAL
1.11	% MOISTURE
85	°F
11	PSIG
26	PSIA
379	ACFM

BATTERY LIMITS

JV	213
DEPLETED BED MEDIA FROM REFORMER LOOP DEPLETED BED MEDIA COOLING SCREW CONVEYOR TO REFORMER LOOP DEPLETED BED MEDIA STORAGE BIN	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
0	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0.00000	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
274,838	LBS/HR - BED MEDIA
274,838	LBS/HR - TOTAL
0.00	% MOISTURE
200	°F

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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NATIONAL RENEWABLE ENERGY LABORATORY

GOLDEN, COLORADO

MATERIAL BALANCE DRAWING

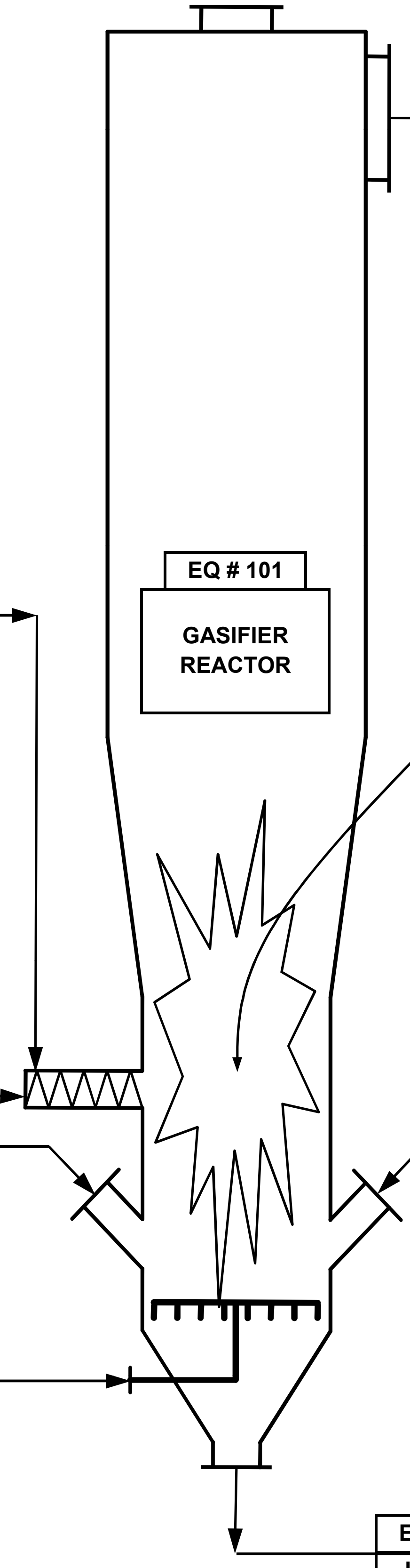
REFORMER BED MEDIA HEATING REACTOR & CYCLONES

PROJ NO.: 30300.00

DWG NO.: MB-1-06

DATE: 08/03/12

APPENDIX F-2
DETAILED ESTIMATE
MASS BALANCE FLOW DIAGRAMS
BFB GASIFIER MODEL



BATTERY LIMITS	
AQ	007
BED MEDIA FROM BATTERY LIMITS TO GASIFIER REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
3	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
349	LBS/HR - BED MEDIA
353	LBS/HR - TOTAL
1.00	% MOISTURE
80	°F
438	PSIG
453	PSIA
--	ACFM

BATTERY LIMITS	
AK	005
NITROGEN GAS FROM BATTERY LIMITS TO GASIFIER REACTOR	
0	LBS/HR - CARBON
1	LBS/HR - HYDROGEN
25	LBS/HR - OXYGEN
989	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
1,015	LBS/HR - TOTAL
0.50	% MOISTURE
80	°F
438	PSIG
453	PSIA
8	ACFM

BIOMASS STORAGE	
M	001
BIOMASS FROM BIOMASS STORAGE TO GASIFIER REACTOR	
50,333	LBS/HR - CARBON
6,558	LBS/HR - HYDROGEN
46,074	LBS/HR - OXYGEN
168	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
910	LBS/HR - ASH
0	LBS/HR - BED MEDIA
104,132	LBS/HR - TOTAL
5.00	% MOISTURE
80	°F
438	PSIG
453	PSIA
--	ACFM

TO: MB-2-02	
AW	008
SYNGAS & ENTRAINED SOLIDS FROM GASIFIER REACTOR TO GASIFIER CYCLONE	
50,333	LBS/HR - CARBON
8,889	LBS/HR - HYDROGEN
86,126	LBS/HR - OXYGEN
1,197	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
1,219	LBS/HR - ASH
525	LBS/HR - BED MEDIA
149,577	LBS/HR - TOTAL
15.08	% MOISTURE
1,600	°F
438	PSIG
453	PSIA
4,652	ACFM

BU	012
BIOMASS, OXY, NIT, STM & BED MEDIA IN BUBBLING FLUID BED	
50,333	LBS/HR - CARBON
8,889	LBS/HR - HYDROGEN
86,126	LBS/HR - OXYGEN
1,197	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
1,219	LBS/HR - ASH
525	LBS/HR - BED MEDIA
149,577	LBS/HR - TOTAL
17.41	% MOISTURE
1,600	°F
438	PSIG
453	PSIA
1,543	ACFM

FROM: MB-2-02	
BC	009
BED MEDIA FROM GASIFIER CYCLONE TO GASIFIER REACTOR	
3,653	LBS/HR - CARBON
356	LBS/HR - HYDROGEN
165	LBS/HR - OXYGEN
5	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
1,121	LBS/HR - ASH
504	LBS/HR - BED MEDIA
5,811	LBS/HR - TOTAL
0.00	% MOISTURE
1,595	°F
437	PSIG
452	PSIA
--	ACFM

BATTERY LIMITS	
S	002
OXYGEN BLAST FROM BATTERY LIMITS TO GASIFIER REACTOR	
0	LBS/HR - CARBON
0	LBS/HR - HYDROGEN
21,528	LBS/HR - OXYGEN
40	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
22,767	LBS/HR - TOTAL
0.00	% MOISTURE
172	°F
438	PSIG
453	PSIA
176	ACFM

BATTERY LIMITS	
Y	003
STEAM FROM BATTERY LIMITS TO GASIFIER REACTOR	
0	LBS/HR - CARBON
2,331	LBS/HR - HYDROGEN
18,496	LBS/HR - OXYGEN
0	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
20,827	LBS/HR - TOTAL
100.00	% MOISTURE
471	°F
438	PSIG
453	PSIA
425	ACFM

OXYGEN & STM HDR	
AE	004
OXYGEN & STEAM FROM OXYGEN & STM HDR TO GASIFIER REACTOR	
0	LBS/HR - CARBON
2,331	LBS/HR - HYDROGEN
40,024	LBS/HR - OXYGEN
40	LBS/HR - NITROGEN
0	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
0	LBS/HR - ASH
0	LBS/HR - BED MEDIA
43,593	LBS/HR - TOTAL
47.78	% MOISTURE
315	°F
438	PSIG
453	PSIA
569	ACFM

ASH DISCHARGE SYSTEM	
BO	011
CHAR, ASH & BED MEDIA FROM BOTTOM OF GASIFIER REACTOR TO ASH DISCHARGE SYSTEM	
3,653	LBS/HR - CARBON
356	LBS/HR - HYDROGEN
165	LBS/HR - OXYGEN
5	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
813	LBS/HR - ASH
328	LBS/HR - BED MEDIA
5,327	LBS/HR - TOTAL
0.00	% MOISTURE
1,600	°F
438	PSIG
453	PSIA
--	ACFM

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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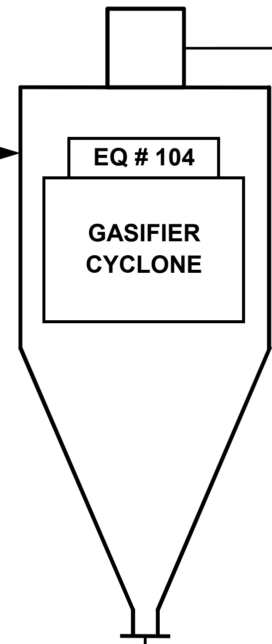
GOLDEN, COLORADO

MATERIAL BALANCE DRAWING
GASIFIER REACTOR SYSTEM

PROJ NO.:	30300.00
DWG NO.:	MB-2-01
DATE:	08/03/12

FROM: MB-2-01	
AW	008
SYNGAS & ENTRAINED SOLIDS FROM GASIFIER REACTOR TO GASIFIER CYCLONE	
50,333	LBS/HR - CARBON
8,889	LBS/HR - HYDROGEN
86,126	LBS/HR - OXYGEN
1,197	LBS/HR - NITROGEN
89	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
1,219	LBS/HR - ASH
525	LBS/HR - BED MEDIA
149,577	LBS/HR - TOTAL
15.08	% MOISTURE
1,600	°F
438	PSIG
453	PSIA
4,652	ACFM

EQ # 103
DUCT-01



EQ # 106
DUCT-02

BATTERY LIMITS	
BI	010
SYNGAS & ENTRAINED SOLIDS FROM GASIFIER CYCLONE TO BATTERY LIMITS	
46,680	LBS/HR - CARBON
8,533	LBS/HR - HYDROGEN
85,961	LBS/HR - OXYGEN
1,192	LBS/HR - NITROGEN
82	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
98	LBS/HR - ASH
21	LBS/HR - BED MEDIA
143,766	LBS/HR - TOTAL
15.69	% MOISTURE
1,595	°F
437	PSIG
452	PSIA
4,651	ACFM

92.0%	ASH REMOVAL EFF
96.0%	BED MEDIA REMOVAL EFF
90.0%	CHAR REMOVAL EFF

EQ # 105
LINE-01

TO: MB-2-01	
BC	009
BED MEDIA FROM GASIFIER CYCLONE TO GASIFIER REACTOR	
3,653	LBS/HR - CARBON
356	LBS/HR - HYDROGEN
165	LBS/HR - OXYGEN
5	LBS/HR - NITROGEN
7	LBS/HR - SULFUR
0	LBS/HR - CHLORINE
1,121	LBS/HR - ASH
504	LBS/HR - BED MEDIA
5,811	LBS/HR - TOTAL
0.00	% MOISTURE
1,595	°F
437	PSIG
452	PSIA
--	ACFM

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

NREL
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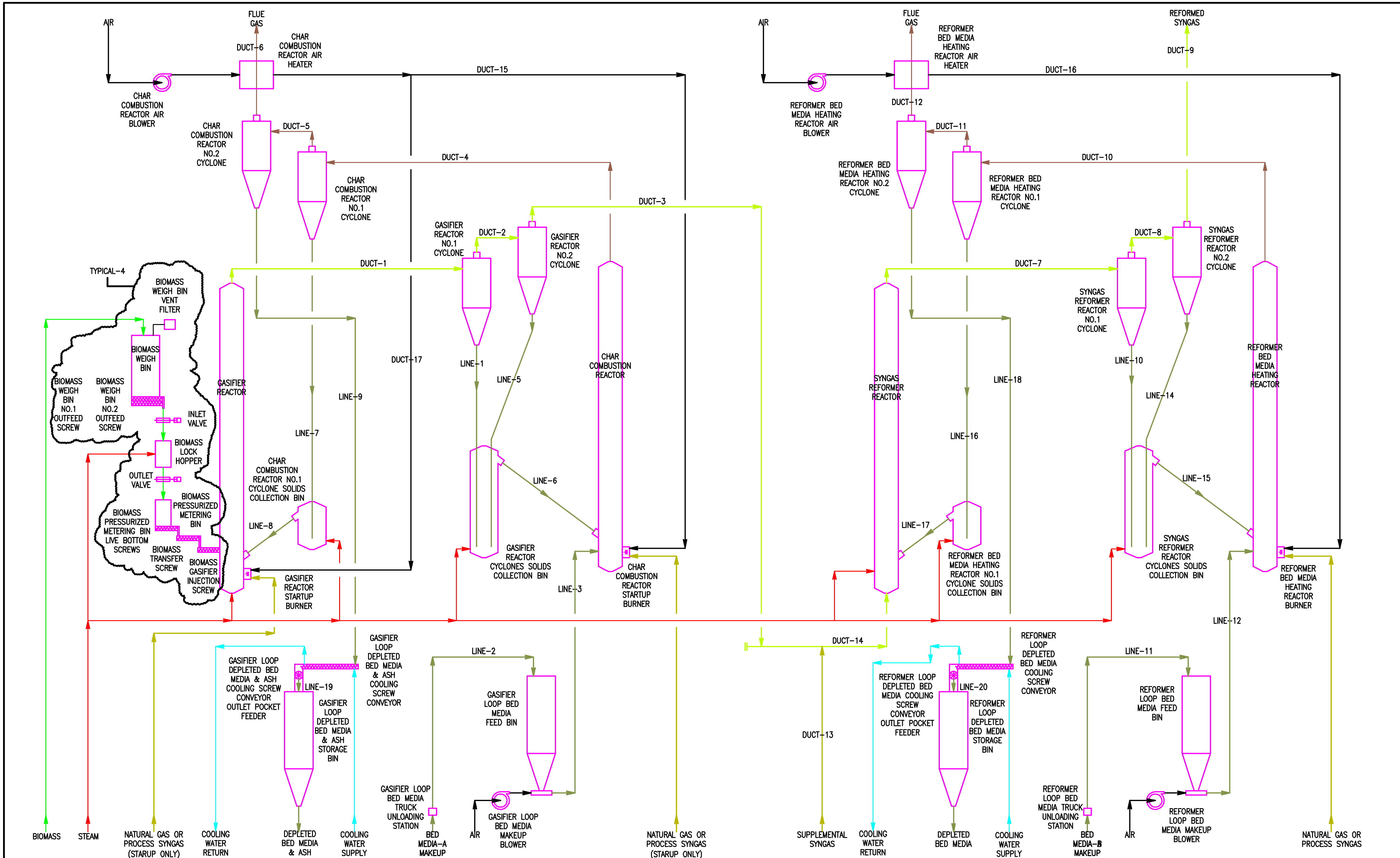
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
MATERIAL BALANCE DRAWING
GASIFIER CYCLONE SYSTEM

PROJ NO.: 30300.00
DWG NO.: MB-2-02
DATE: 08/03/12

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\BFB Gasifier Model\[2012-08-03 - BFB Gasifier Model.xlsx]MB-2-02

8/3/12 9:01 AM

APPENDIX G-1
DETAILED ESTIMATE
DRAWINGS
CFB GASIFIER MODEL



							08/03/12	FOR INFORMATION ONLY	JRY			
REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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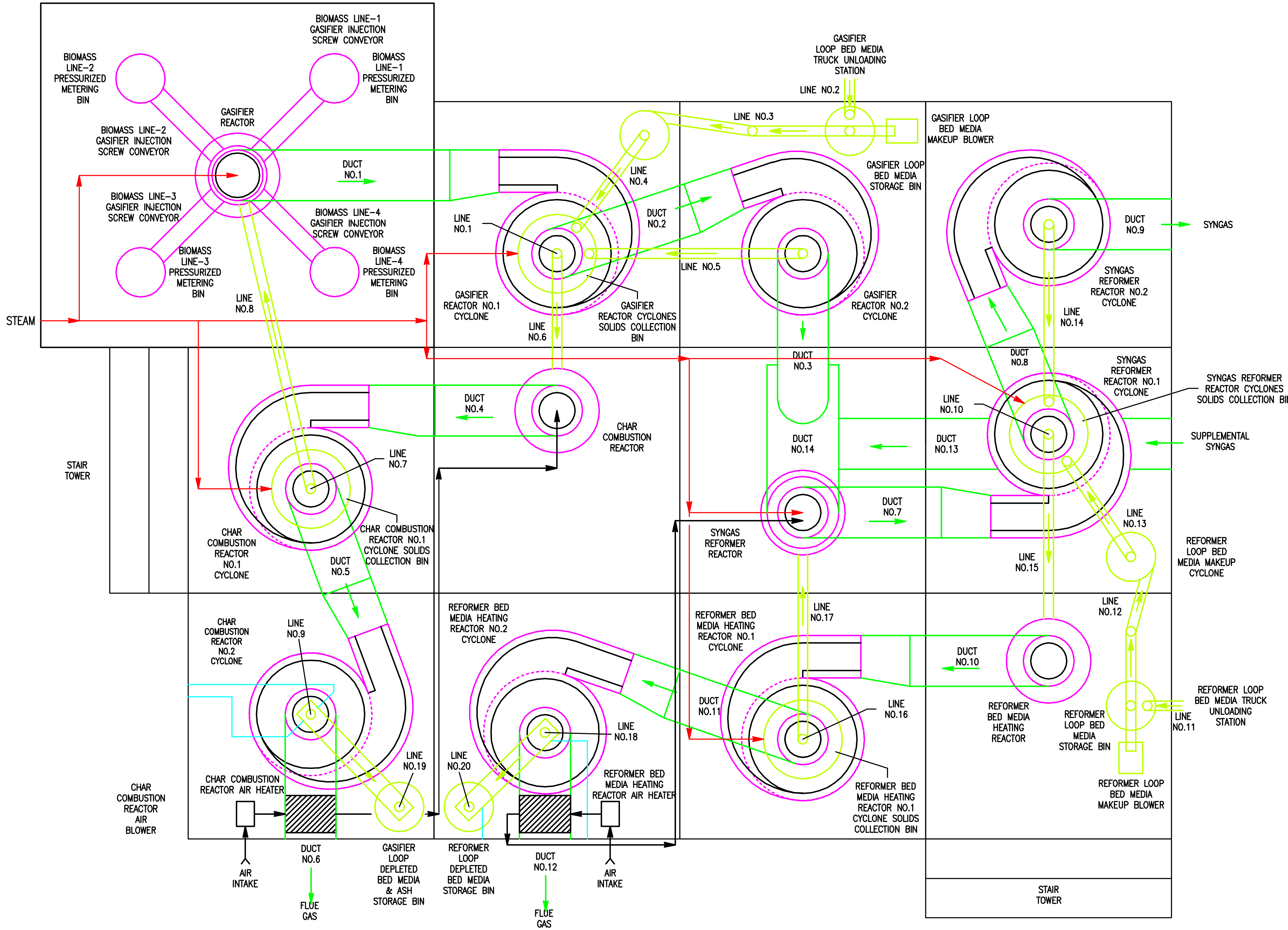
GOLDEN, COLORADO

CFB GASIFICATION SYSTEM
PROCESS FLOW DIAGRAM

PROJ NO.: 30300.00
DWG NO.: PFD-1-01
DATE: 08/03/12



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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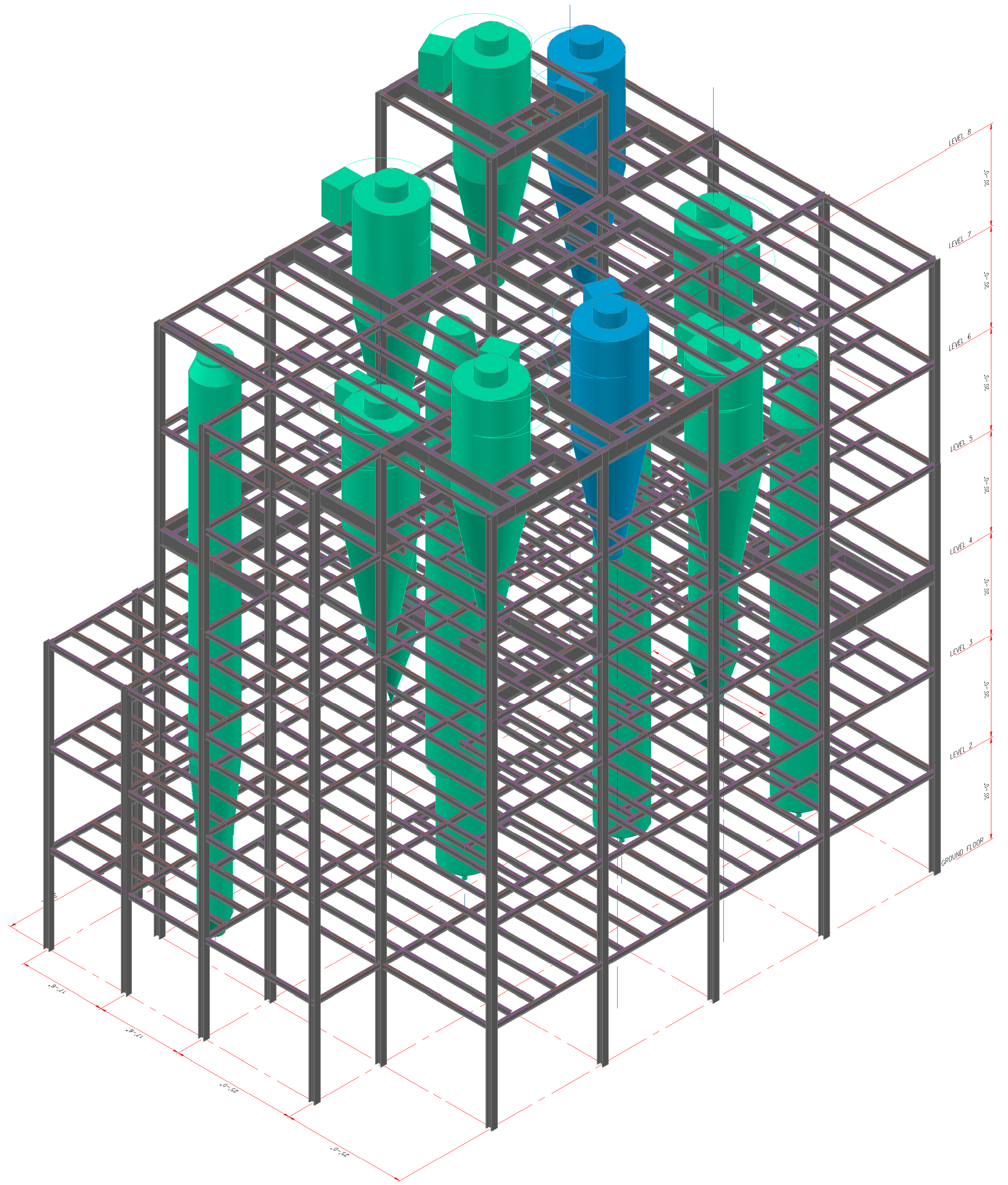
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

CFB GASIFICATION SYSTEM
GENERAL ARRANGEMENT – PLAN DRAWING

PROJ NO.: 30300.00
DWG NO.: GA–1–01
DATE: 08/03/12



GENERAL NOTES

1. NOT USED.

KEYED NOTES

1 NOT USED.

PLAN

PRELIMINARY - NOT FOR CONSTRUCTION

Reference Drawings	
Drawing No	Title

Revisions			
Rev	Date	By	Description

Revisions			
Rev	Date	By	Description

Rev	Date	App'd	Client Approval Milestone

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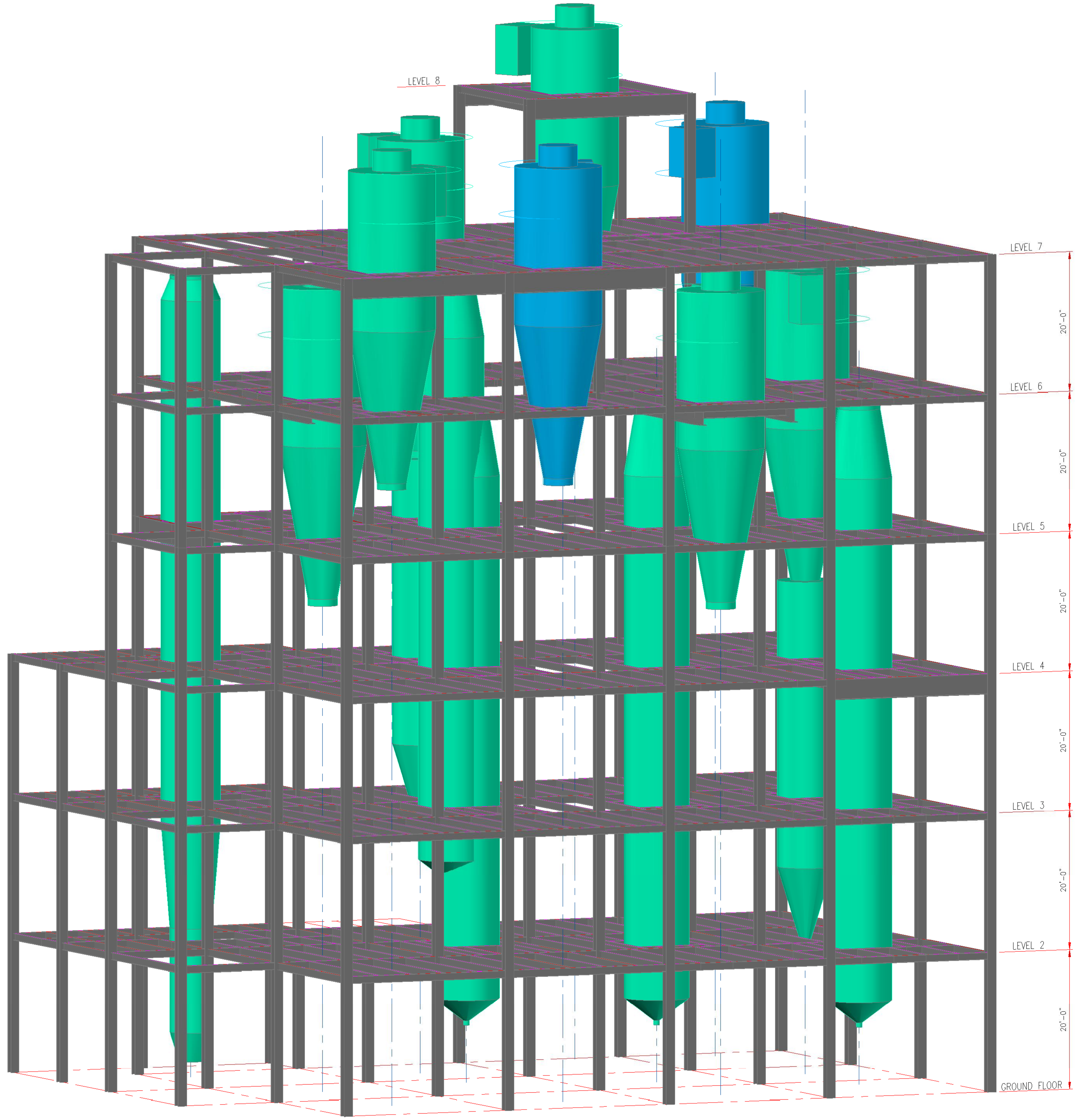
Subconsultant:
Drawn: Check:
Engr: Check:
Appr: PMgr:

Project No:
Drawing: SW ISO
Rev:

Save Date: 11/28/11 By: Miller, Robert File Location: U:\30074.00\Drawings\SW ISO.dwg



GENERAL NOTES

1. NOT USED.

KEYED NOTES

1 NOT USED.

PLAN

PRELIMINARY - NOT FOR CONSTRUCTION

Reference Drawings		Revisions				Revisions			
Drawing No	Title	Rev	Date	By	Description	Rev	Date	By	Description

Rev	Date	App'd	Client Approval Milestone

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Subconsultant:
Drawn: Check:
Engr: Check:
Appr: PMgr:

Project No: | Drawing: ROTATED A | Rev:

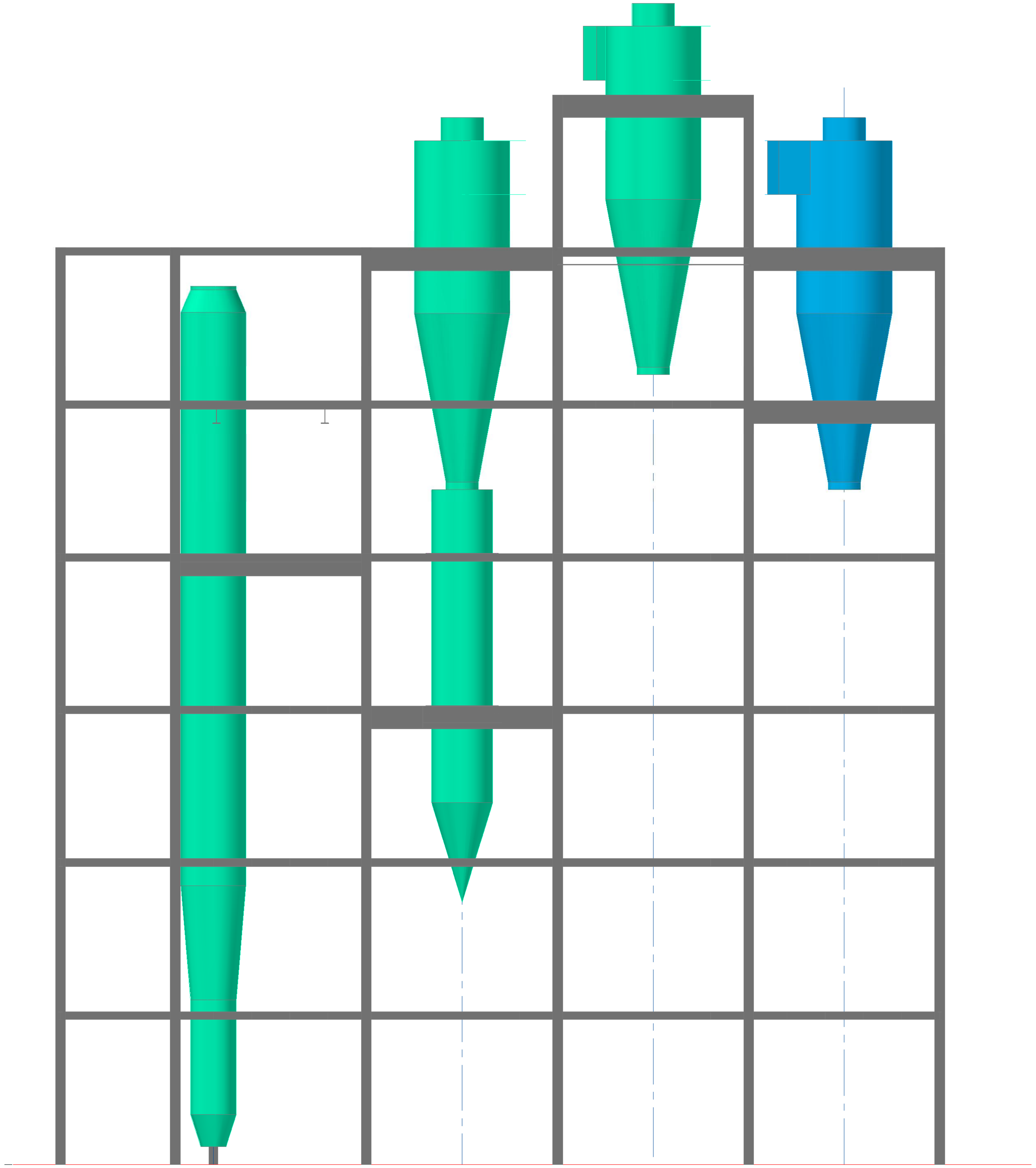
Save Date: 12/1/11 By: Miller, Robert File Location: U:\30074.00\Drawings\ROTATED A.dwg

GENERAL NOTES

1. NOT USED.

KEYED NOTES

1 NOT USED.



SECTION A

PRELIMINARY - NOT FOR CONSTRUCTION

Reference Drawings	
Drawing No	Title

Revisions			
Rev	Date	By	Description

Revisions			
Rev	Date	By	Description

Rev	Date	App'd	Client Approval Milestone

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Subconsultant:
Drawn: Check:
Engr: Check:
Appr: PMgr:

Project No:

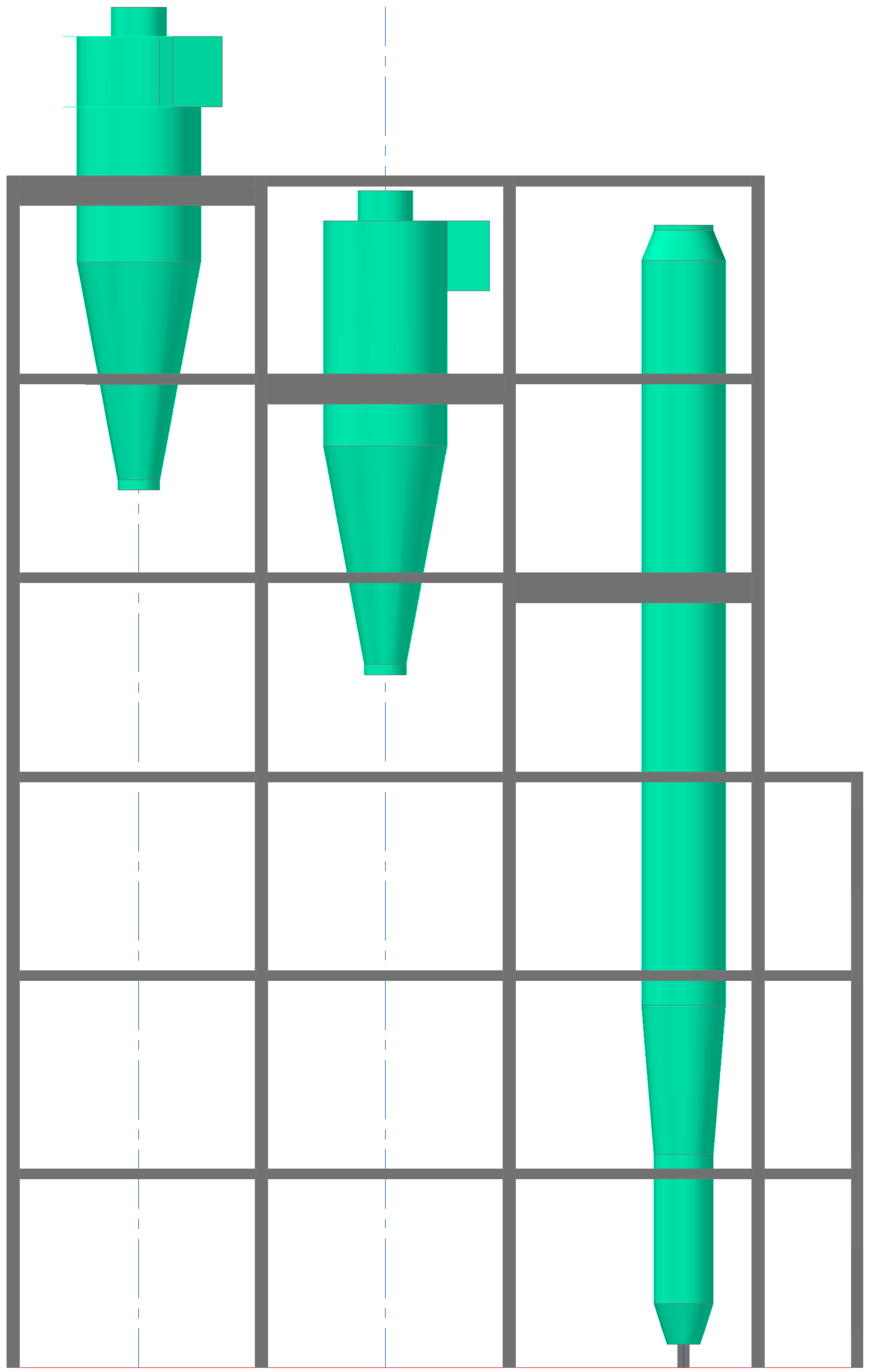
Drawing: SECTION A

Rev:

File Location: U:\30074.00\Drawings\SECTION A.dwg

By: Miller, Robert

Save Date:12/1/11



SECTION B

GENERAL NOTES

1. NOT USED.

KEYED NOTES

1 NOT USED.

PRELIMINARY - NOT FOR CONSTRUCTION

Reference Drawings	
Drawing No	Title

Revisions			
Rev	Date	By	Description

Revisions			
Rev	Date	By	Description

Rev	Date	App'd	Client Approval Milestone

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Subconsultant:
Drawn: Check:
Engr: Check:
Appr: PMgr:

Project No:
Drawing: SECTION B
Rev:

Save Date: 12/1/11 By: Miller, Robert File Location: U:\30074.00\Drawings\SECTION B.dwg

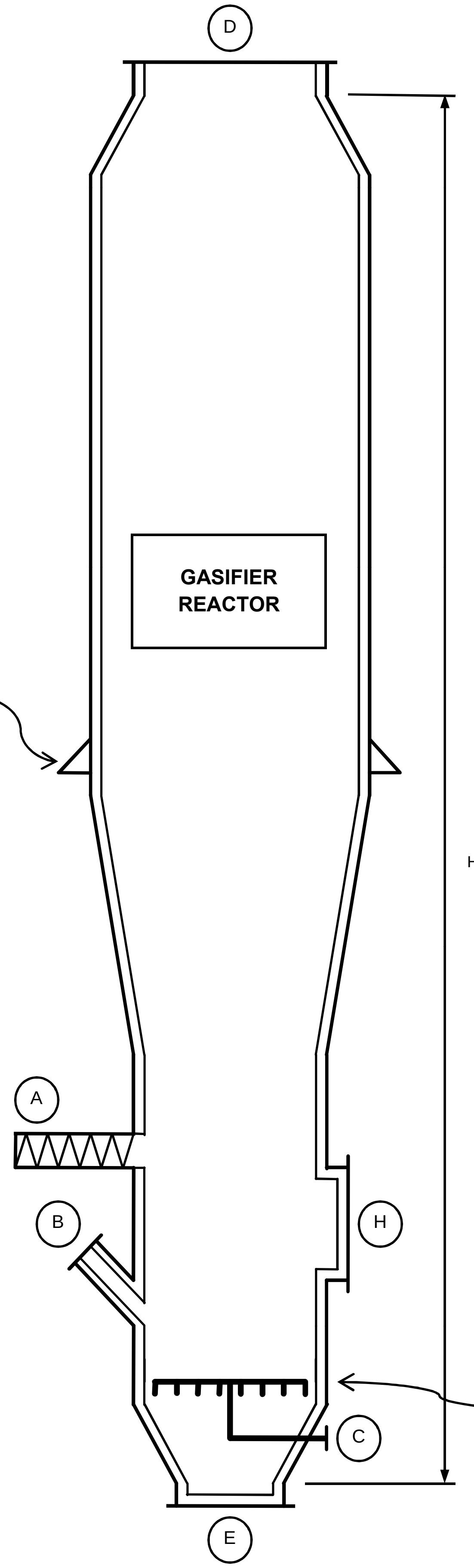
SECTION - 5	
CONE TOP	
HEIGHT -	5.9'
OD -	8.4' X 6.5'
SURFACE AREA	140 SQFT
WEIGHT -	2,853 LBS
OPEN VOLUME -	136 CUFT

SECTION-4	
TOP CYLINDER	
HEIGHT -	75.0'
OD -	8.4'
SURFACE AREA	1,976 SQFT
WEIGHT -	40,304 LBS
OPEN VOLUME -	2,363 CUFT

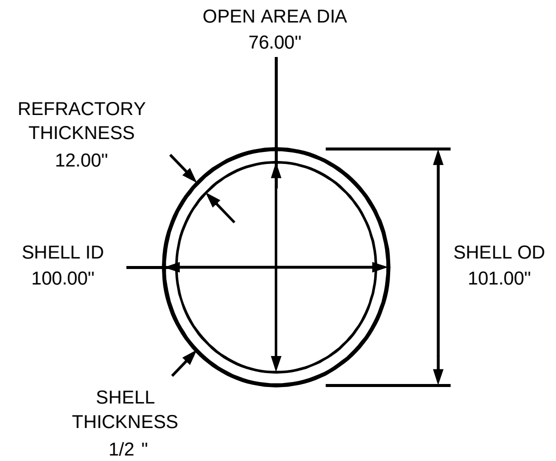
SECTION-3	
SWEDGED TRANS	
HEIGHT -	15.0'
OD -	6.1' X 8.4'
SURFACE AREA	343 SQFT
WEIGHT -	6,991 LBS
OPEN VOLUME -	320 CUFT

SECTION-2	
BOTTOM CYLINDER	
HEIGHT -	15.0'
OD -	6.1'
SURFACE AREA	287 SQFT
WEIGHT -	5,848 LBS
OPEN VOLUME -	188 CUFT

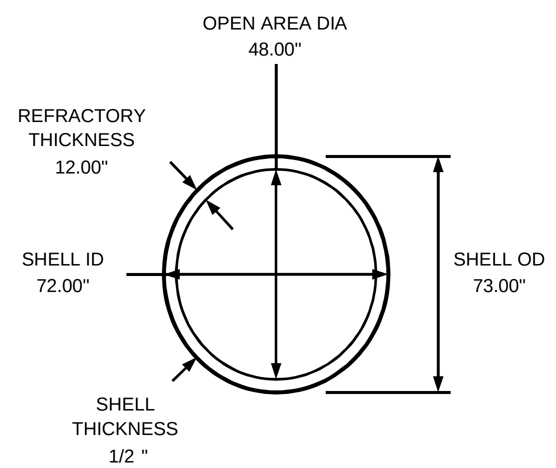
SECTION-1	
CONE BOTTOM	
HEIGHT -	4.3'
OD -	3.7' X 6.1'
SURFACE AREA	68 SQFT
WEIGHT -	1,383 LBS
OPEN VOLUME -	35 CUFT



SECTION-4
TOP CYLINDER



SECTION-2
BOTTOM CYLINDER



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	25.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	40.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,562.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,800.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	2,813 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	410,824 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	22"	INLET - SCREW FEEDER	4	150#	WATER COOLED	3"	243 LBS	
B	30"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	420 LBS	
C	10"	INLET - STEAM	1	150#		3"	62 LBS	
D	78"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	4,284 LBS	
E	44"	DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,019 LBS	2,717 LBS
F	1.5"	THERMOCOUPLE	8	150#	WATER COOLED	3"	5 LBS	
G	1.5"	PRESSURE TRANSMITTER	8	150#	WATER COOLED	3"	5 LBS	
H	48"	MANWAY	3	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
J								
K								
L								
M	0.75"	INLET - COOLING WATER	20	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	20	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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Harris Group Inc.
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NATIONAL RENEWABLE ENERGY LABORATORY

GOLDEN, COLORADO

EQUIPMENT DRAWING

GASIFIER REACTOR

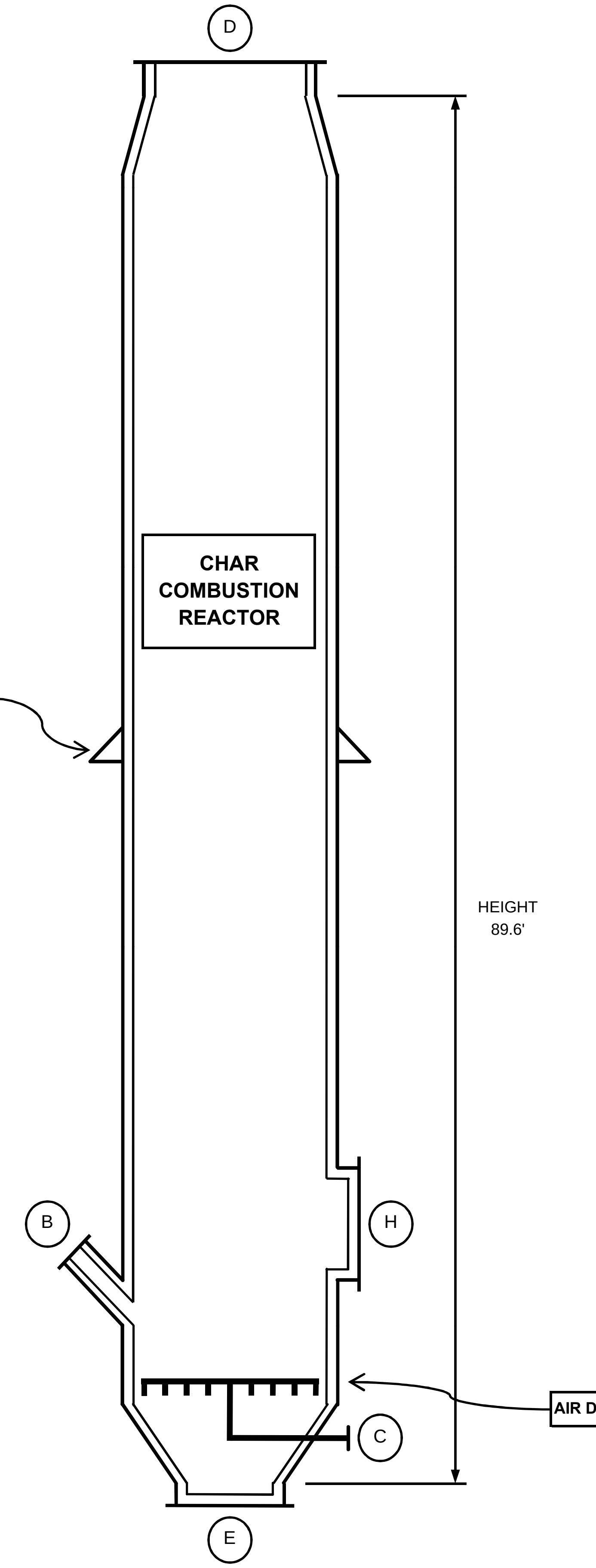
PROJ NO.: **30300.00**

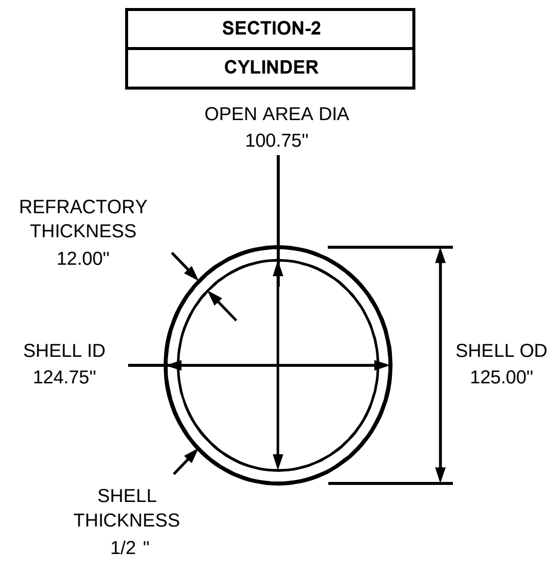
DWG NO.: **EQ-1-01**

DATE: **08/03/12**

SECTION - 3	
CONE TOP	
HEIGHT -	7.3'
OD -	10.4' X 6.5'
SURFACE AREA	201 SQFT
WEIGHT -	4,093 LBS
OPEN VOLUME -	243 CUFT

SECTION-2	
CYLINDER	
HEIGHT -	75.0'
OD -	10.4'
SURFACE AREA	2,454 SQFT
WEIGHT -	50,069 LBS
OPEN VOLUME -	4,152 CUFT





SECTION-1	
CONE BOTTOM	
HEIGHT -	7.3'
OD -	3.7' X 10.4'
SURFACE AREA	178 SQFT
WEIGHT -	3,626 LBS
OPEN VOLUME -	184 CUFT

DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	15.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	25.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,650.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	2,833 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	379,343 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
AIR DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A								
B	30"	INLET - CHAR & BED MEDIA	1	150#	REFRACTORY LINED	2"	420 LBS	
C	72"	INLET - AIR	1	150#		1"	3,168 LBS	
D	94"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	5,863 LBS	
E	44"	DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,019 LBS	2,717 LBS
F	1.5"	THERMOCOUPLE	8	150#	WATER COOLED	3"	5 LBS	
G	1.5"	PRESSURE TRANSMITTER	8	150#	WATER COOLED	3"	5 LBS	
H	48"	MANWAY	3	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
J								
K								
L								
M	0.75"	INLET - COOLING WATER	16	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	16	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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Harris Group Inc.
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GOLDEN, COLORADO

EQUIPMENT DRAWING
CHAR COMBUSTION REACTOR

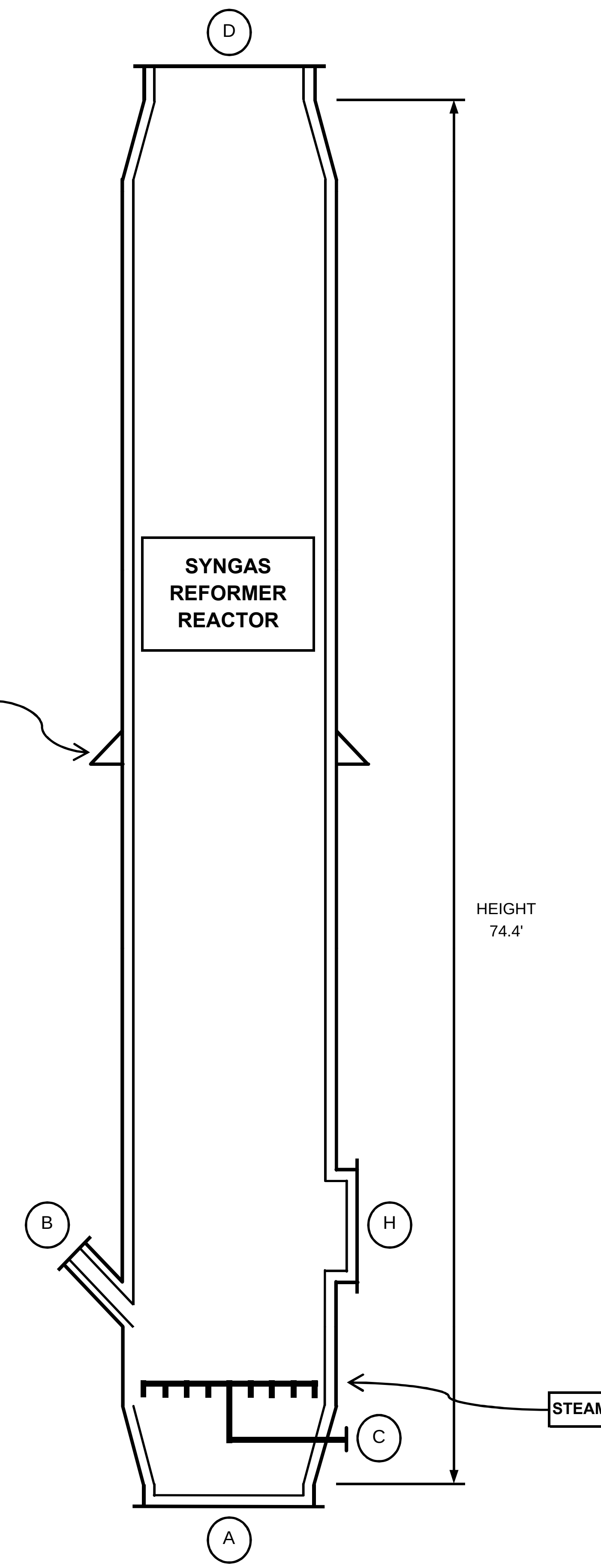
PROJ NO.: **30300.00**
DWG NO.: **EQ-1-02**
DATE: **08/03/12**

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-02

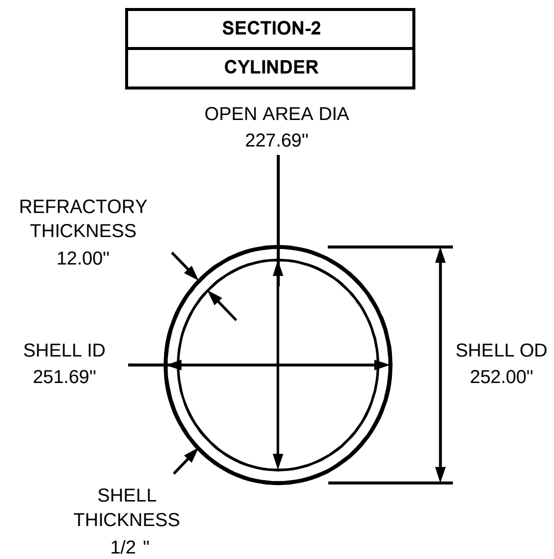
8/3/12 9:47 AM

SECTION - 3	
CONE TOP	
HEIGHT -	14.7'
OD -	21' X 6.5'
SURFACE AREA	708 SQFT
WEIGHT -	14,444 LBS
OPEN VOLUME -	1,785 CUFT

SECTION-2	
CYLINDER	
HEIGHT -	45.0'
OD -	21.0'
SURFACE AREA	2,969 SQFT
WEIGHT -	60,564 LBS
OPEN VOLUME -	12,724 CUFT



SECTION-1	
CONE BOTTOM	
HEIGHT -	14.7'
OD -	6.7' X 21'
SURFACE AREA	711 SQFT
WEIGHT -	14,499 LBS
OPEN VOLUME -	1,890 CUFT



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	21.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	35.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,652.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	4,388 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	600,175 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	80"	INLET - SYNGAS	1	150#	REFRACTORY LINED	1"	4,048 LBS	
B	30"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	420 LBS	
C	16"	INLET STEAM	1	150#		3"	155 LBS	
D	100"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	6,747 LBS	
E								
F	1.5"	THERMOCOUPLE	8	150#	WATER COOLED	3"	5 LBS	
G	1.5"	PRESSURE TRANSMITTER	8	150#	WATER COOLED	3"	5 LBS	
H	48"	MANWAY	3	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
J								
K								
L								
M	0.75"	INLET - COOLING WATER	16	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	16	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING
SYNGAS REFORMER REACTOR

PROJ NO.: 30300.00
DWG NO.: EQ-1-03
DATE: 08/03/12

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-03

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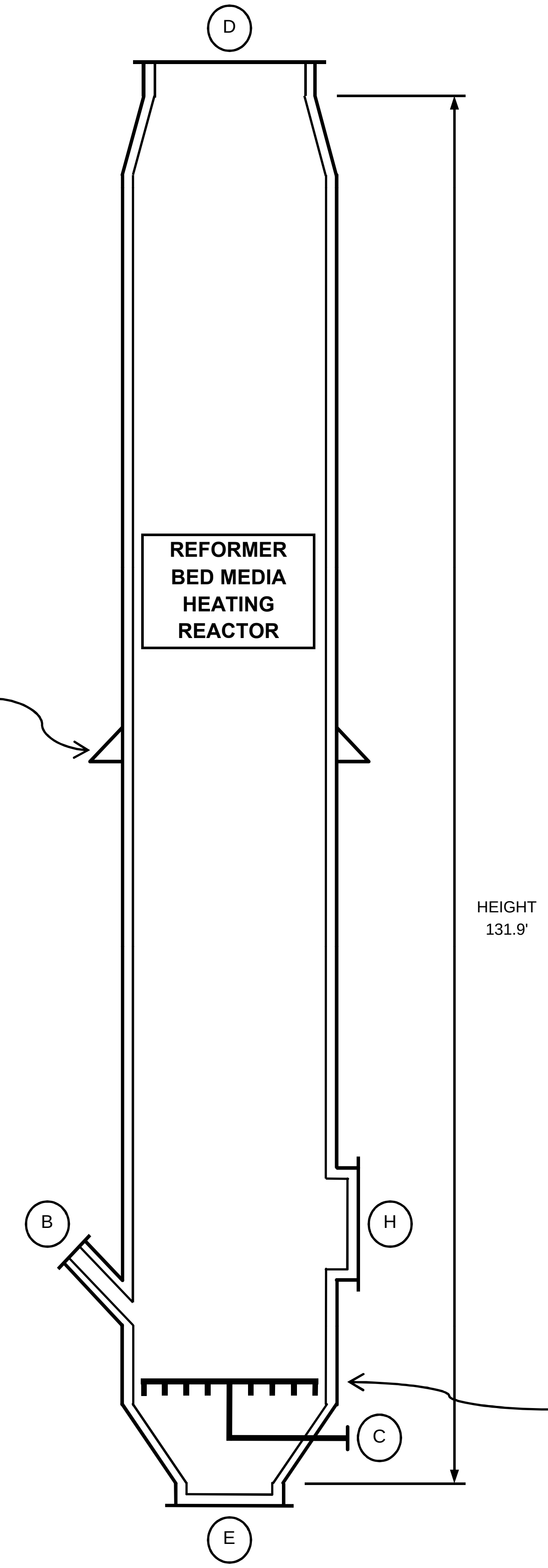
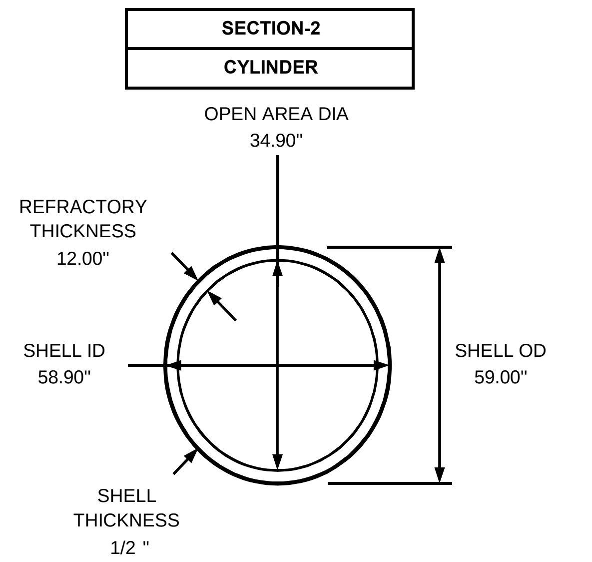
SECTION - 3	
CONE TOP	
HEIGHT -	3.4'
OD -	4.9' X 6.7'
SURFACE AREA	65 SQFT
WEIGHT -	1,318 LBS
OPEN VOLUME -	39 CUFT

SECTION-2	
CYLINDER	
HEIGHT -	125.0'
OD -	4.9'
SURFACE AREA	1,931 SQFT
WEIGHT -	39,388 LBS
OPEN VOLUME -	830 CUFT

SECTION-1	
CONE BOTTOM	
HEIGHT -	3.4'
OD -	3.7' X 4.9'
SURFACE AREA	47 SQFT
WEIGHT -	962 LBS
OPEN VOLUME -	19 CUFT





DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	11.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	20.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,750.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	2,000.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	2,043 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	269,725 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
NATURAL GAS / AIR BURNER INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A								
B	30"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	420 LBS	
C	42"	INLET - AIR	1	150#		2"	918 LBS	
D	52"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	2"	1,436 LBS	
E	44"	DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,019 LBS	2,717 LBS
F	1.5"	THERMOCOUPLE	8	150#	WATER COOLED	3"	5 LBS	
G	1.5"	PRESSURE TRANSMITTER	8	150#	WATER COOLED	3"	5 LBS	
H	48"	MANWAY	3	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
J								
K								
L								
M	0.75"	INLET - COOLING WATER	16	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	16	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

REFORMER BED MEDIA HEATING REACTOR

PROJ NO.: 30300.00

DWG NO.: EQ-1-04

DATE: 08/03/12

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-04

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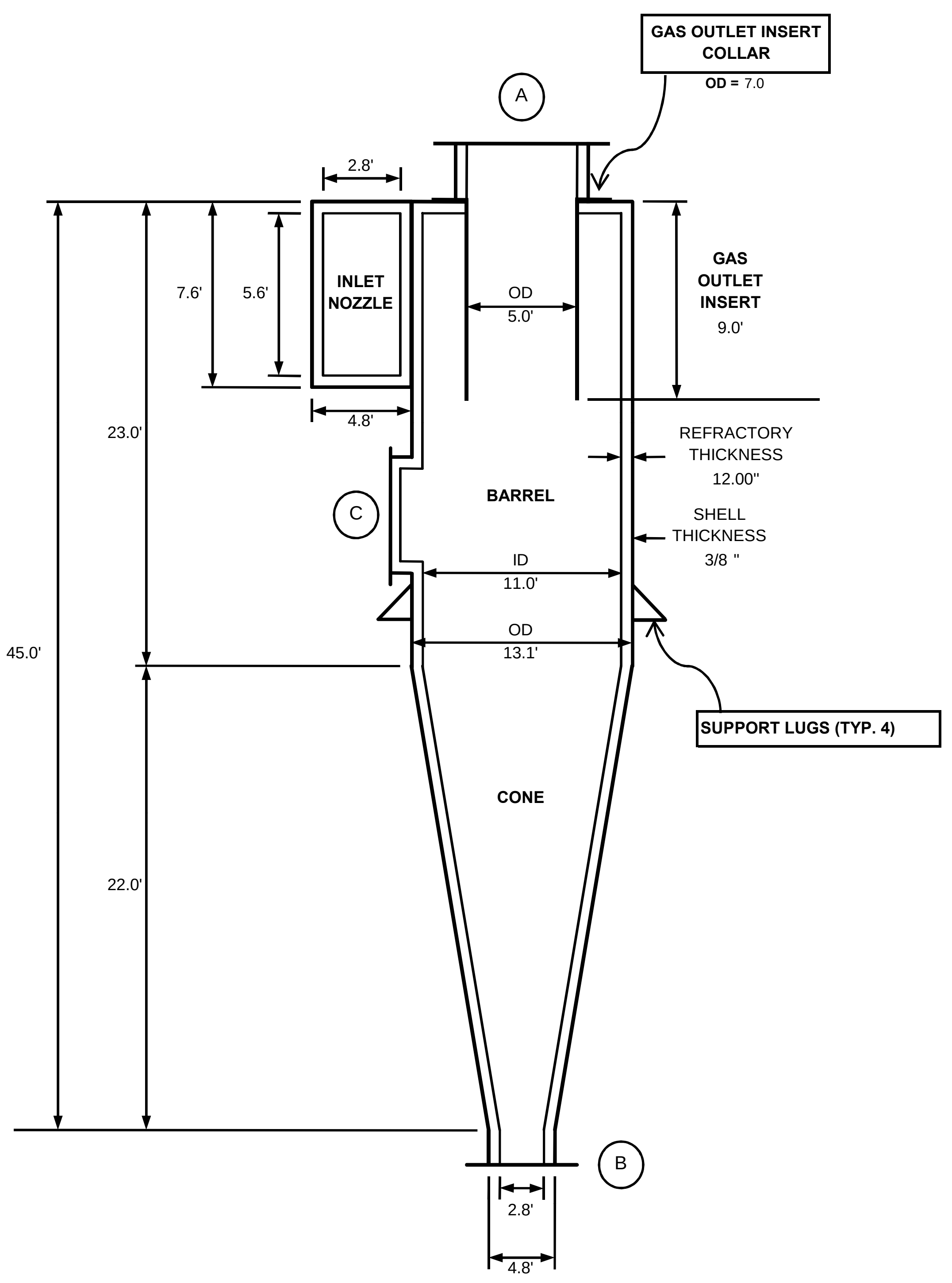
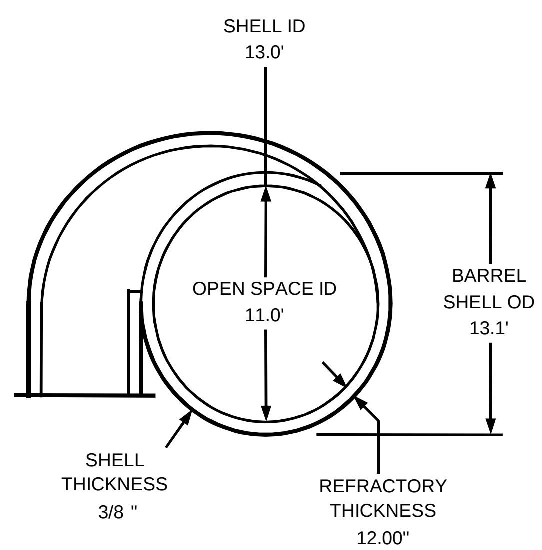


ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	24.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	40.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,547.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,800.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	1,241 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	486,741 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	78"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	4,284 LBS	
B	58"	OUTLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	1,944 LBS	5,675 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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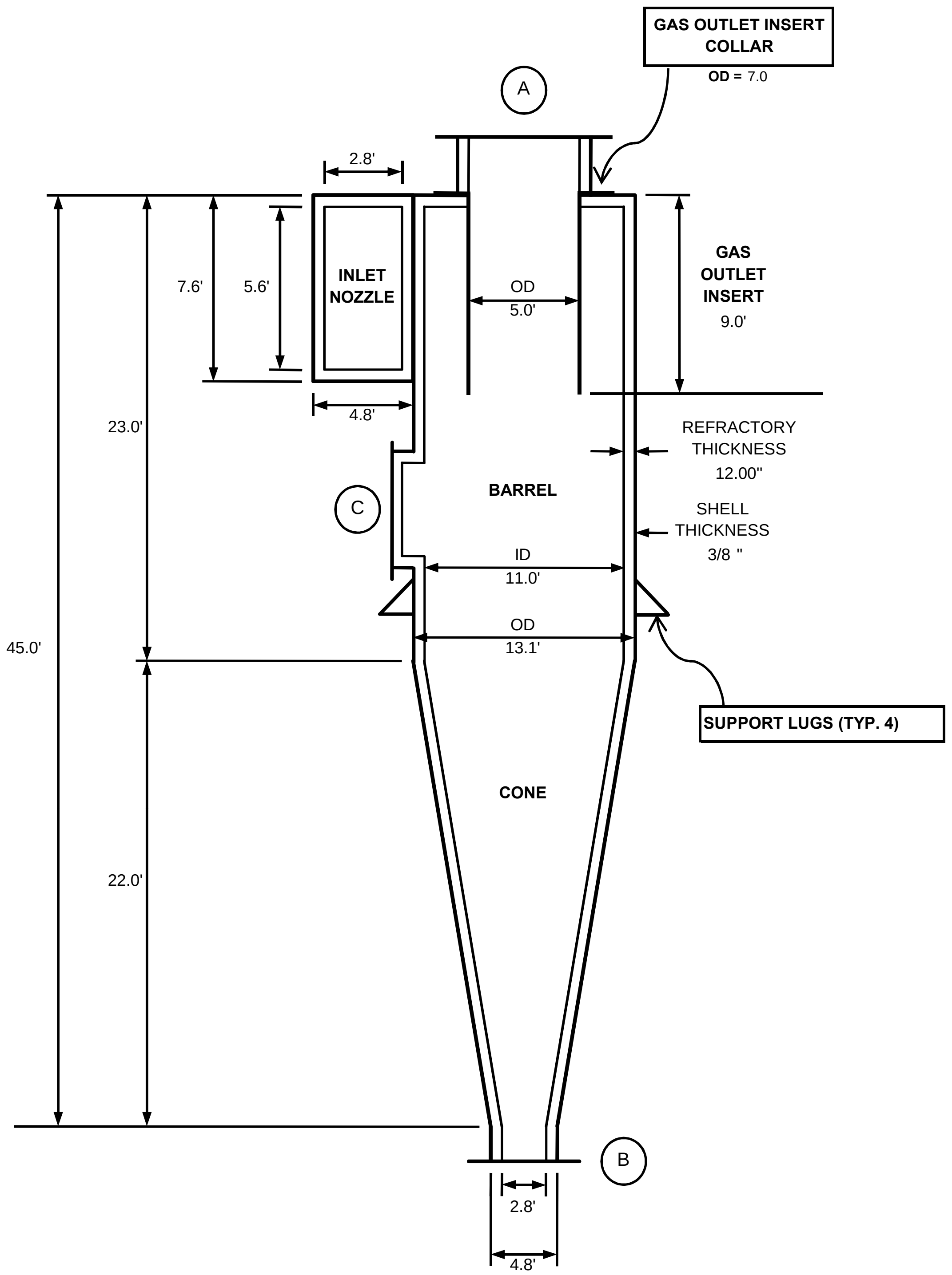
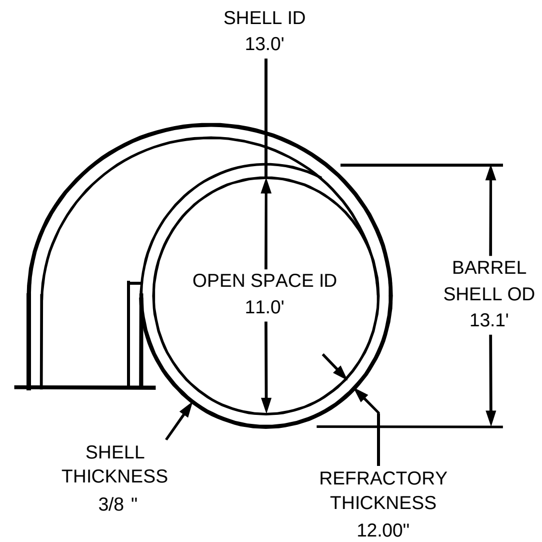
EQUIPMENT DRAWING
GASIFIER REACTOR NO.1 CYCLONE

PROJ NO.: 30300.00
DWG NO.: EQ-1-05
DATE: 08/03/12



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	23.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	40.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,537.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,800.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	1,241 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	479,285 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	80"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	4,048 LBS	
B	58"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,944 LBS	5,675 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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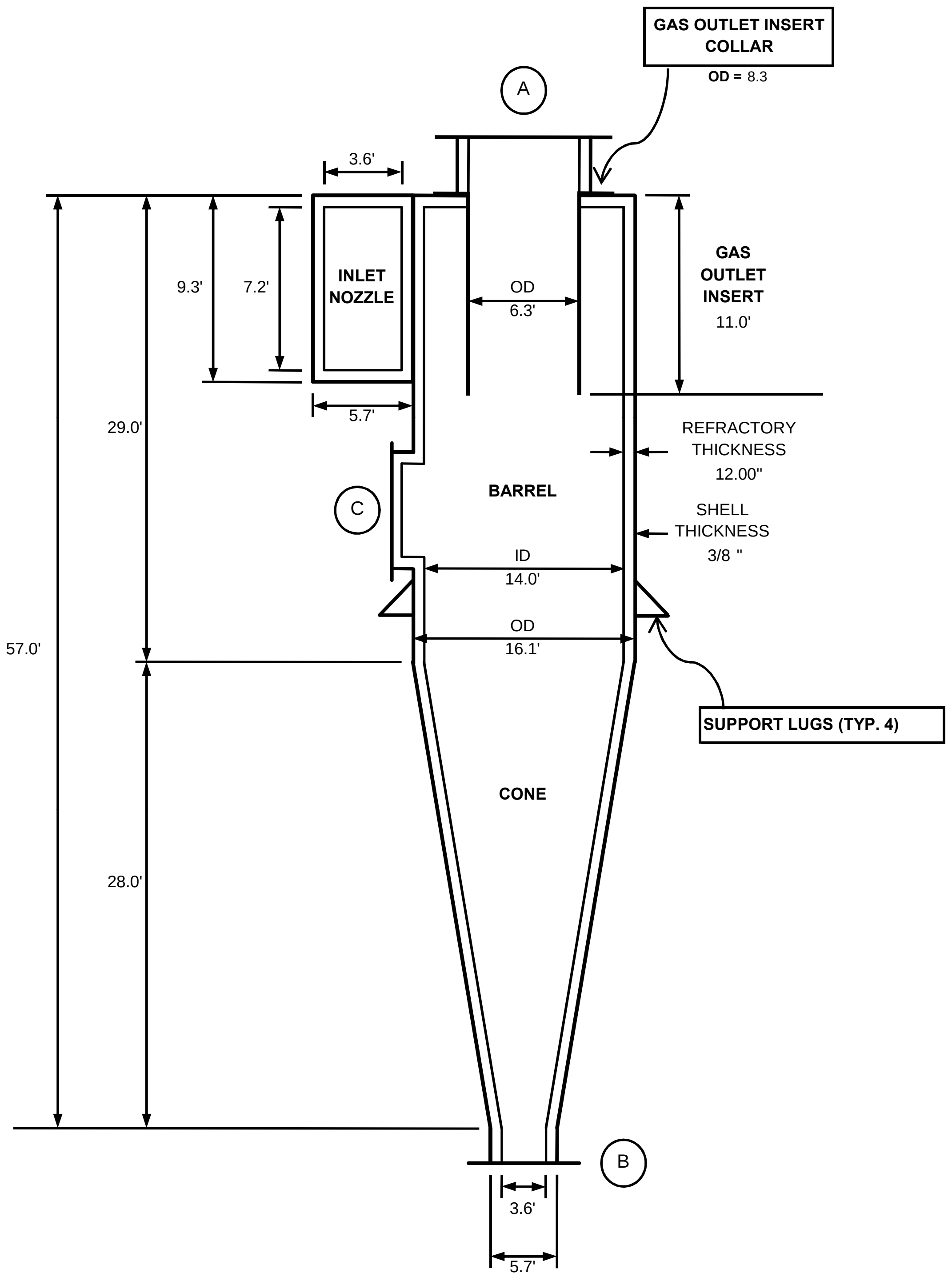
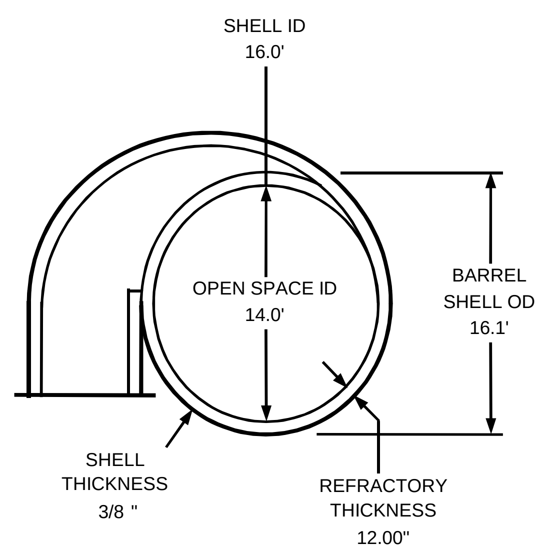
NATIONAL RENEWABLE ENERGY LABORATORY GOLDEN, COLORADO	PROJ NO.: 30300.00
EQUIPMENT DRAWING GASIFIER REACTOR NO.2 CYCLONE	DWG NO.: EQ-1-06
	DATE: 08/03/12



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	14.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	25.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,635.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	1,955 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	758,731 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	92"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	5,582 LBS	
B	68"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

CHAR COMBUSTION REACTOR NO.1 CYCLONE

PROJ NO.: 30300.00

DWG NO.: EQ-1-07

DATE: 08/03/12

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-07

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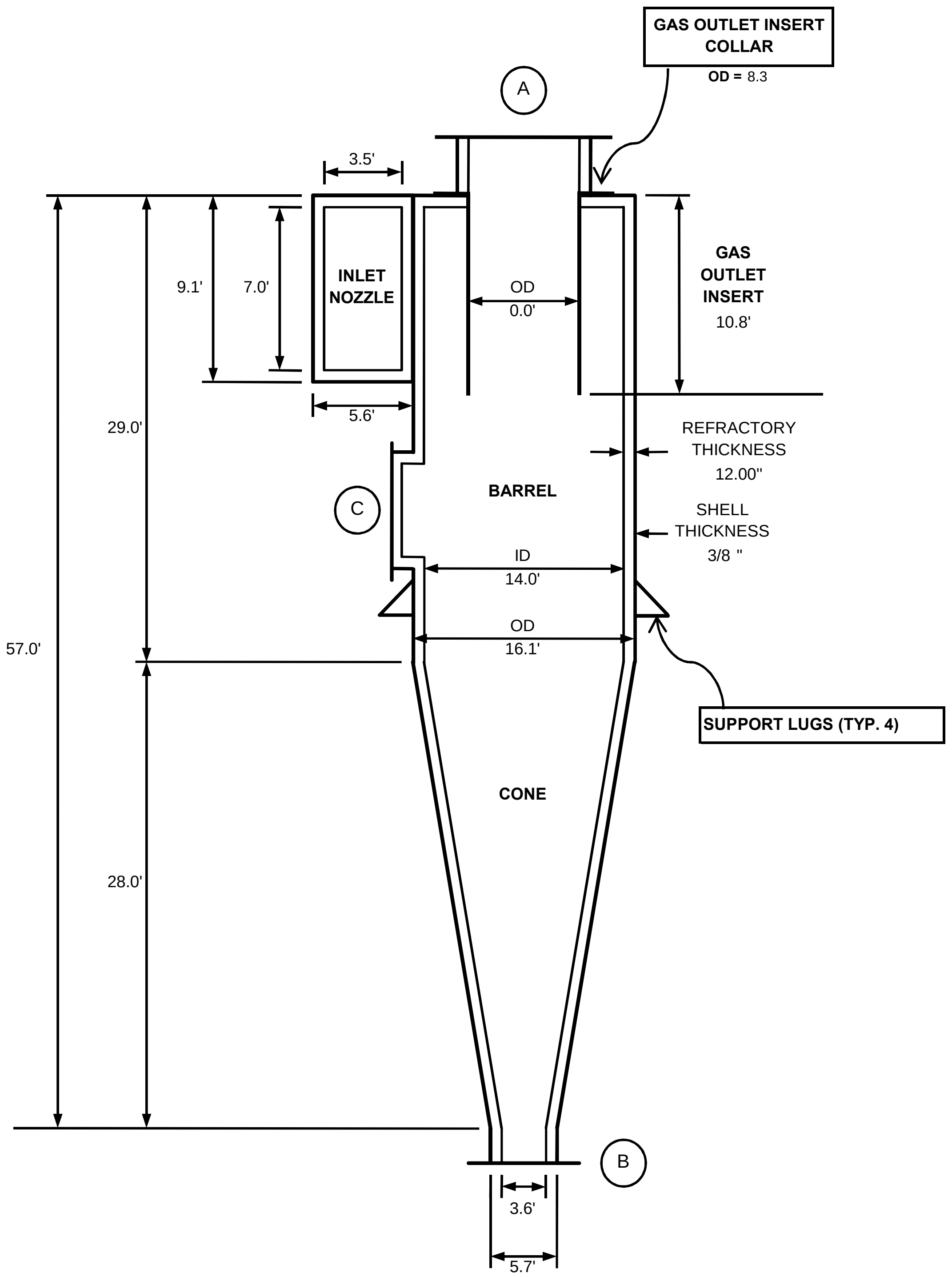

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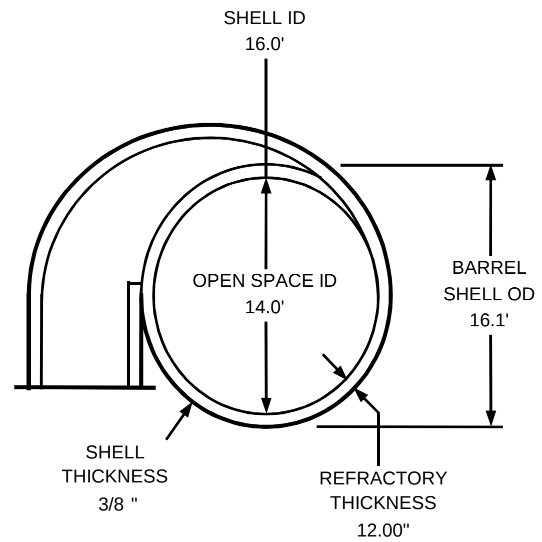

SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	13.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	25.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,625.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	1,942 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	752,354 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	94"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	5,863 LBS	
B	68"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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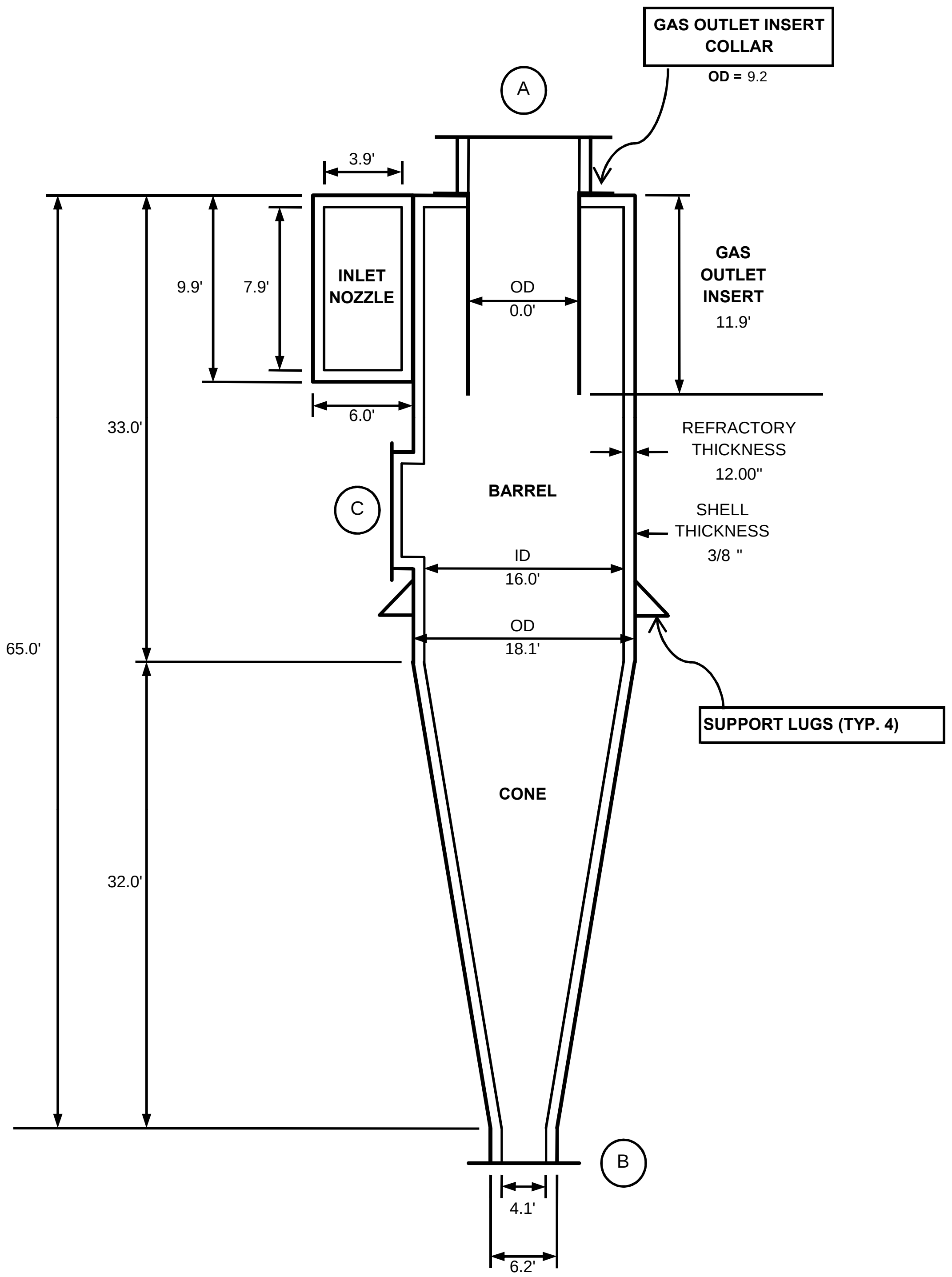
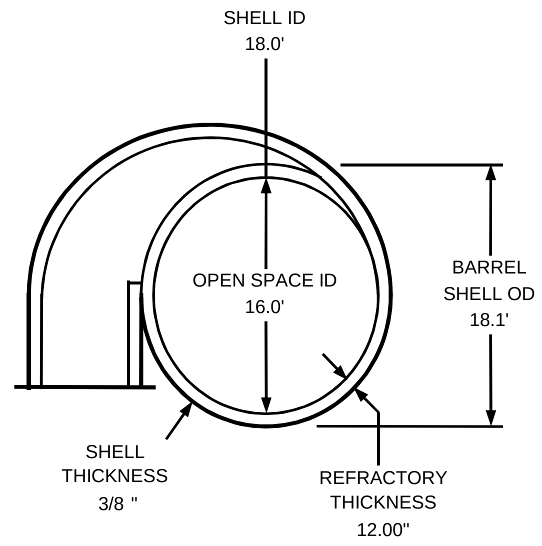
GOLDEN, COLORADO
EQUIPMENT DRAWING
CHAR COMBUSTION REACTOR NO.2 CYCLONE

PROJ NO.: **30300.00**
DWG NO.: **EQ-1-08**
DATE: **08/03/12**

12.0"



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	20.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	30.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,637.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	2,494 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	966,290 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	100"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	6,747 LBS	
B	74"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	1"	3,377 LBS	10,513 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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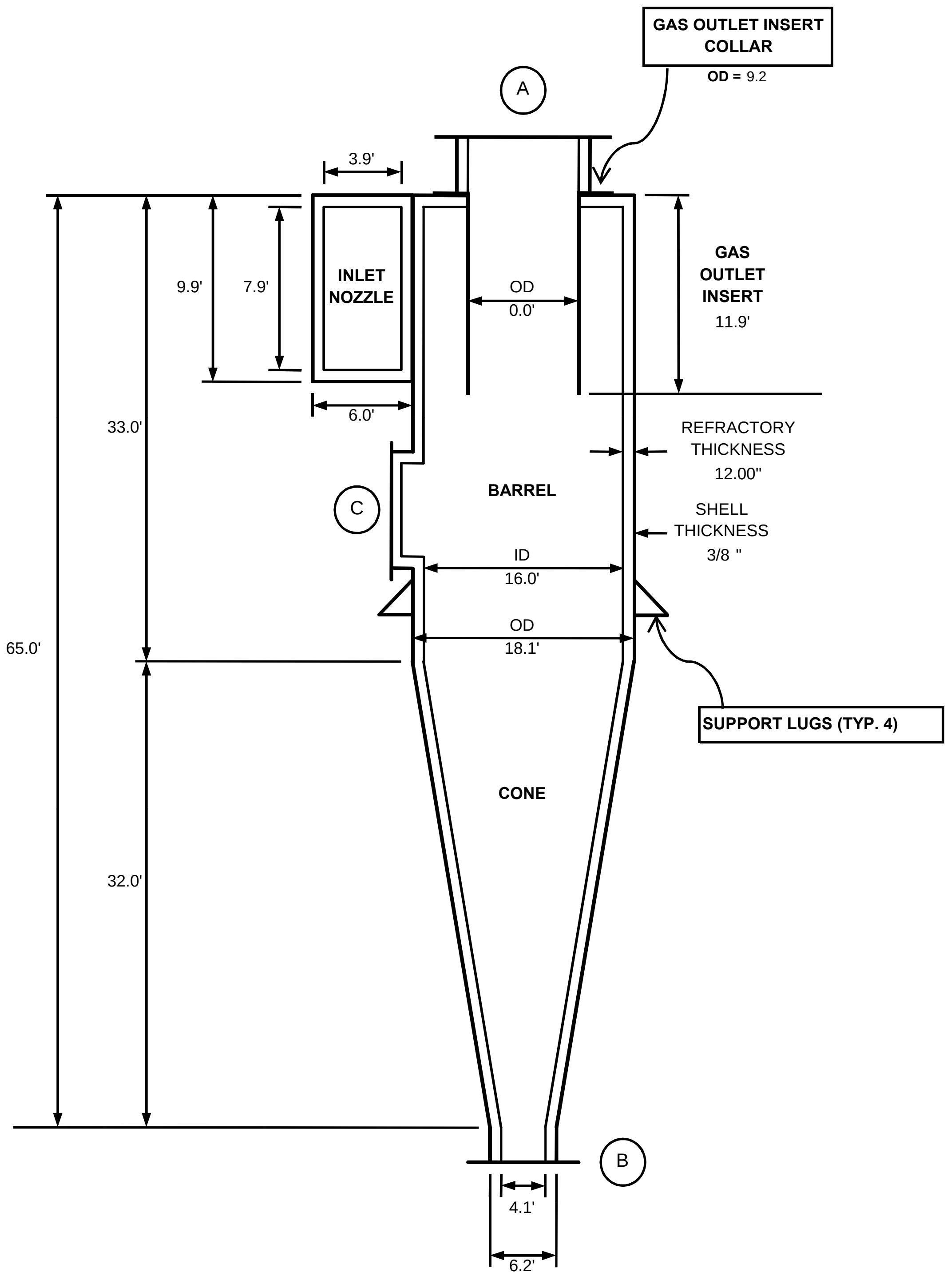
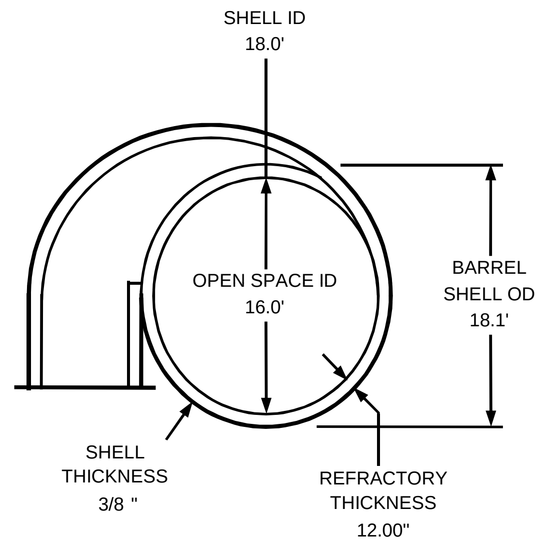
GOLDEN, COLORADO
EQUIPMENT DRAWING
SYNGAS REFORMER REACTOR NO.1 CYCLONE

PROJ NO.: 30300.00
DWG NO.: EQ-1-09
DATE: 08/03/12



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	19.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	30.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,627.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	2,494 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	966,290 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	100"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	1"	6,747 LBS	
B	74"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	1"	3,377 LBS	10,513 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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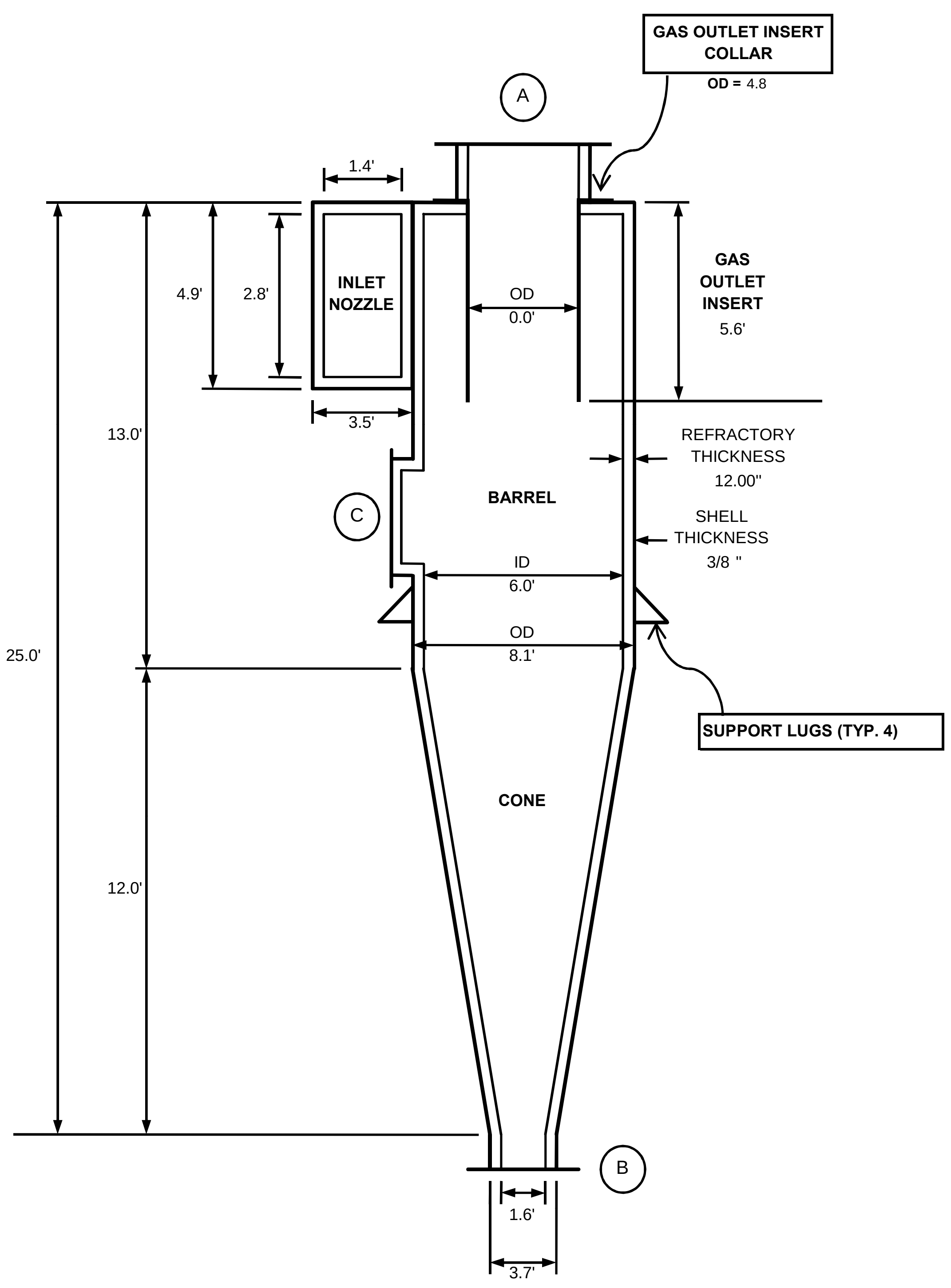
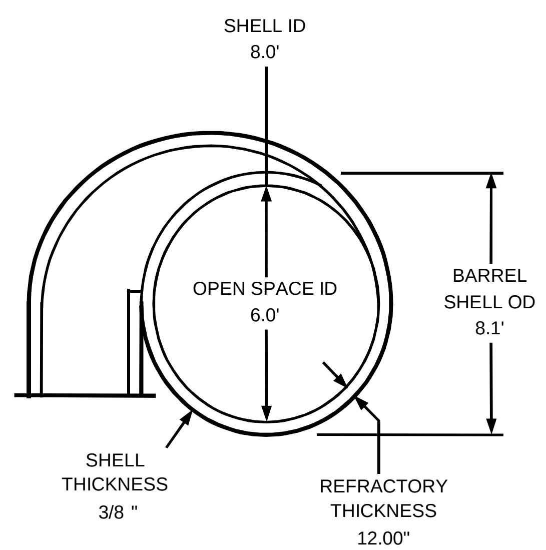
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
EQUIPMENT DRAWING
SYNGAS REFORMER REACTOR NO.2 CYCLONE

PROJ NO.: **30300.00**
DWG NO.: **EQ-1-10**
DATE: **08/03/12**

12.0"



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	10.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	15.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,735.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	2,000.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	427 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	174,580 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	52"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	2"	1,436 LBS	
B	44"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,019 LBS	2,717 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE

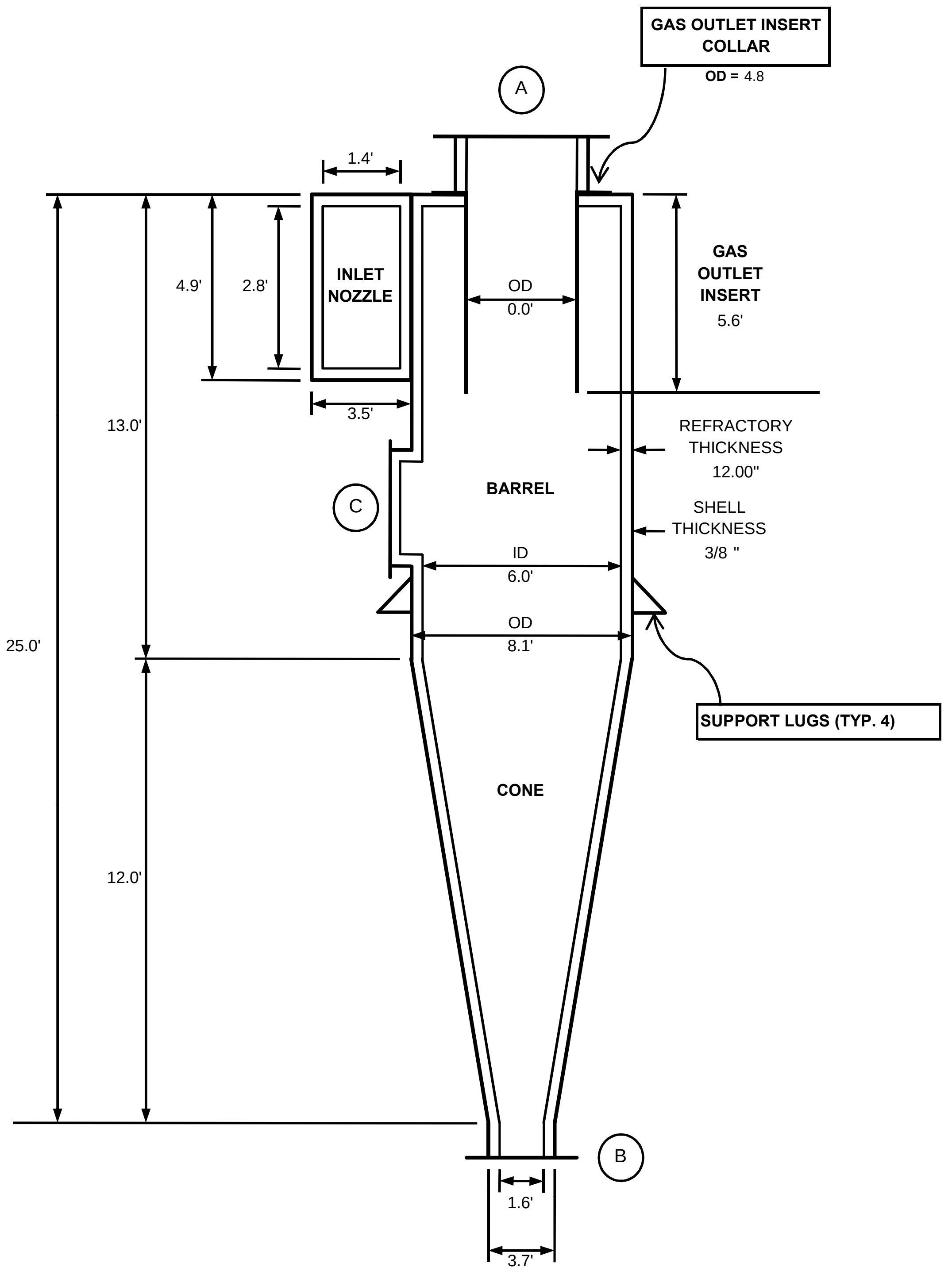
PROJ NO.: **30300.00**

DWG NO.: **EQ-1-11**

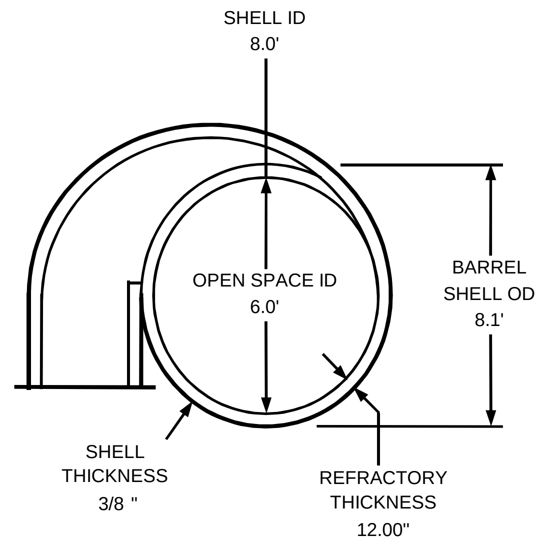
DATE: **08/03/12**

U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-11

8/3/12 9:47 AM



ELEVATION VIEW



SECTION VIEW

DESIGN DATA

VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
VESSEL - INTERNAL GAS PRESSURE - OPERATING	9.0 PSIG
VESSEL - INTERNAL GAS PRESSURE - DESIGN	15.0 PSIG
INTERNAL GAS TEMPERATURE - OPERATING	1,725.0 °F
INTERNAL GAS TEMPERATURE - DESIGN	2,000.0 °F
VESSEL - SHELL TEMPERATURE - DESIGN	240.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	12.0"
TOTAL SHELL SURFACE AREA	427 SQFT
CYCLONE - TOTAL WEIGHT (READY TO SHIP)	174,580 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	52"	OUTLET - SYNGAS	1	150#	REFRACTORY LINED	2"	1,436 LBS	
B	44"	OUTLET - DRAIN / CLEANOUT	1	150#	REFRACTORY LINED	2"	1,019 LBS	2,717 LBS
C	48"	MANWAY	1	150#	REFRACTORY LINED	2"	1,209 LBS	3,348 LBS
D	1.5"	THERMOCOUPLE	3	150#	WATER COOLED	3"	5 LBS	
E	1.5"	PRESSURE TRANSMITTER	3	150#	WATER COOLED	3"	5 LBS	
F								
G								
H								
J								
K								
L								
M	0.75"	INTLET - COOLING WATER	6	150#		3"	2 LBS	
N	0.75"	OUTLET - COOLING WATER	6	150#		3"	2 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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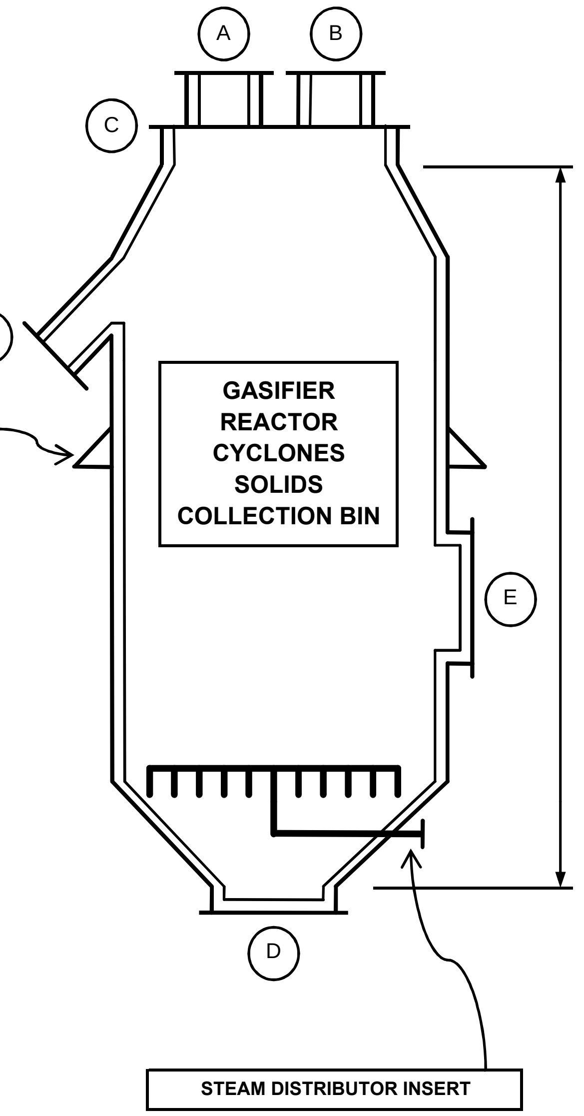
GOLDEN, COLORADO
EQUIPMENT DRAWING
REFORMER BED MEDIA HEATING REACTOR NO.2 CYCLONE

PROJ NO.: **30300.00**
DWG NO.: **EQ-1-12**
DATE: **08/03/12**

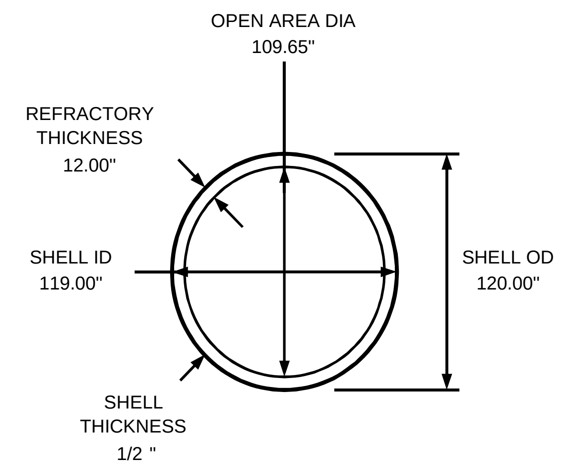
SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT



SECTION - 2	
CENTRAL SECTION	
HEIGHT -	30.0'
OD -	10.0'
SURFACE AREA	942 SQFT
WEIGHT -	19,227 LBS
OPEN VOLUME -	1,967 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT

SECTION - 2
CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	15.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	22.5 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,546.8 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,800.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	1,105 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	81,940 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	42"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	918 LBS	
B	36"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
C	68"	TANK TOP	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
D	68"	BOTTOM CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
E	50"	MANWAY	1	150#	REFRACTORY LINED	2"	1,295 LBS	3,716 LBS
F	36"	OUTLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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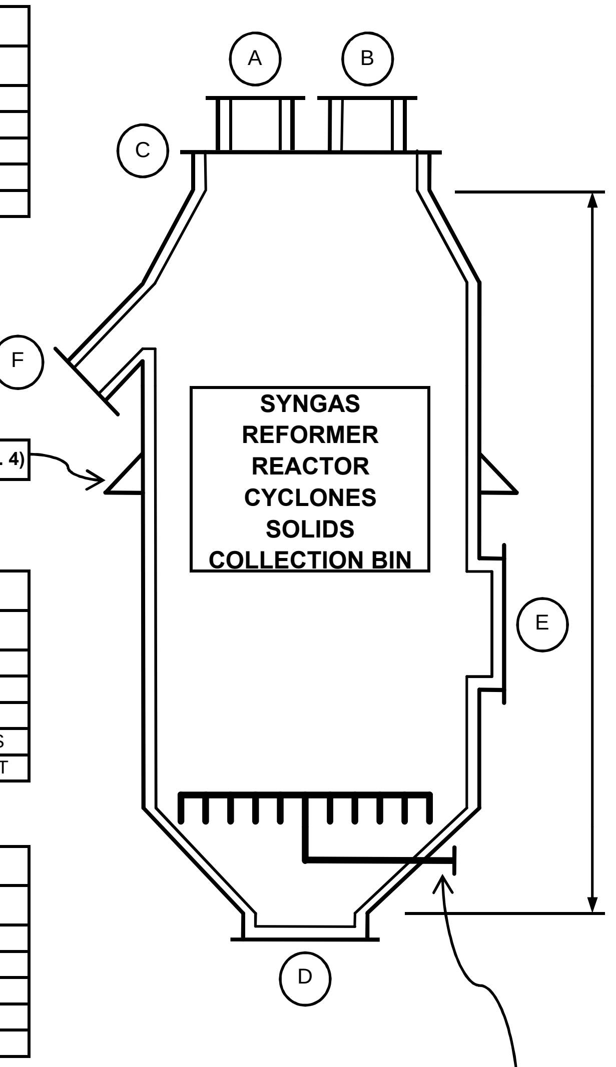
GOLDEN, COLORADO
EQUIPMENT DRAWING
GASIFIER REACTOR CYCLONES SOLIDS COLLECTION BIN

PROJ NO.: **30300.00**
DWG NO.: **EQ-1-13**
DATE: **08/03/12**

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT

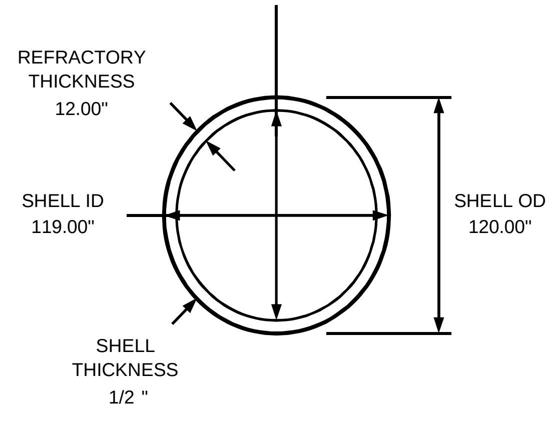
SECTION - 2	
CENTRAL SECTION	
HEIGHT -	30.0'
OD -	10.0'
SURFACE AREA	942 SQFT
WEIGHT -	19,227 LBS
OPEN VOLUME -	1,967 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT



SECTION - 2

CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	11.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	16.5 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,627.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	1,105 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	82,129 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	48"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	1,209 LBS	
B	34"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	562 LBS	
C	68"	TANK TOP	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
D	68"	BOTTOM CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
E	50"	MANWAY	1	150#	REFRACTORY LINED	2"	1,295 LBS	3,716 LBS
F	36"	OUTLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

SYNGAS REFORMER REACTOR CYCLONES SOLIDS COLLECTION BIN

PROJ NO.: 30300.00

DWG NO.: EQ-1-14

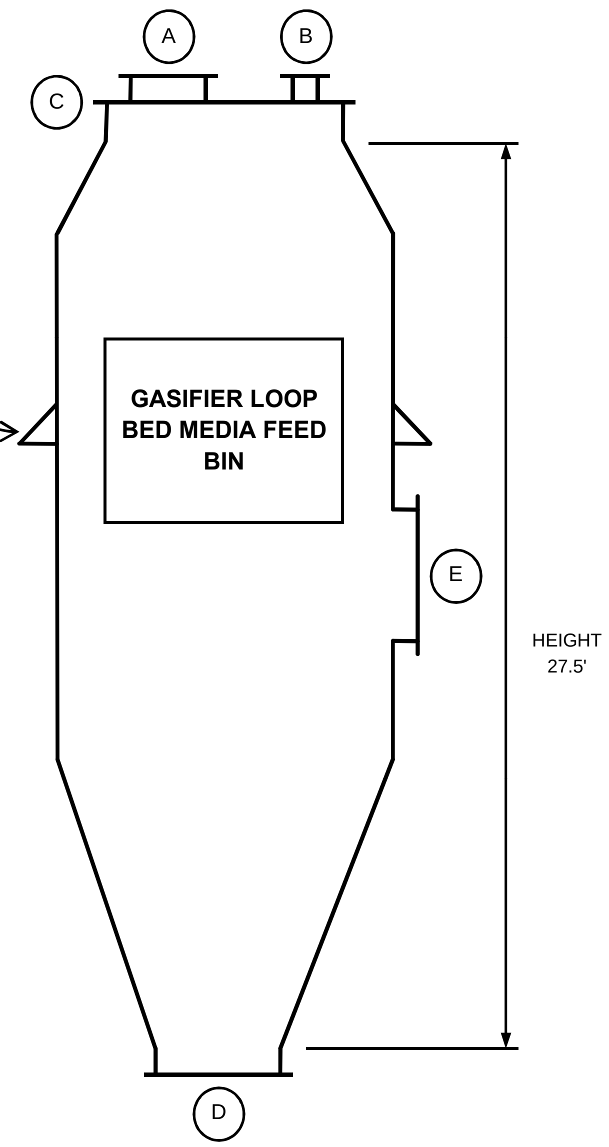
DATE: 08/03/12

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 3.3'
SURFACE AREA	87 SQFT
WEIGHT -	1,780 LBS
OPEN VOLUME -	93 CUFT

SUPPORT LUGS (TYP. 4)

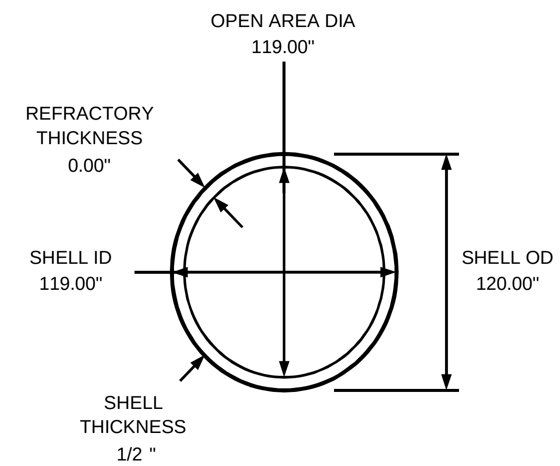
SECTION - 2	
CENTRAL SECTION	
HEIGHT -	20.0'
OD -	10.0'
SURFACE AREA	628 SQFT
WEIGHT -	12,818 LBS
OPEN VOLUME -	1,545 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	5.0'
OD -	10' X 1.5'
SURFACE AREA	119 SQFT
WEIGHT -	2,418 LBS
OPEN VOLUME -	150 CUFT



SECTION - 2

CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	80.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	100.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	100.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (0.0") AND GUNNED ABRASION LAYER (0.0")
TOTAL SHELL SURFACE AREA	834 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	22,046 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	10"	INLET - BED MEDIA	1	150#		3"	62 LBS	
B	10"	VENT	1	150#		3"	62 LBS	
C	40"	TANK TOP	1	150#		2"	801 LBS	2,040 LBS
D	18"	OUTLET - BED MEDIA	1	150#		3"	180 LBS	220 LBS
E	36"	MANWAY	1	150#		2"	664 LBS	
F								
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

GASIFIER LOOP BED MEDIA FEED BIN

PROJ NO.: 30300.00

DWG NO.: EQ-1-15

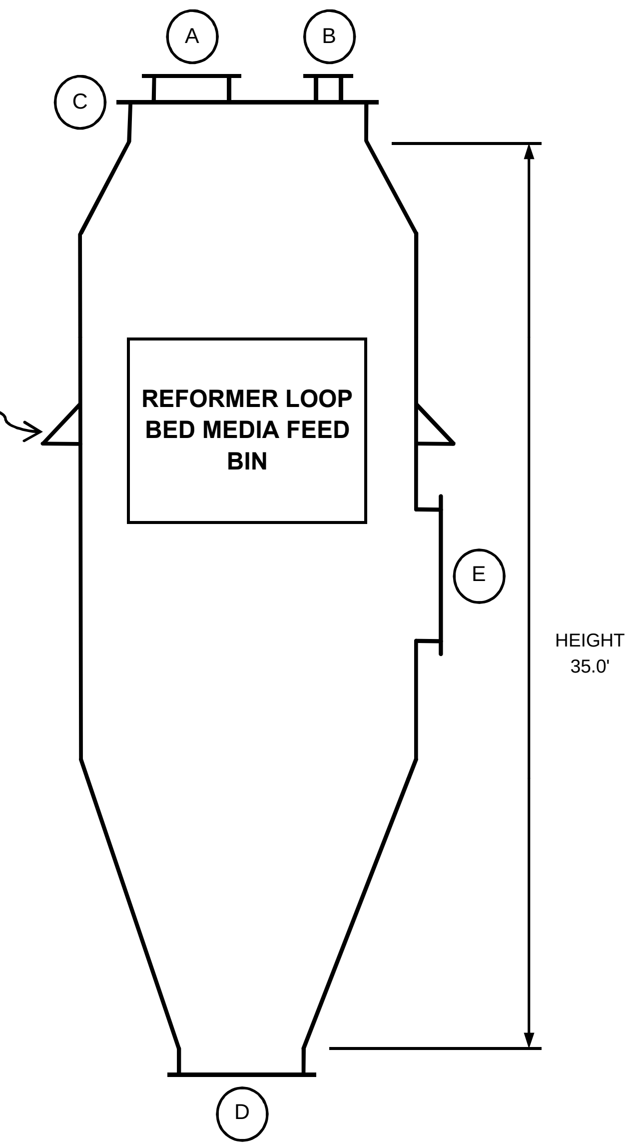
DATE: 08/03/12

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 3.3'
SURFACE AREA	87 SQFT
WEIGHT -	1,780 LBS
OPEN VOLUME -	93 CUFT

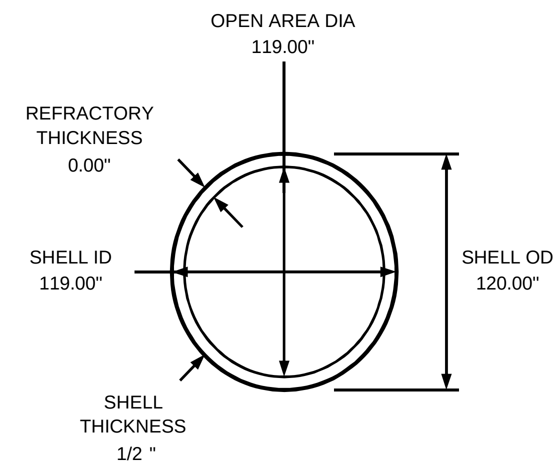
SECTION - 2	
CENTRAL SECTION	
HEIGHT -	20.0'
OD -	10.0'
SURFACE AREA	628 SQFT
WEIGHT -	12,818 LBS
OPEN VOLUME -	1,545 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	5.0'
OD -	10' X 1.5'
SURFACE AREA	119 SQFT
WEIGHT -	2,418 LBS
OPEN VOLUME -	150 CUFT

SUPPORT LUGS (TYP. 4)



SECTION - 2
CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	80.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	100.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	100.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (0.0") AND GUNNED ABRASION LAYER (0.0")
TOTAL SHELL SURFACE AREA	834 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	22,046 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - 0.546, SEAMLESS PIPE
	EXTENSION: 26"-96" - 25.25, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	10"	INLET - BED MEDIA	1	150#		3"	62 LBS	
B	10"	VENT	1	150#		3"	62 LBS	
C	40"	TANK TOP	1	150#		2"	801 LBS	2,040 LBS
D	18"	MANWAY	1	150#		3"	180 LBS	220 LBS
E	36"	MANWAY	1	150#		2"	664 LBS	
F								
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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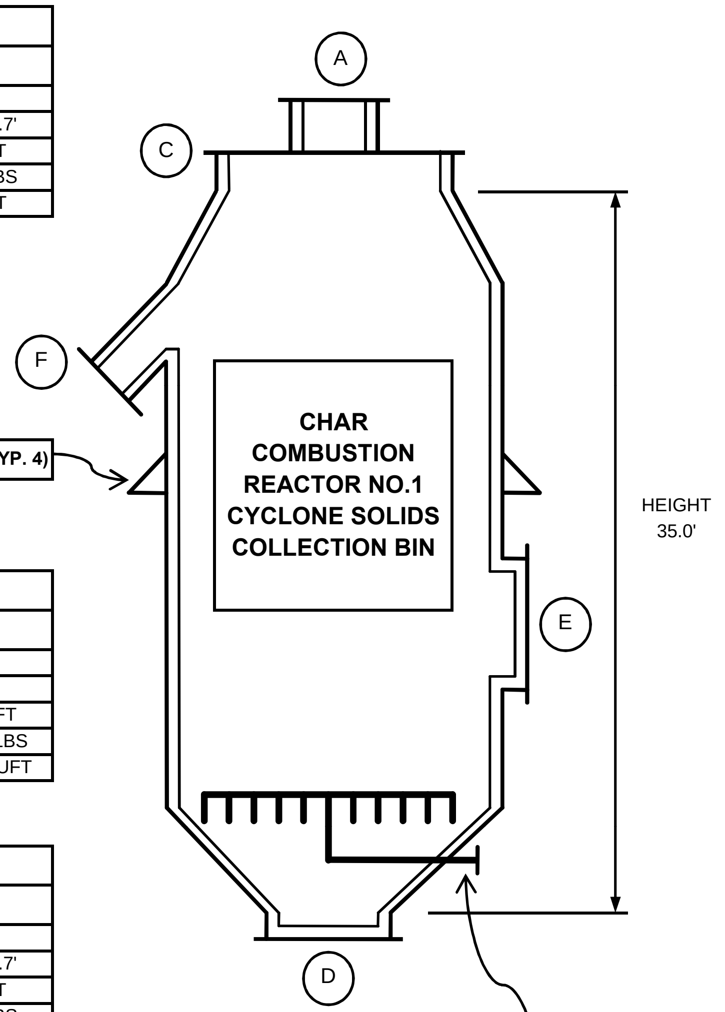
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
EQUIPMENT DRAWING
REFORMER LOOP BED MEDIA FEED BIN

PROJ NO.: **30300.00**
DWG NO.: **EQ-1-16**
DATE: **08/03/12**

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT



SUPPORT LUGS (TYP. 4)

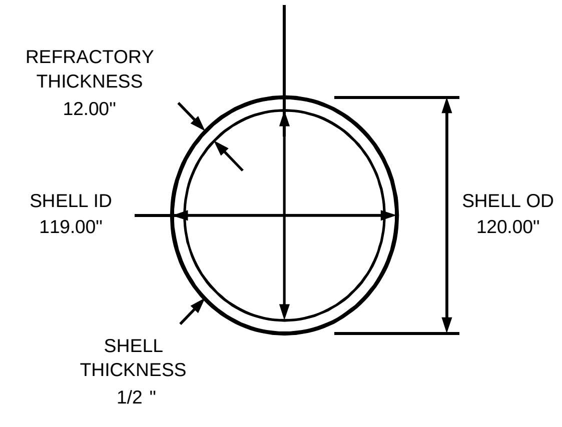
STEAM DISTRIBUTOR INSERT

SECTION - 2	
CENTRAL SECTION	
HEIGHT -	30.0'
OD -	10.0'
SURFACE AREA	942 SQFT
WEIGHT -	19,227 LBS
OPEN VOLUME -	1,967 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT

SECTION - 2

CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	25.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	37.5 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,635.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	1,900.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	1,105 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	81,022 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	36"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
B								
C	68"	TANK TOP	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
D	68"	BOTTOM CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
E	50"	MANWAY	1	150#	REFRACTORY LINED	2"	1,295 LBS	3,716 LBS
F	36"	OUTLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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NATIONAL RENEWABLE ENERGY LABORATORY

GOLDEN, COLORADO

EQUIPMENT DRAWING

CHAR COMBUSTION REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN

PROJ NO.: **30300.00**

DWG NO.: **EQ-1-17**

DATE: **08/03/12**

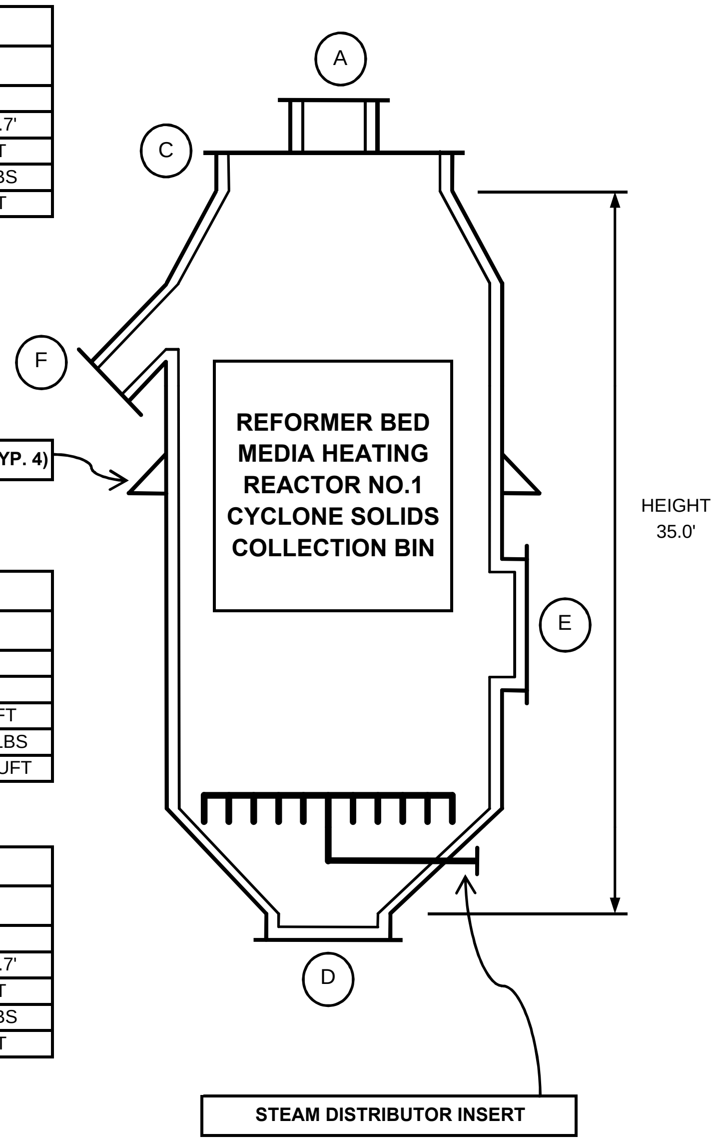
U:\30251.00\4200 Process\4215 Design Data\01 - HGI Files\Workbooks\CFB Gasifier Model\[2012-08-03 - CFB Gasifier Model.xlsx]EQ-1-17

8/3/12 9:47 AM

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT

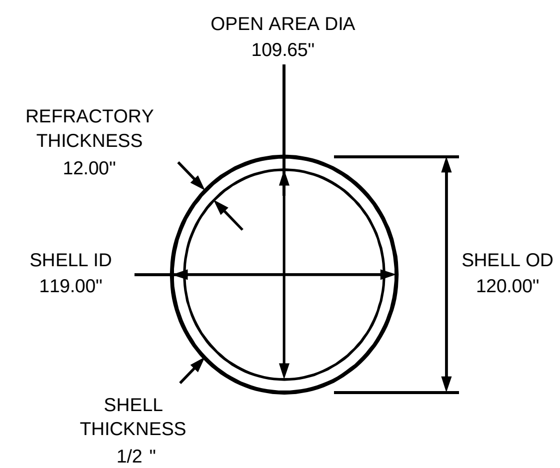
SECTION - 2	
CENTRAL SECTION	
HEIGHT -	30.0'
OD -	10.0'
SURFACE AREA	942 SQFT
WEIGHT -	19,227 LBS
OPEN VOLUME -	1,967 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	2.5'
OD -	10' X 5.7'
SURFACE AREA	81 SQFT
WEIGHT -	1,661 LBS
OPEN VOLUME -	99 CUFT



SECTION - 2

CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	21.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	31.5 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	1,735.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	2,000.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	300.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (4.7") AND GUNNED ABRASION LAYER (7.3")
TOTAL SHELL SURFACE AREA	1,105 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	81,276 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY LINING	HARBISON-WALKER REFRACTORIES
STEAM DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	42"	INLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	918 LBS	
B								
C	68"	TANK TOP	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
D	68"	BOTTOM CLEANOUT	1	150#	REFRACTORY LINED	1"	2,771 LBS	8,483 LBS
E	50"	MANWAY	1	150#	REFRACTORY LINED	2"	1,295 LBS	3,716 LBS
F	36"	OUTLET - BED MEDIA	1	150#	REFRACTORY LINED	2"	664 LBS	
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

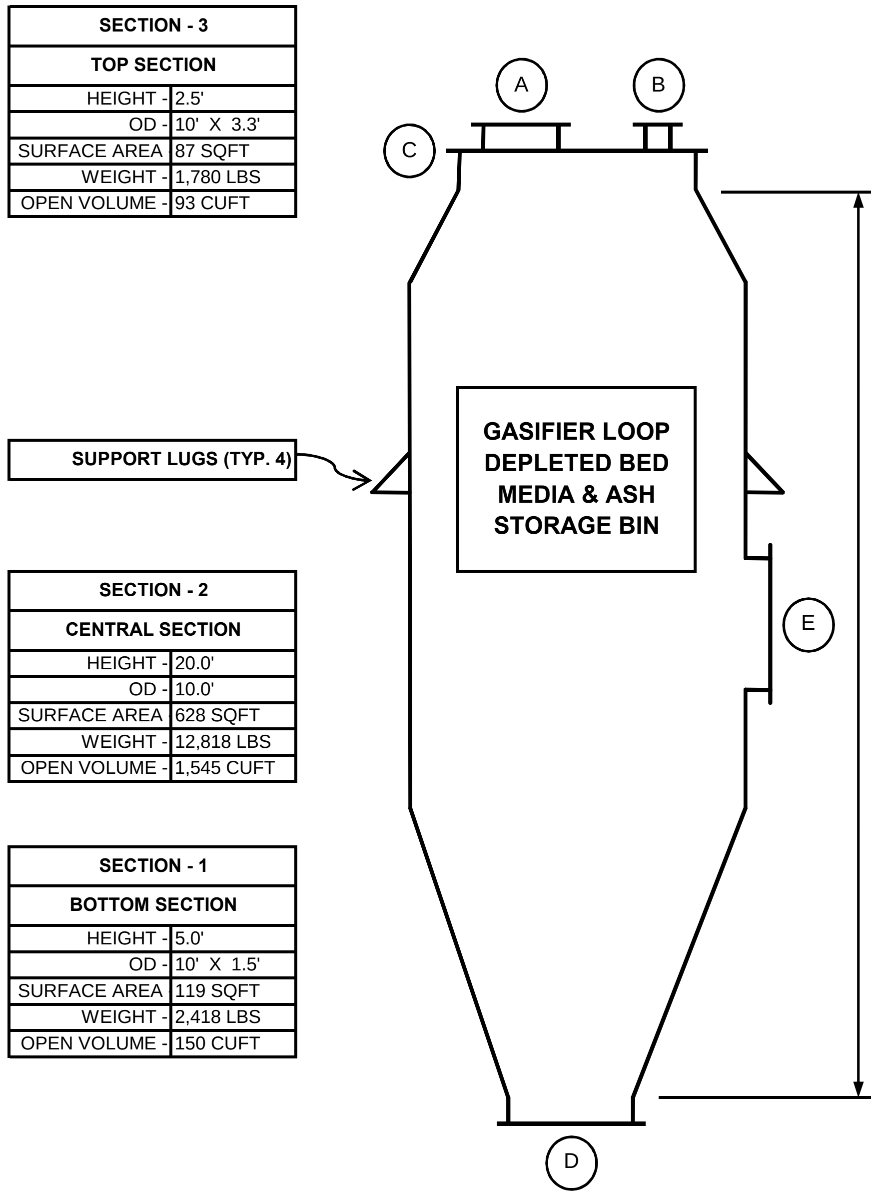
EQUIPMENT DRAWING

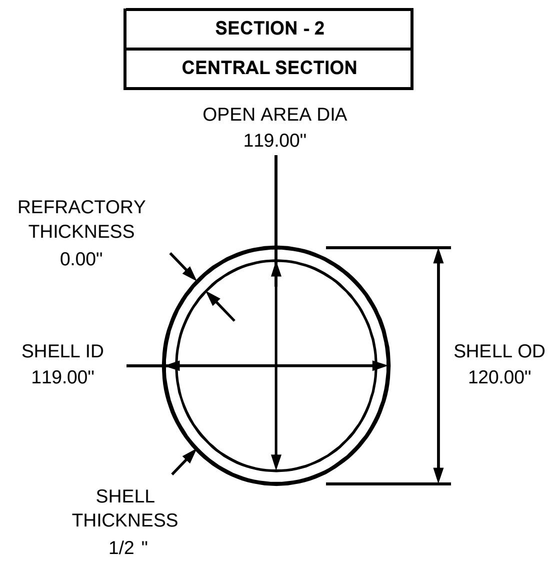
REFORMER BED MEDIA HEATING REACTOR NO.1 CYCLONE SOLIDS COLLECTION BIN

PROJ NO.: **30300.00**

DWG NO.: **EQ-1-18**

DATE: **08/03/12**





DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	190.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	200.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	200.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (0.0") AND GUNNED ABRASION LAYER (0.0")
TOTAL SHELL SURFACE AREA	834 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	22,046 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - 1.09, SEAMLESS PIPE
	EXTENSION: 26"-96" - 102.72, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	10"	INLET - BED MEDIA	1	150#		3"	62 LBS	
B	10"	VENT	1	150#		3"	62 LBS	
C	40"	TANK TOP	1	150#		2"	801 LBS	2,040 LBS
D	18"	OUTLET - BED MEDIA	1	150#		3"	180 LBS	220 LBS
E	36"	MANWAY	1	150#		2"	664 LBS	
F								
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO
EQUIPMENT DRAWING
GASIFIER LOOP DEPLETED BED MEDIA & ASH STORAGE BIN

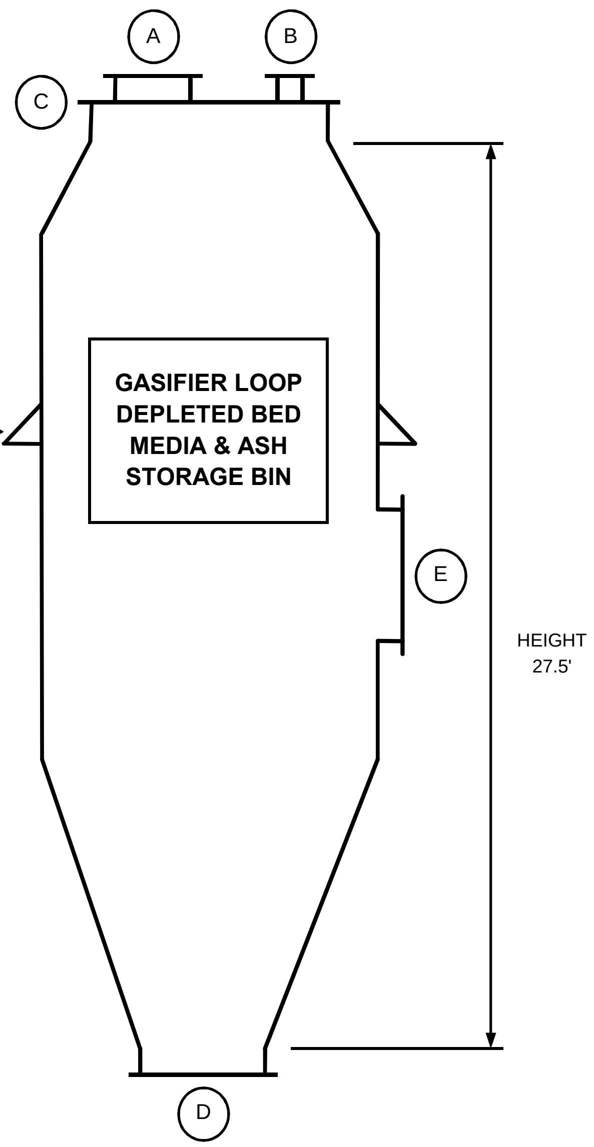
PROJ NO.: **30300.00**
DWG NO.: **EQ-1-19**
DATE: **08/03/12**

SECTION - 3	
TOP SECTION	
HEIGHT -	2.5'
OD -	10' X 3.3'
SURFACE AREA	87 SQFT
WEIGHT -	1,780 LBS
OPEN VOLUME -	93 CUFT

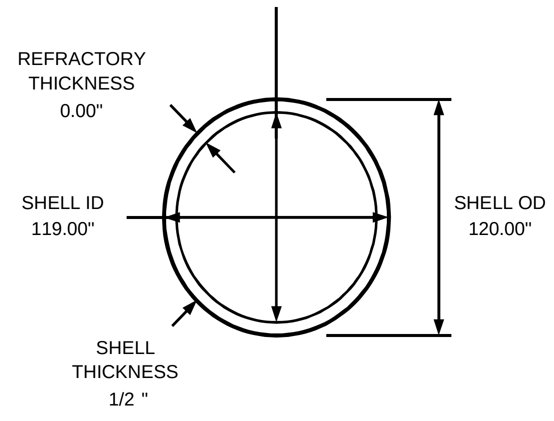
SUPPORT LUGS (TYP. 4)

SECTION - 2	
CENTRAL SECTION	
HEIGHT -	20.0'
OD -	10.0'
SURFACE AREA	628 SQFT
WEIGHT -	12,818 LBS
OPEN VOLUME -	1,545 CUFT

SECTION - 1	
BOTTOM SECTION	
HEIGHT -	5.0'
OD -	10' X 1.5'
SURFACE AREA	119 SQFT
WEIGHT -	2,418 LBS
OPEN VOLUME -	150 CUFT



SECTION - 2
CENTRAL SECTION



DESIGN DATA

GASIFIER VESSEL - CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
GASIFIER VESSEL - INTERNAL GAS PRESSURE - OPERATING	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS PRESSURE - DESIGN	0.0 PSIG
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - OPERATING	190.0 °F
GASIFIER VESSEL - INTERNAL GAS TEMPERATURE - DESIGN	200.0 °F
GASIFIER VESSEL - SHELL TEMPERATURE - DESIGN	200.0 °F
CORROSION ALLOWANCE	0.125"
REFRACTORY LINING	GUNNED INSULATING LAYER (0.0") AND GUNNED ABRASION LAYER (0.0")
TOTAL SHELL SURFACE AREA	834 SQFT
TOTAL VESSEL WEIGHT (INCL. REFRACTORY, NOZZLES, LUGS, ETC.)	22,046 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" - 3, SEAMLESS PIPE
	EXTENSION: 26"-96" - 2.5, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
A	10"	INLET - BED MEDIA	1	150#		3"	62 LBS	
B	10"	VENT	1	150#		3"	62 LBS	
C	40"	TANK TOP	1	150#		2"	801 LBS	2,040 LBS
D	18"	OUTLET - BED MEDIA	1	150#		3"	180 LBS	220 LBS
E	36"	MANWAY	1	150#		2"	664 LBS	
F								
G								
H								
J								
K								
L								
M								
N								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

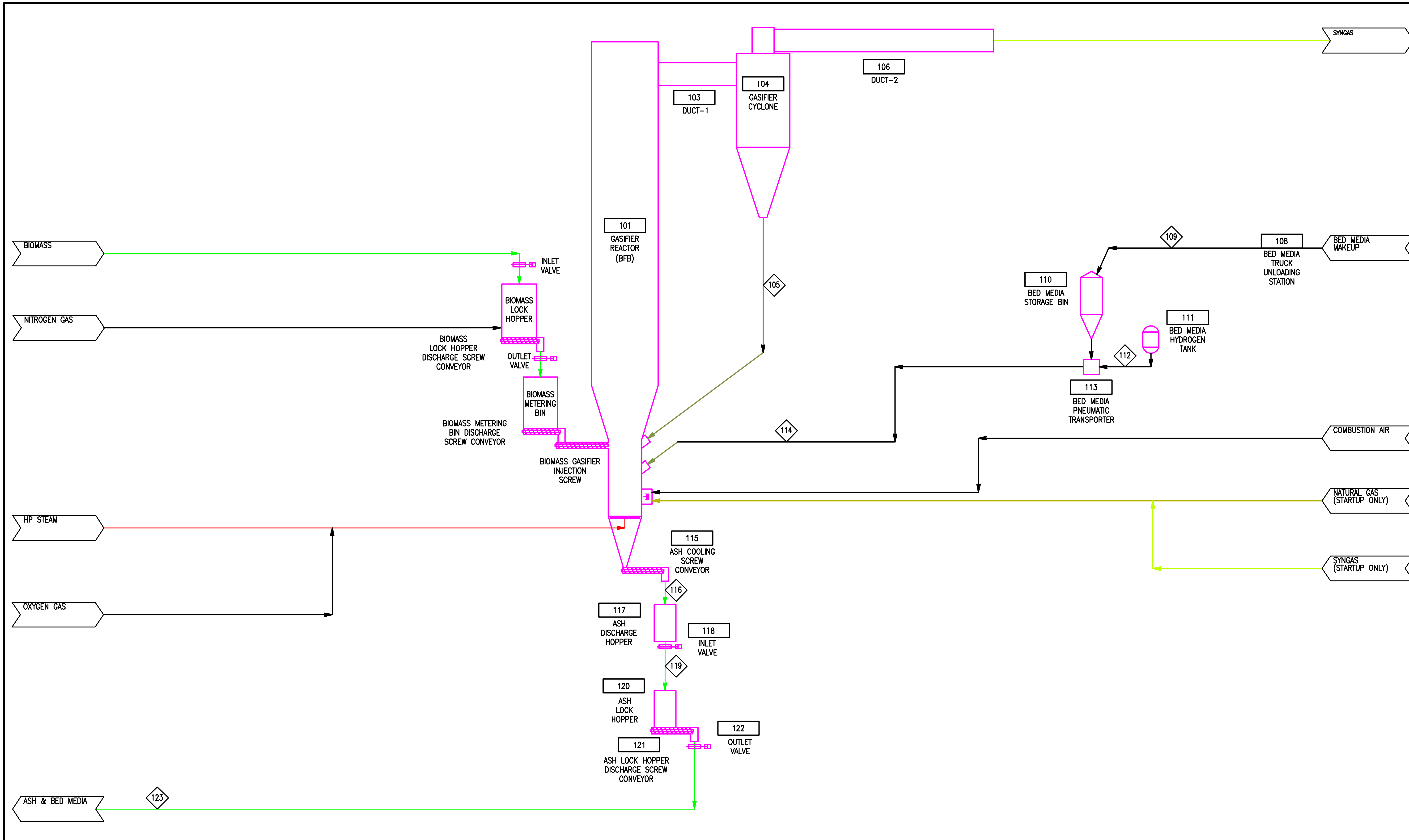
REFORMER LOOP DEPLETED BED MEDIA STORAGE BIN

PROJ NO.: **30300.00**

DWG NO.: **EQ-1-20**

DATE: **08/03/12**

APPENDIX G-2
DETAILED ESTIMATE
DRAWINGS
BFB GASIFIER MODEL



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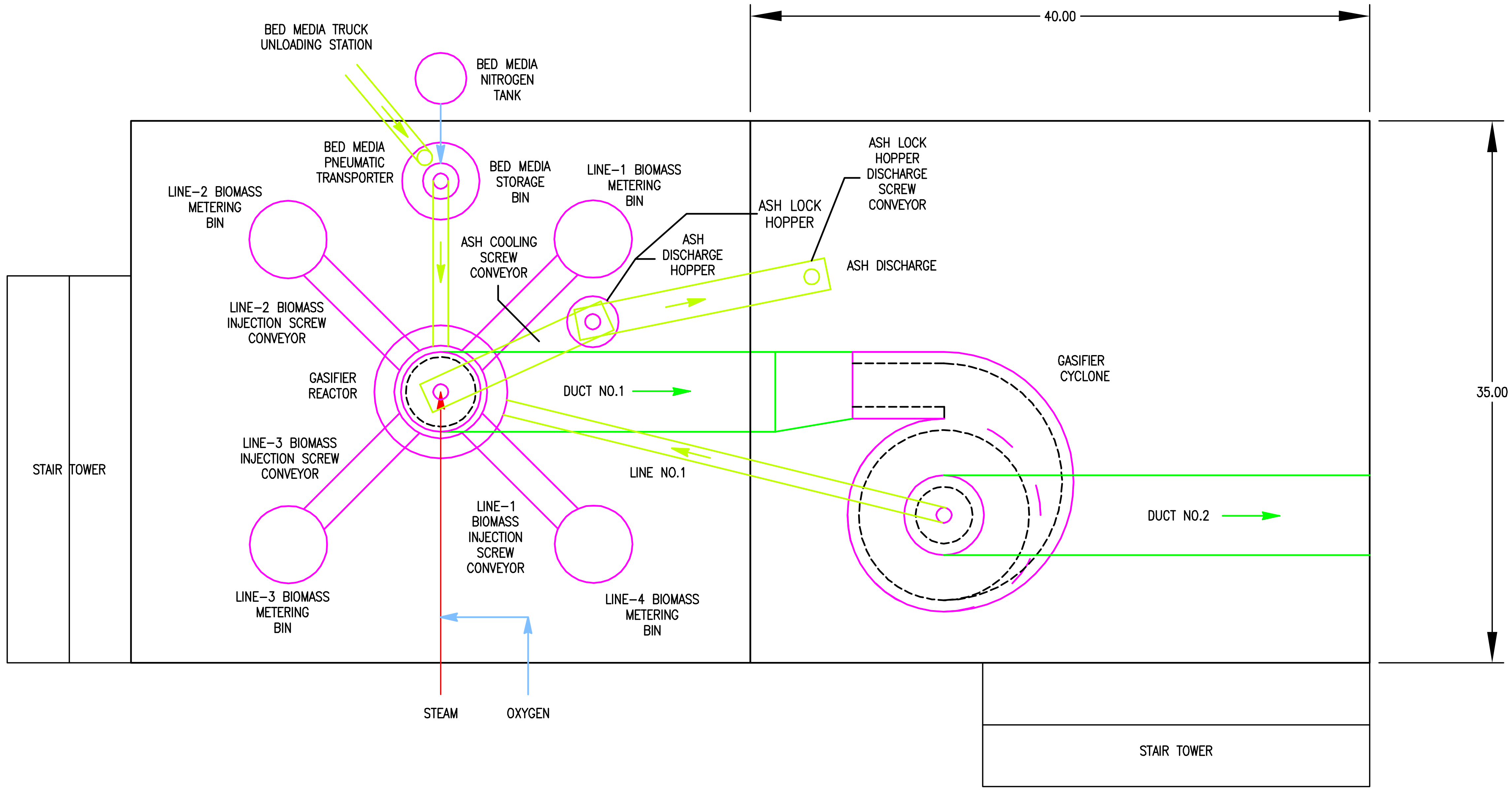
							08/03/12	FOR INFORMATION ONLY	JRY			
REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	

NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

BFB GASIFICATION SYSTEM
PROCESS FLOW DIAGRAM

PROJ NO.: 30300.00
DWG NO.: PFD-2-01
DATE: 08/03/12



							08/03/12	FOR INFORMATION ONLY	JRY		
REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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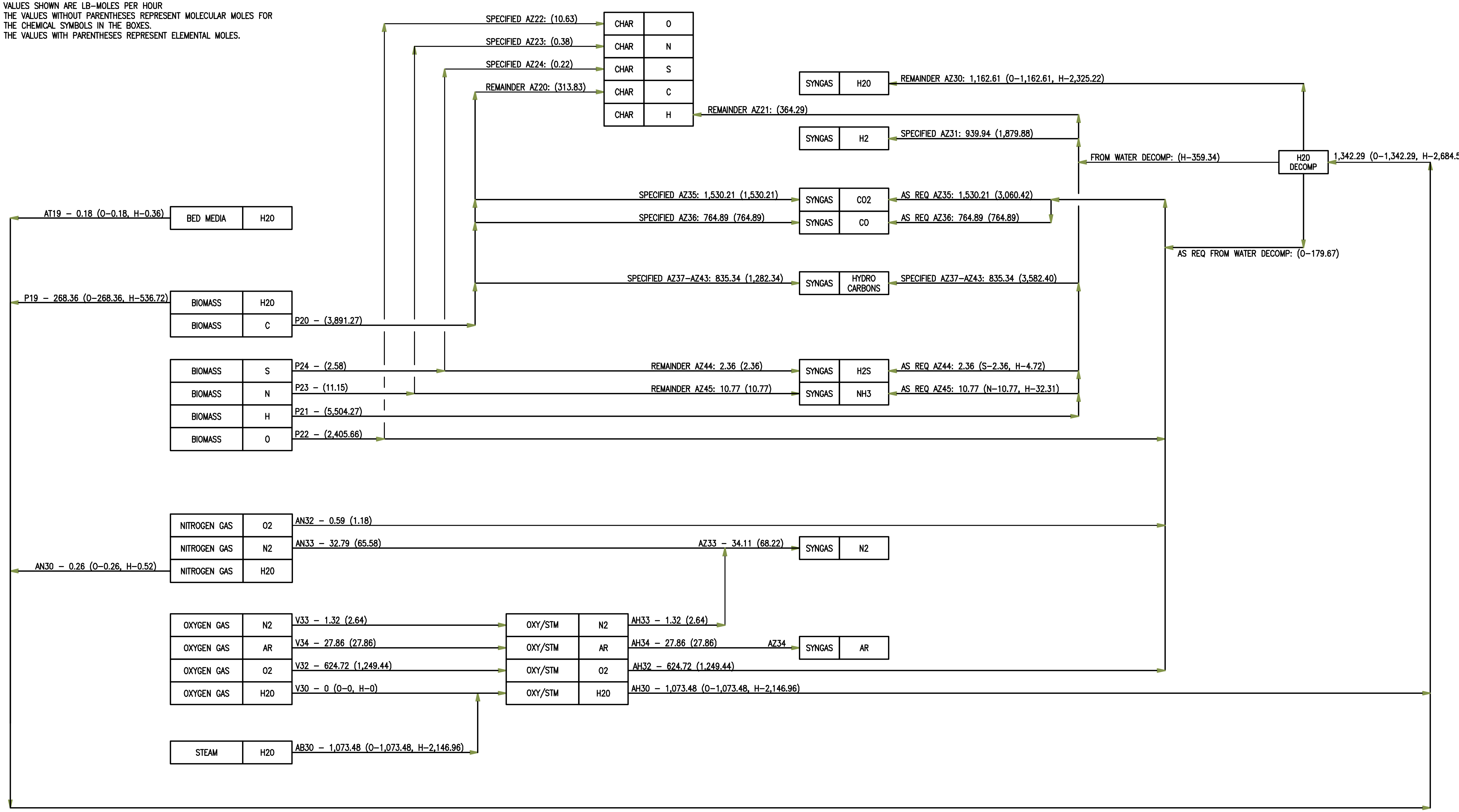
GOLDEN, COLORADO

BFB GASIFICATION SYSTEM
GENERAL ARRANGEMENT – PLAN DRAWING

PROJ NO.: 30300.00
DWG NO.: GA–2–01
DATE: 08/03/12

THE LETER/NUMBER COMBINATIONS ARE REFERENCES TO CELLS IN THE BFB-GM EXCEL WORKBOOK.

THE VALUES SHOWN ARE LB-MOLES PER HOUR
- THE VALUES WITHOUT PARENTHESES REPRESENT MOLECULAR MOLES FOR THE CHEMICAL SYMBOLS IN THE BOXES.
- THE VALUES WITH PARENTHESES REPRESENT ELEMENTAL MOLES.



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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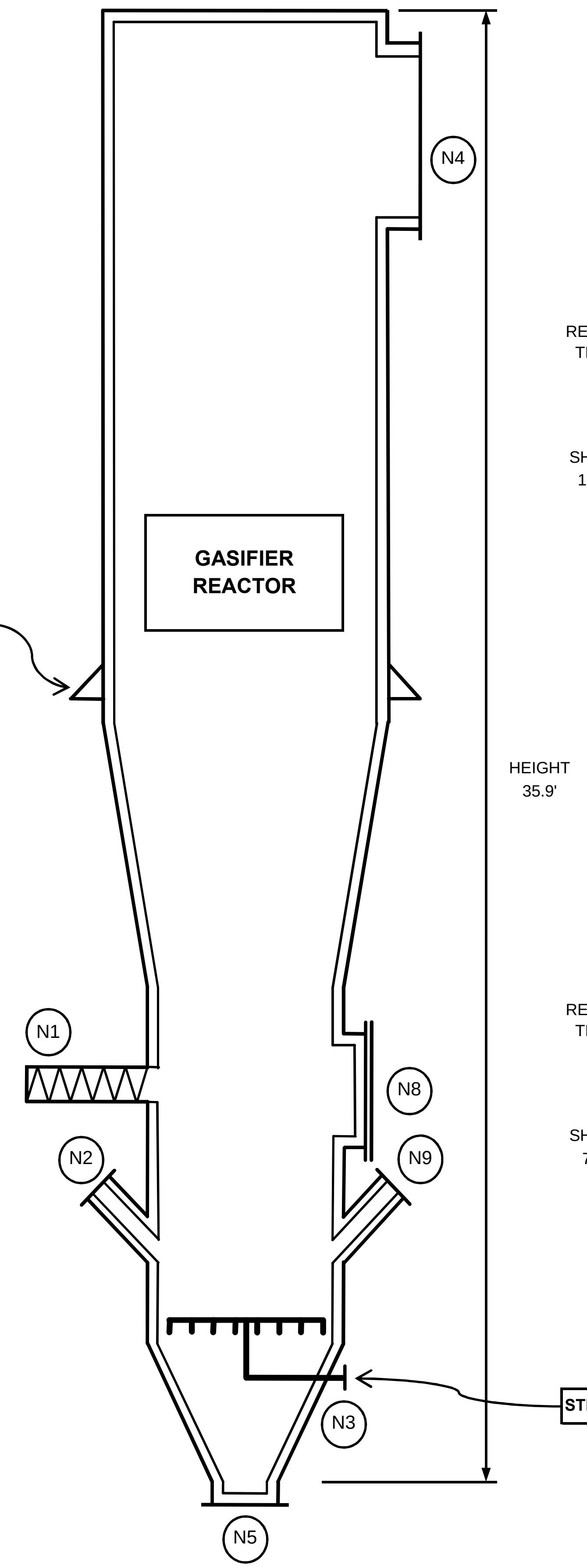
GOLDEN, COLORADO

BFB GASIFICATION SYSTEM
GASIFICATION REACTION DIAGRAM

PROJ NO.: 30300.00
DWG NO.: SK-2-01
DATE: 08/03/12

SECTION-5	
TOP PLATE	
HEIGHT -	0.1'
OD -	9.1
SURFACE AREA	14 SQFT
WEIGHT -	800 LBS
OPEN VOLUME -	--

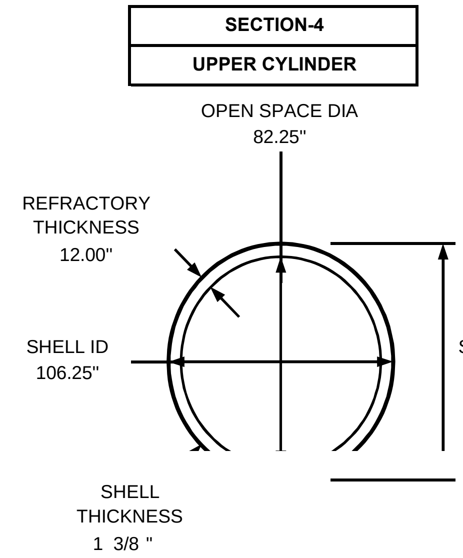
SECTION-4	
UPPER CYLINDER	
HEIGHT -	14.3'
OD -	9.1
SURFACE AREA	409 SQFT
WEIGHT -	22,656 LBS
OPEN VOLUME -	529 CUFT

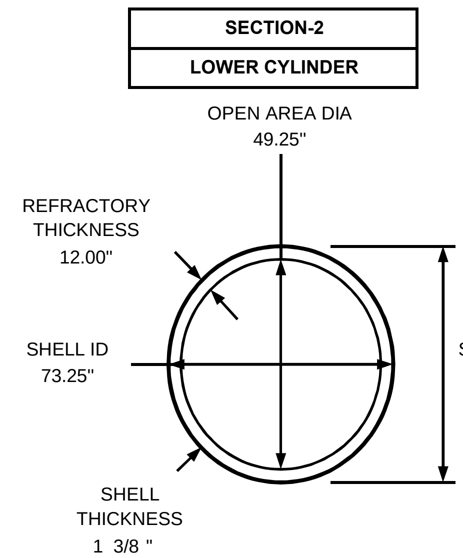


SECTION-3	
TRANSITION CONE	
HEIGHT -	6.4'
OD -	6.3' X 9.1'
SURFACE AREA	158 SQFT
WEIGHT -	8,706 LBS
OPEN VOLUME -	153 CUFT

SECTION-2	
LOWER CYLINDER	
HEIGHT -	10.0'
OD -	6.3
SURFACE AREA	199 SQFT
WEIGHT -	10,960 LBS
OPEN VOLUME -	132 CUFT

SECTION-1	
CONE BOTTOM	
HEIGHT -	5.1'
OD -	3.7' X 6.3'
SURFACE AREA	82 SQFT
WEIGHT -	4,511 LBS
OPEN VOLUME -	33 CUFT





DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
PRESSURE - OPERATING	438.0 PSIG
PRESSURE - DESIGN	505.0 PSIG
TEMPERATURE - OPERATING	1,600.0 °F
TEMPERATURE - DESIGN	1,800.0 °F
MAXIMUM STEEL TEMPERATURE - DESIGN	300.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125
TOTAL STEEL SHELL EXTERIOR SURFACE AREA	862 SQFT
TOTAL WEIGHT (READY TO SHIP)	227,776 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
REFRACTORY - INSULATING LAYER - MATERIAL	GUNNED INSULATING LAYER (4.7") - HARBISON-WALKER, KAST-O-LITE 20-45 G PLU (IN 25 LB SACKS)
REFRACTORY - ABRASION LAYER - MATERIAL	GUNNED ABRASION LAYER (7.3") - HARBISON-WALKER, WM-7214 GUN MIX (IN 55 LB SACKS)
STEAM/OXYGEN DISTRIBUTOR INSERT	HGI ESTIMATE USING HIGH TEMPERATURE RESISTANT STEEL (E.G. HAYNES ALLOY 556 OR HASTELLOY)
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	INLET - SCREW FEEDER	2	900#	WATER COOLED	3"	2,133 LBS	
N2	30"	INLET - RECYCLED BED MEDIA	1	900#	REFRACTORY LINED	2"	2,146 LBS	
N3	12"	INLET - STEAM	1	900#		3"	386 LBS	
N4	40"	OUTLET - SYNGAS	1	900#	REFRACTORY LINED	2"	3,655 LBS	
N5	44"	OUTLET - ASH	1	900#	REFRACTORY LINED	2"	4,339 LBS	
N6	1.5"	THERMOCOUPLE	6	900#	WATER COOLED	3"	15 LBS	
N7	1.5"	PRESSURE TRANSMITTER	6	900#	WATER COOLED	3"	15 LBS	
N8	52"	MANWAY	3	900#	REFRACTORY LINED	2"	5,457 LBS	13,237 LBS
N9	32"	INLET - MAKEUP BED MEDIA	1	900#	REFRACTORY LINED	2"	2,573 LBS	
N10								
N11								
N12	0.75"	INTLET - COOLING WATER	14	900#		3"	7 LBS	
N13	0.75"	OUTLET - COOLING WATER	14	900#		3"	7 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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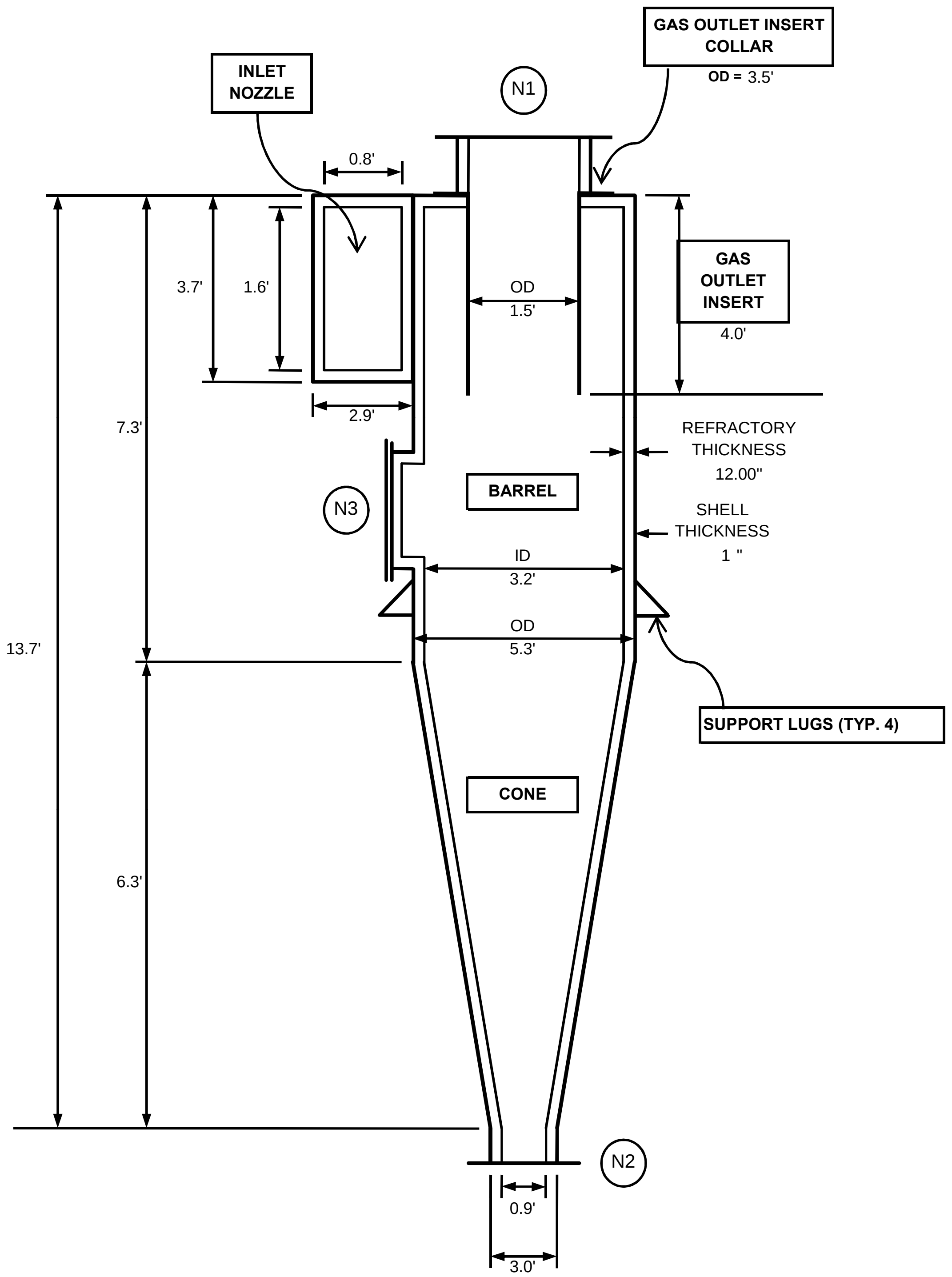
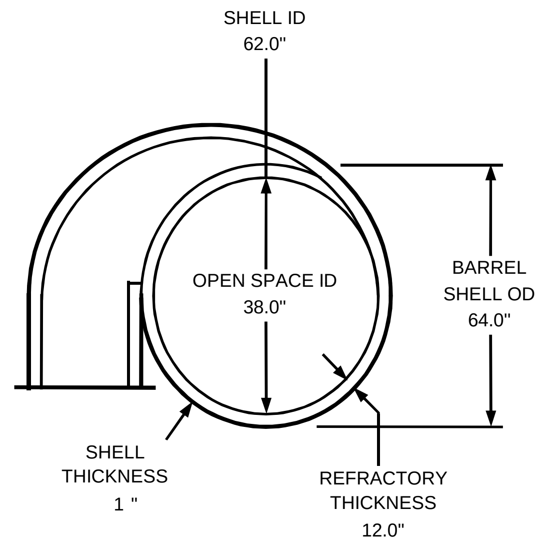
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

EQUIPMENT DRAWING
GASIFIER REACTOR

PROJ NO.: 30300.00
DWG NO.: EQ-2-01
DATE: 08/03/12





DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
PRESSURE - OPERATING	437.0 PSIG
PRESSURE - DESIGN	505.0 PSIG
TEMPERATURE - OPERATING	1,595.0 °F
TEMPERATURE - DESIGN	1,800.0 °F
MAXIMUM STEEL TEMPERATURE - DESIGN	300.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
TOTAL VESSEL EXTERIOR SURFACE AREA	166 SQFT
TOTAL WEIGHT (READY TO SHIP)	77,227 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
BARREL - INSULATING LAYER	GUNNED (3.8") - HARBISON-WALKER, KAST-O-LITE 20-45 G PLU (IN 25 LB SACKS)
BARREL - ABRASION LAYER	GUNNED (16.9") - HARBISON-WALKER, SHOT-TECH 60 (IN 55 LB SACKS)
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	42"	TOP OUTLET - SYNGAS	1	900#	REFRACTORY LINED	2"	3,997 LBS	
N2	36"	CONE OUTLET - SOLIDS	1	900#	REFRACTORY LINED	1"	3,427 LBS	
N3	52"	MANWAY	1	900#	REFRACTORY LINED	1"	5,457 LBS	13,237 LBS
N4	1.5"	THERMOCOUPLE	3	900#	WATER COOLED	3"	15 LBS	
N5	1.5"	PRESSURE TRANSMITTER	3	900#	WATER COOLED	3"	15 LBS	
N6								
N7								
N8								
N9								
N10								
N11								
N12	0.75"	INTLET - COOLING WATER	6	900#		6"	7 LBS	
N13	0.75"	OUTLET - COOLING WATER	6	900#		6"	7 LBS	

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO
EQUIPMENT DRAWING
GASIFIER CYCLONE

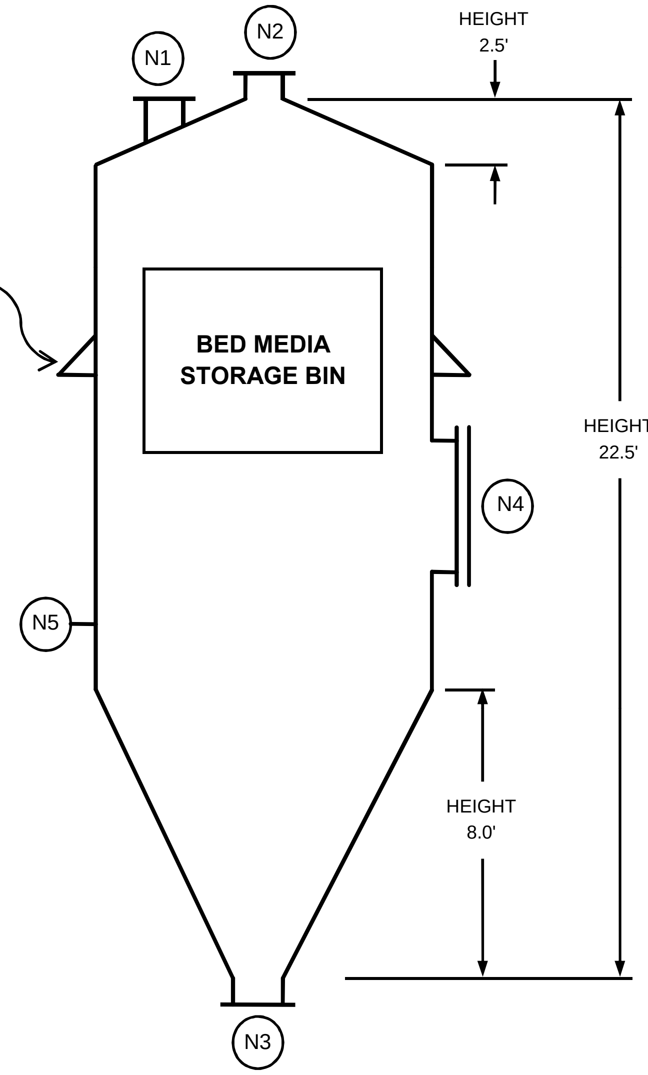
PROJ NO.: **30300.00**
DWG NO.: **EQ-2-02**
DATE: **08/03/12**

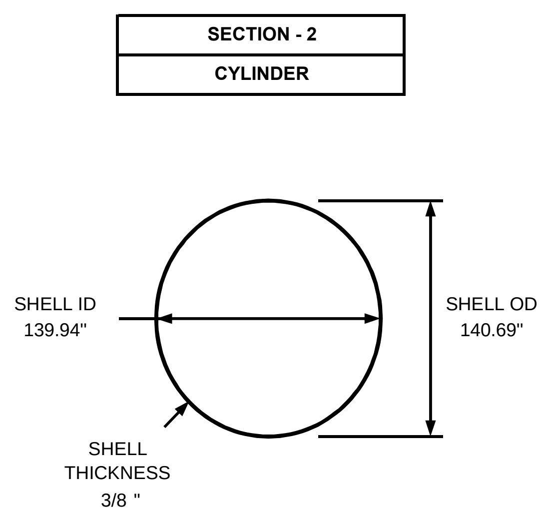
SECTION - 3	
CONE TOP	
HEIGHT -	2.5'
OD -	11.7' X 0.8'
SURFACE AREA	118 SQFT
WEIGHT -	1,799 LBS
OPEN VOLUME -	95 CUFT

SUPPORT LUGS (TYP. 4)

SECTION - 2	
CYLINDER	
HEIGHT -	12.0'
OD -	12.0'
SURFACE AREA	452 SQFT
WEIGHT -	6,824 LBS
OPEN VOLUME -	1,282 CUFT

SECTION - 1	
CONE BOTTOM	
HEIGHT -	8.0'
OD -	11.7' X 0.7'
SURFACE AREA	108 SQFT
WEIGHT -	1,642 LBS
OPEN VOLUME -	300 CUFT





DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - NOT CODE STAMPED
PRESSURE - OPERATING	0.0 PSIG
PRESSURE - DESIGN	0.0 PSIG
TEMPERATURE - OPERATING	100.0 °F
TEMPERATURE - DESIGN	115.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	678 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS)- TOTAL WEIGHT	15,575 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26"-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	12"	INLET - BED MEDIA	1	150#		3"	98 LBS	
N2	10"	TOP VENT	1	150#		3"	62 LBS	
N3	8"	OUTLET - BOTTOM DISCHARGE	1	150#		3"	48 LBS	
N4	36"	MANWAY	2	150#		2"	664 LBS	1,676 LBS
N5	2"	LEVEL SWITCH	3	150#		3"	7 LBS	
N6								
N7								
N8								
N9								
N10								
N11								
N12								
N13								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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EQUIPMENT DRAWING
BED MEDIA STORAGE BIN

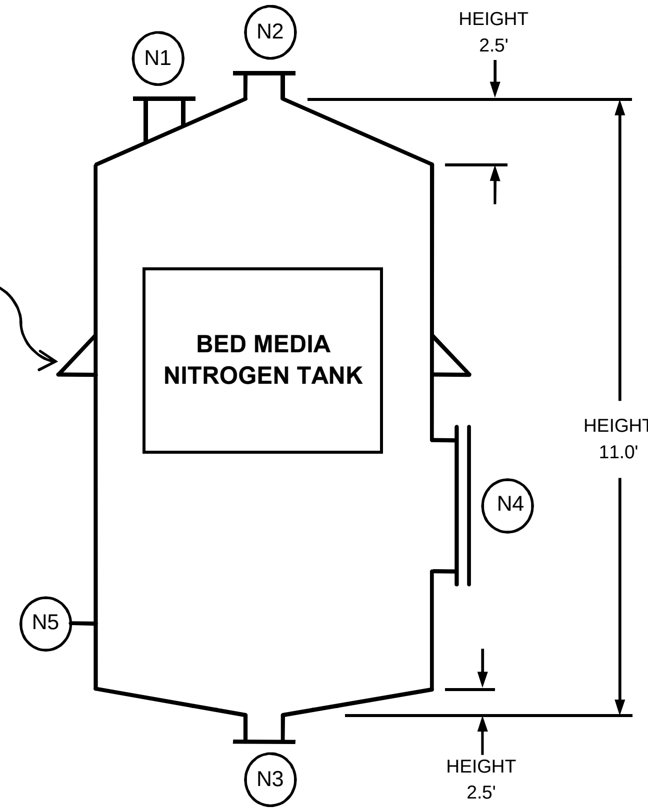
PROJ NO.: 30300.00
DWG NO.: EQ-2-03
DATE: 08/03/12

SECTION - 3	
CONE TOP	
HEIGHT -	2.5'
OD -	5.4' X 0.7'
SURFACE AREA	33 SQFT
WEIGHT -	1,780 LBS
OPEN VOLUME -	19 CUFT

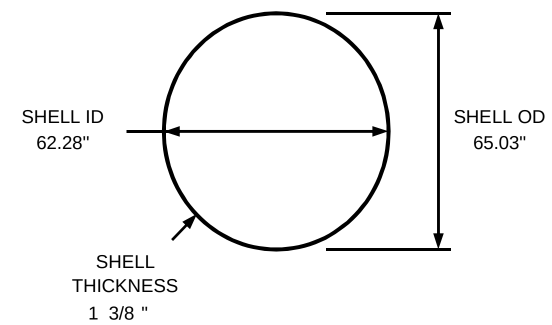
SUPPORT LUGS (TYP. 4)

SECTION - 2	
CYLINDER	
HEIGHT -	6.0'
OD -	6.0'
SURFACE AREA	113 SQFT
WEIGHT -	5,917 LBS
OPEN VOLUME -	127 CUFT

SECTION - 1	
CONE BOTTOM	
HEIGHT -	2.5'
OD -	5.4' X 0.7'
SURFACE AREA	26 SQFT
WEIGHT -	1,417 LBS
OPEN VOLUME -	19 CUFT



SECTION - 2
CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
PRESSURE - OPERATING	438.0 PSIG
PRESSURE - DESIGN	505.0 PSIG
TEMPERATURE - OPERATING	100.0 °F
TEMPERATURE - DESIGN	115.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	172 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS)- TOTAL WEIGHT	14,200 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26'-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	4"	INLET - NITROGEN	1	900#		3"	57 LBS	
N2	6"	PRESSURE RELIEF	1	900#		3"	117 LBS	
N3	8"	OUTLET - BOTTOM DRAIN	1	900#		3"	196 LBS	
N4	30"	MANWAY	2	900#		2"	2,146 LBS	
N5	1.5"	LEVEL TRANSMITTER	1	900#		3"	15 LBS	
N6	1.5"	HIGH LEVEL SWITCH	1	900#		3"	15 LBS	
N7	1"	PRESSUREL TRANSMITTER	1	900#		3"	9 LBS	
N8								
N9								
N10								
N11								
N12								
N13								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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EQUIPMENT DRAWING

BED MEDIA NITROGEN TANK

PROJ NO.: **30300.00**

DWG NO.: **EQ-2-04**

DATE: **08/03/12**

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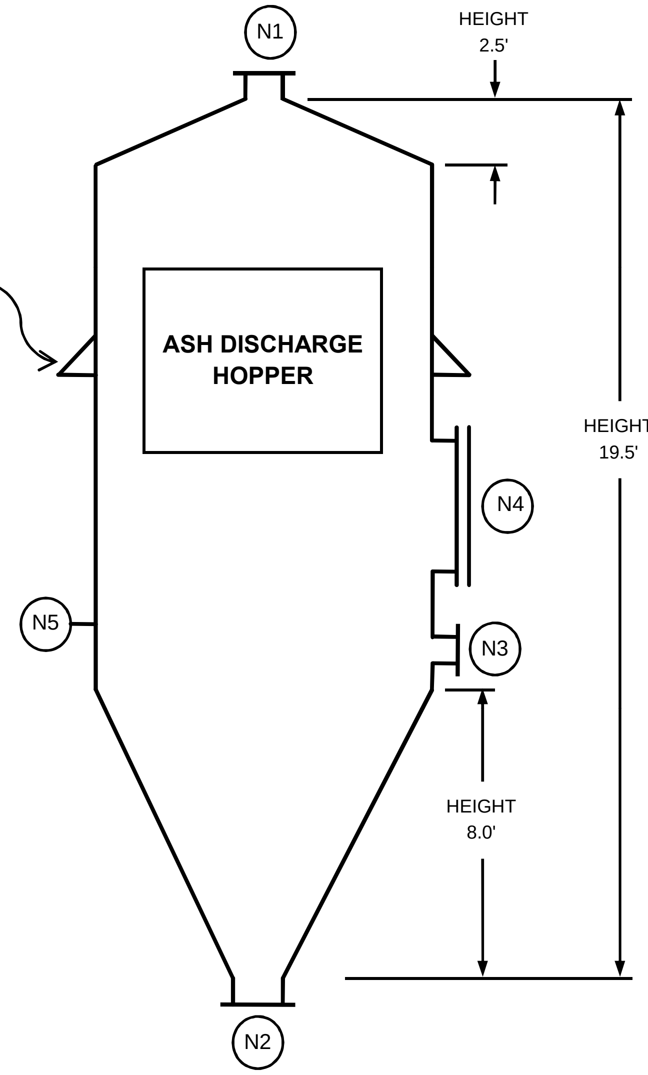
SECTION - 3	
CONE TOP	
HEIGHT -	2.5'
OD -	8.3' X 2'
SURFACE AREA	66 SQFT
WEIGHT -	3,882 LBS
OPEN VOLUME -	52 CUFT

SUPPORT LUGS (TYP. 4)

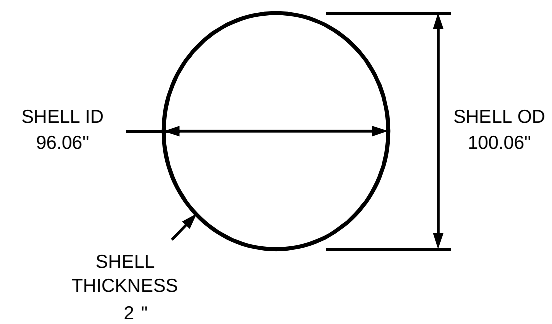
SECTION - 2	
CYLINDER	
HEIGHT -	9.0'
OD -	9.0'
SURFACE AREA	254 SQFT
WEIGHT -	14,712 LBS
OPEN VOLUME -	453 CUFT

SECTION - 1	
CONE BOTTOM	
HEIGHT -	8.0'
OD -	8.3' X 2'
SURFACE AREA	61 SQFT
WEIGHT -	3,604 LBS
OPEN VOLUME -	168 CUFT



SECTION - 2

CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
PRESSURE - OPERATING	438.0 PSIG
PRESSURE - DESIGN	505.0 PSIG
TEMPERATURE - OPERATING	300.0 °F
TEMPERATURE - DESIGN	345.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	381 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS)- TOTAL WEIGHT	27,288 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 026'-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	INLET - ASH	1	900#		3"	2,133 LBS	
N2	24"	OUTLET - ASH	1	900#		3"	2,133 LBS	
N3	8"	PRESSURE EQUALIZATION	1	900#		3"	196 LBS	
N4	2"	MANWAY	2	900#		3"	25 LBS	25 LBS
N5	2"	INSTRUMENTS	5	900#		3"	25 LBS	
N6								
N7								
N8								
N9								
N10								
N11								
N12								
N13								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO

EQUIPMENT DRAWING

ASH DISCHARGE HOPPER

PROJ NO.: **30300.00**

DWG NO.: **EQ-2-05**

DATE: **08/03/12**

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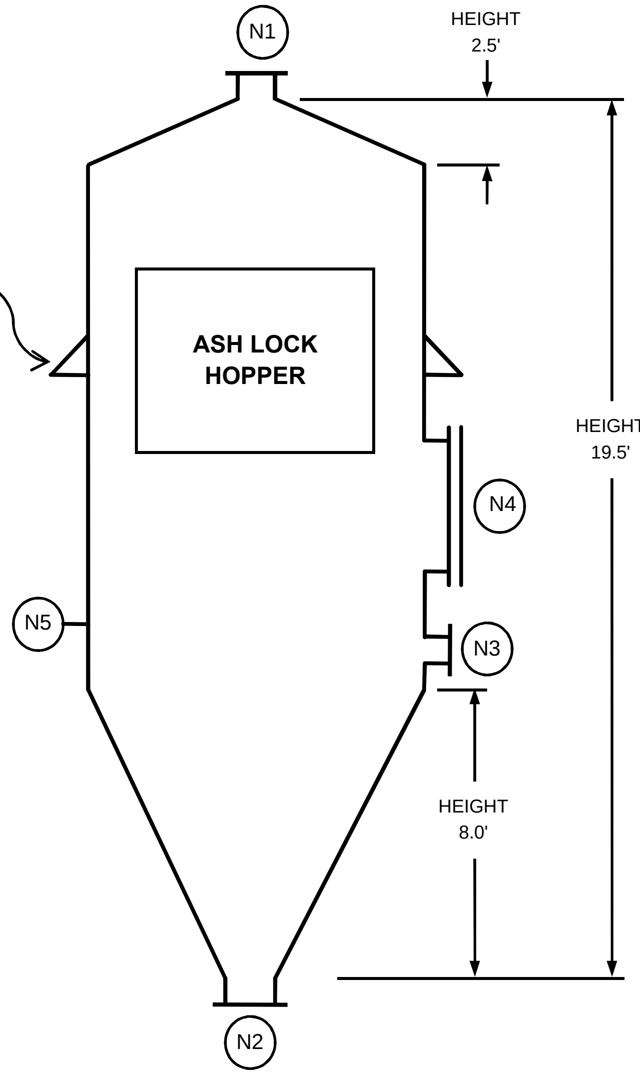
SECTION - 3	
CONE TOP	
HEIGHT -	2.5'
OD -	8.3' X 2'
SURFACE AREA	66 SQFT
WEIGHT -	3,906 LBS
OPEN VOLUME -	54 CUFT

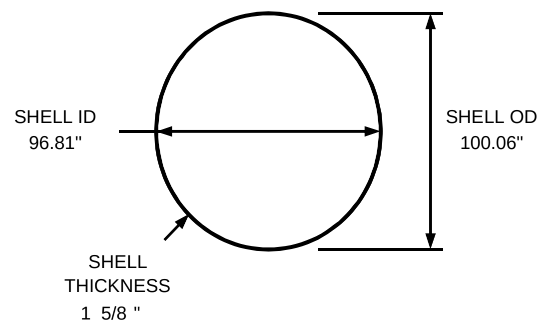
SUPPORT LUGS (TYP. 4)

SECTION - 2	
CYLINDER	
HEIGHT -	9.0'
OD -	9.0'
SURFACE AREA	254 SQFT
WEIGHT -	14,766 LBS
OPEN VOLUME -	460 CUFT

SECTION - 1	
CONE BOTTOM	
HEIGHT -	8.0'
OD -	8.3' X 2'
SURFACE AREA	58 SQFT
WEIGHT -	3,447 LBS
OPEN VOLUME -	172 CUFT



SECTION - 2
CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - CODE STAMPED
PRESSURE - OPERATING	438.0 PSIG
PRESSURE - DESIGN	505.0 PSIG
TEMPERATURE - OPERATING	300.0 °F
TEMPERATURE - DESIGN	345.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	378 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS)- TOTAL WEIGHT	27,208 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
SUPPORT - LUGS	ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 026'-96" NOZZLES - ASME SA-516, GRADE 7, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	EXTENSION LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	INLET - ASH	1	900#		3"	2,133 LBS	
N2	24"	OUTLET - ASH	1	900#		3"	2,133 LBS	
N3	8"	PRESSURE EQUALIZATION	1	900#		3"	196 LBS	
N4	2"	MANWAY	2	900#		3"	25 LBS	25 LBS
N5	2"	INSTRUMENTS	5	900#		3"	25 LBS	
N6								
N7								
N8								
N9								
N10								
N11								
N12								
N13								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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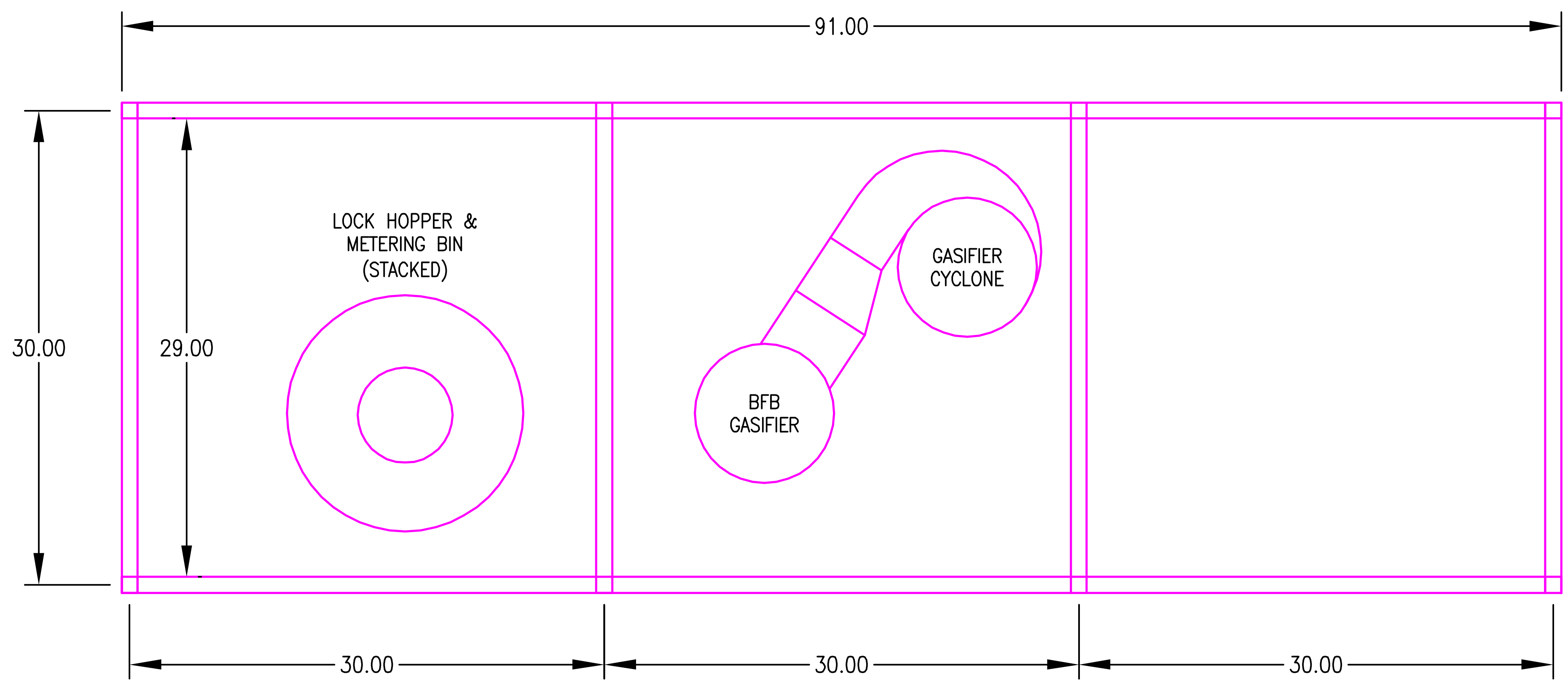
GOLDEN, COLORADO
EQUIPMENT DRAWING
ASH LOCK HOPPER

PROJ NO.: 30300.00
DWG NO.: EQ-2-06
DATE: 08/03/12

APPENDIX G-3
DETAILED ESTIMATE
DRAWINGS
HP BIOMASS FEED SYSTEM MODEL



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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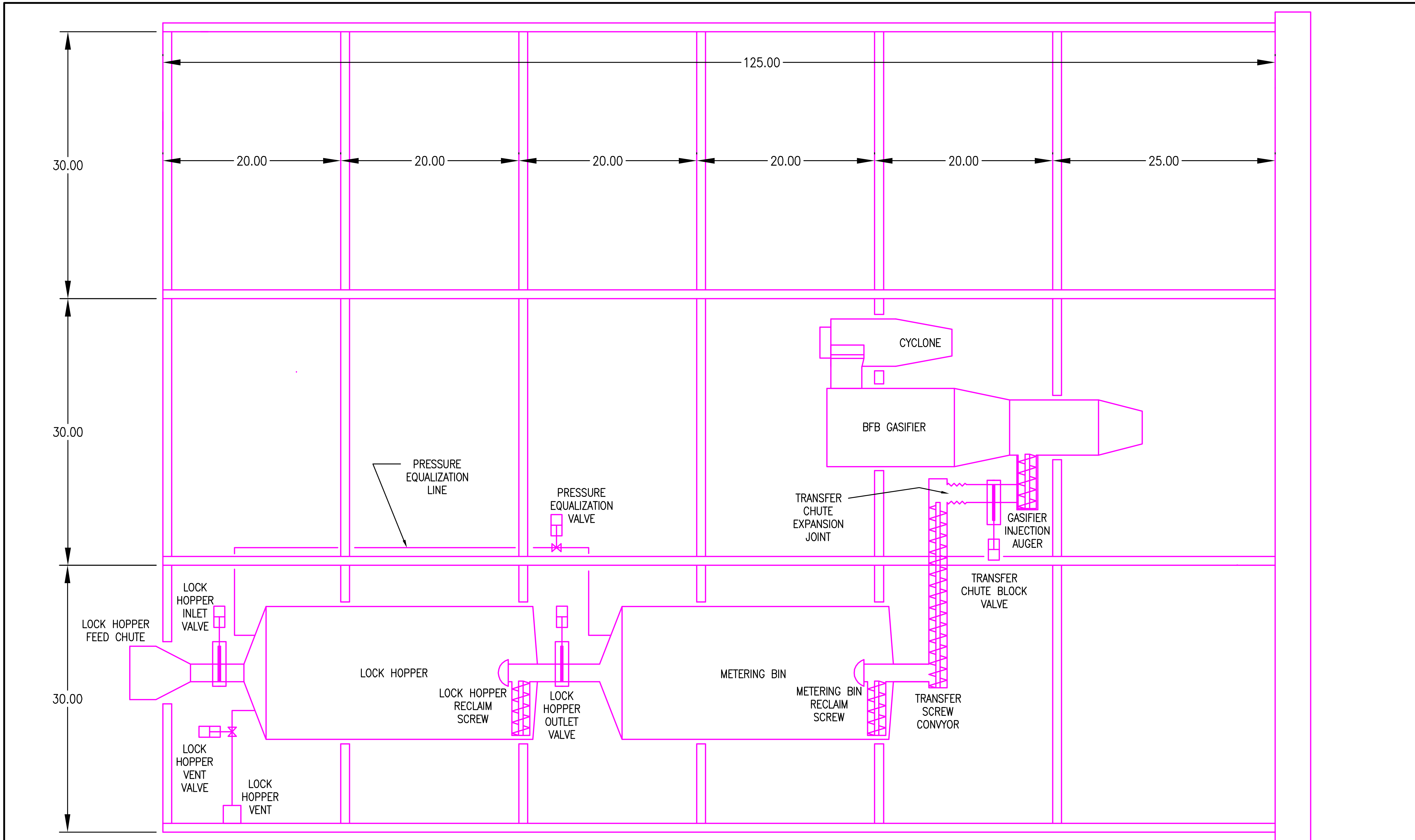
HIGH PRESSURE BIOMASS FEED SYSTEM
GENERAL ARRANGEMENT – PLAN DRAWING

PROJ NO.: 30300.00
DWG NO.: GA-3-01
DATE: 08/03/12



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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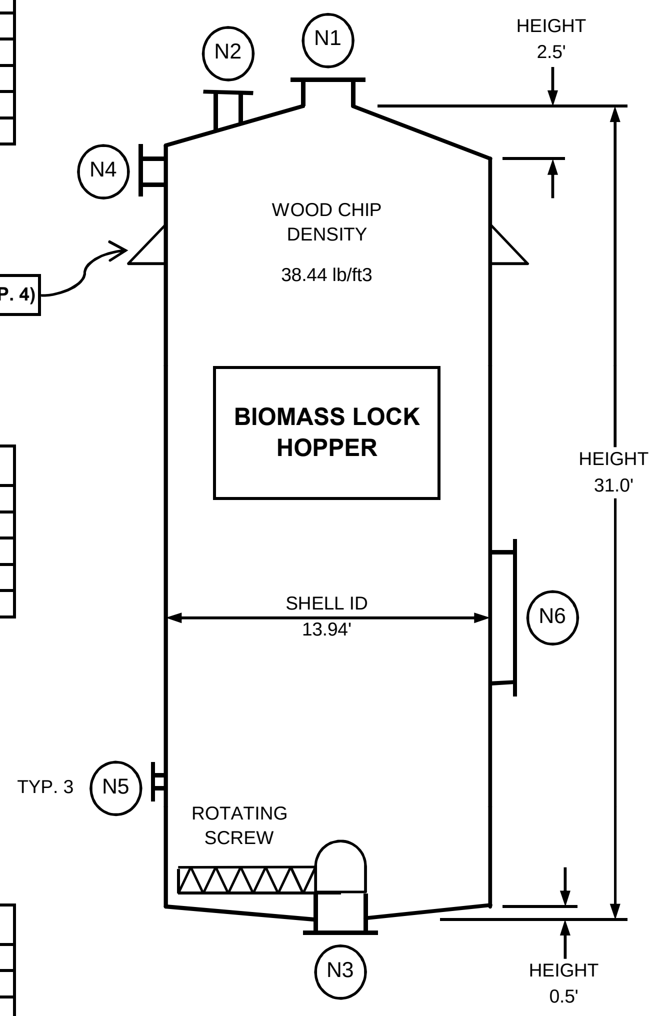
GOLDEN, COLORADO

HIGH PRESSURE BIOMASS FEED SYSTEM
GENERAL ARRANGEMENT – ELEVATION DRAWING

PROJ NO.: 30300.00
DWG NO.: GA-3-02
DATE: 08/03/12

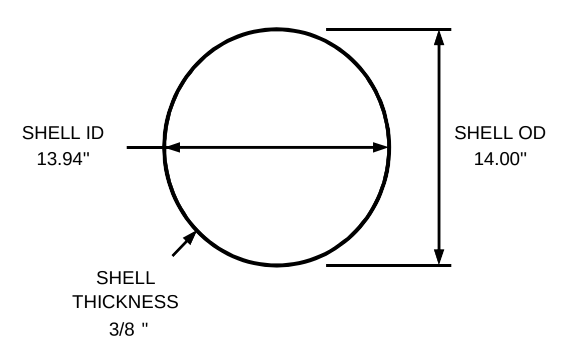
CONE TOP	
HEIGHT -	2.5'
OD -	14' X 2'
SURFACE AREA	163 SQFT
WEIGHT -	2,490 LBS
OPEN VOLUME -	147 CUFT



CYLINDER	
HEIGHT -	28.0'
OD -	14.0
SURFACE AREA	1,232 SQFT
WEIGHT -	18,800 LBS
OPEN VOLUME -	4,272 CUFT

CONE BOTTOM	
HEIGHT -	0.5'
OD -	14' X 2'
SURFACE AREA	151 SQFT
WEIGHT -	2,304 LBS
OPEN VOLUME -	29 CUFT

CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - NOT CODE STAMPED
PRESSURE - OPERATING	300.0 PSIG
PRESSURE - DESIGN	345.0 PSIG
TEMPERATURE - OPERATING	250.0 °F
TEMPERATURE - DESIGN	288.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	1,546 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS) - TOTAL WEIGHT	38,413 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	FLANGE: ASME SA-36
NOZZLES	FLANGE: ASME SA-387, GRADE 11 (REF-1)
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26'-96" NOZZLES - ASME SA-516, GRADE 70, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	TOP BIOMASS INLET	1	900#		14"	2,143 LBS	
N2	12"	TOP VENT	1	900#		10"	390 LBS	
N3	24"	BOTTOM BIOMASS DISCH	1	900#		14"	2,143 LBS	
N4	8"	PRESS EQUALIZATION	1	900#		9"	196 LBS	
N5	2"	LEVEL SWITCH	3	900#		7"	25 LBS	
N6	30"	MANWAY	1	900#		14"	2,146 LBS	3,758 LBS
N7								
N8								
N9								
N10								
N11								
N12								
N13								
N14								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO
HP BIOMASS FEED SYSTEM - EQUIPMENT DRAWING
BIOMASS LOCK HOPPER

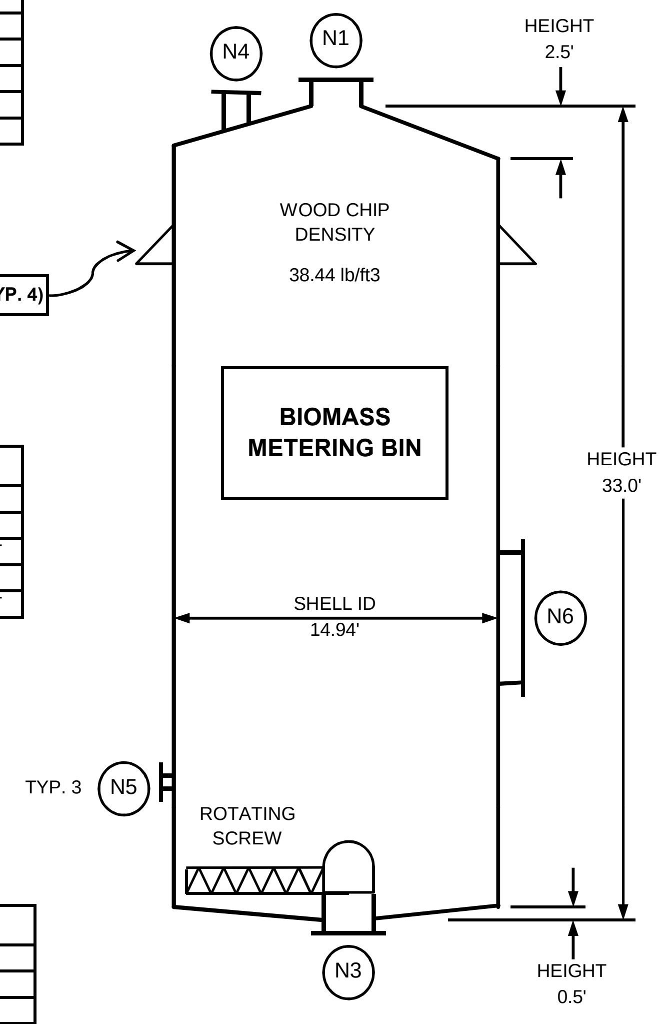
PROJ NO.: **30300.00**
DWG NO.: **EQ-3-01**
DATE: **08/03/12**

CONE TOP	
HEIGHT -	2.5'
OD -	15' X 2'
SURFACE AREA	186 SQFT
WEIGHT -	2,835 LBS
OPEN VOLUME -	167 CUFT

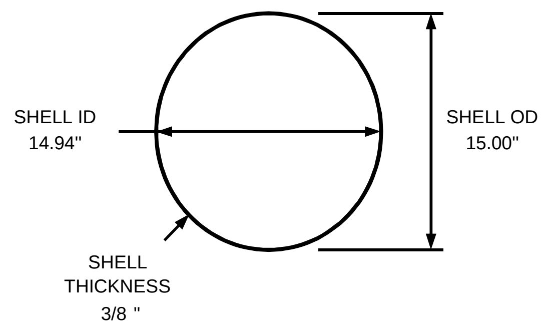
SUPPORT LUGS (TYP. 4)

CYLINDER	
HEIGHT -	30.0'
OD -	15.0
SURFACE AREA	1,414 SQFT
WEIGHT -	21,585 LBS
OPEN VOLUME -	5,257 CUFT

CONE BOTTOM	
HEIGHT -	0.5'
OD -	15' X 2'
SURFACE AREA	174 SQFT
WEIGHT -	2,651 LBS
OPEN VOLUME -	33 CUFT



CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - NOT CODE STAMPED
PRESSURE - OPERATING	300.0 PSIG
PRESSURE - DESIGN	345.0 PSIG
TEMPERATURE - OPERATING	250.0 °F
TEMPERATURE - DESIGN	288.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	1,774 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS) - TOTAL WEIGHT	41,501 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	FLANGE: ASME SA-36
NOZZLES	FLANGE: 0.84
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26'-96" NOZZLES - ASME SA-516, GRADE 70, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	TOP BIOMASS INLET	1	900#		14"	2,143 LBS	
N2								
N3	24"	BOTTOM BIOMASS DISCH	1	900#		14"	2,143 LBS	
N4	8"	PRESS EQUALIZATION	1	900#		9"	196 LBS	
N5	2"	LEVEL SWITCH	3	900#		7"	25 LBS	
N6	30"	MANWAY	1	900#		14"	2,146 LBS	3,758 LBS
N7								
N8								
N9								
N10								
N11								
N12								
N13								
N14								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

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GOLDEN, COLORADO
HP BIOMASS FEED SYSTEM - EQUIPMENT DRAWING
BIOMASS METERING BIN

PROJ NO.: **30300.00**
DWG NO.: **EQ-3-02**
DATE: **08/03/12**

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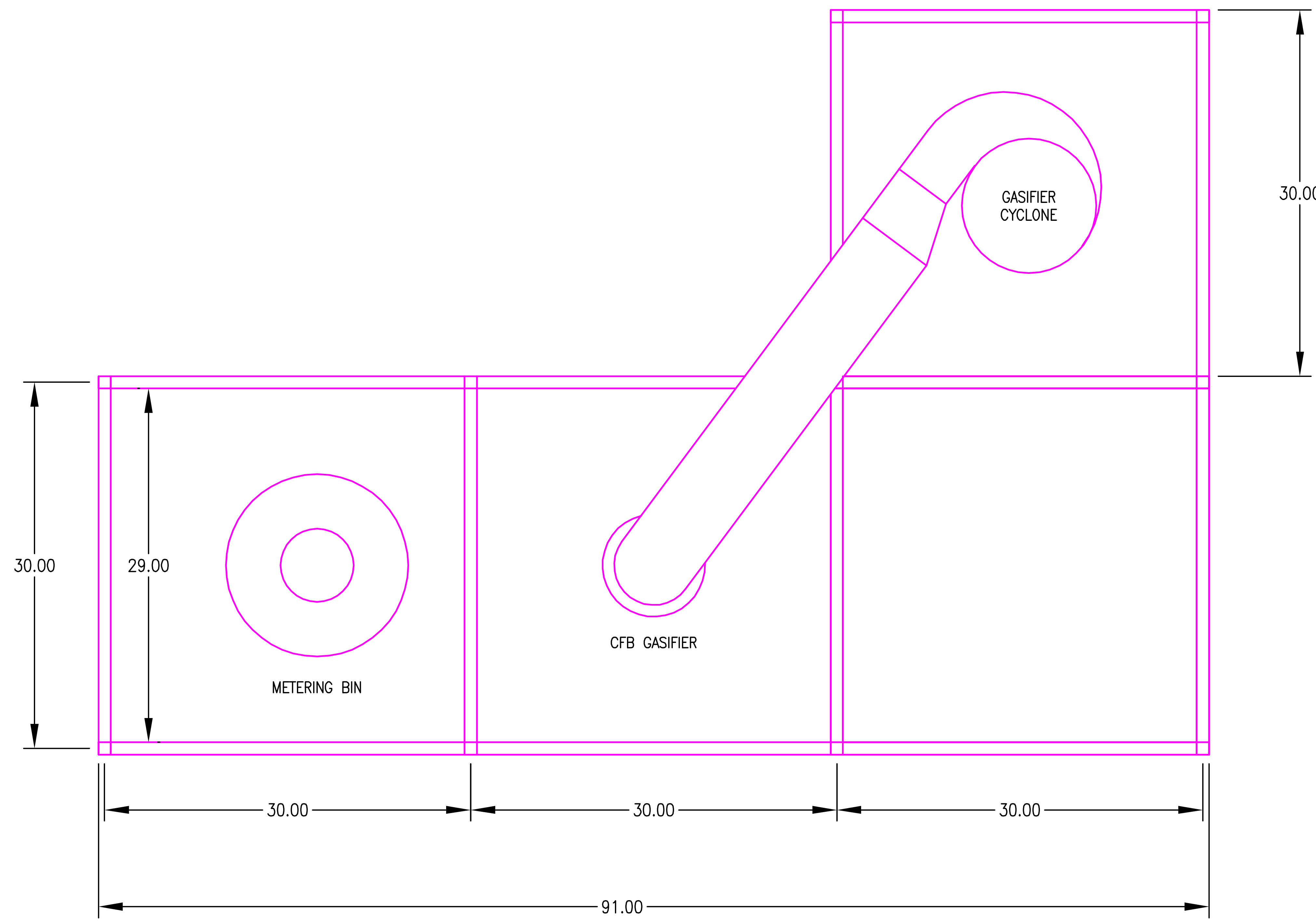
APPENDIX G-4
DETAILED ESTIMATE
DRAWINGS
LP BIOMASS FEED SYSTEM MODEL



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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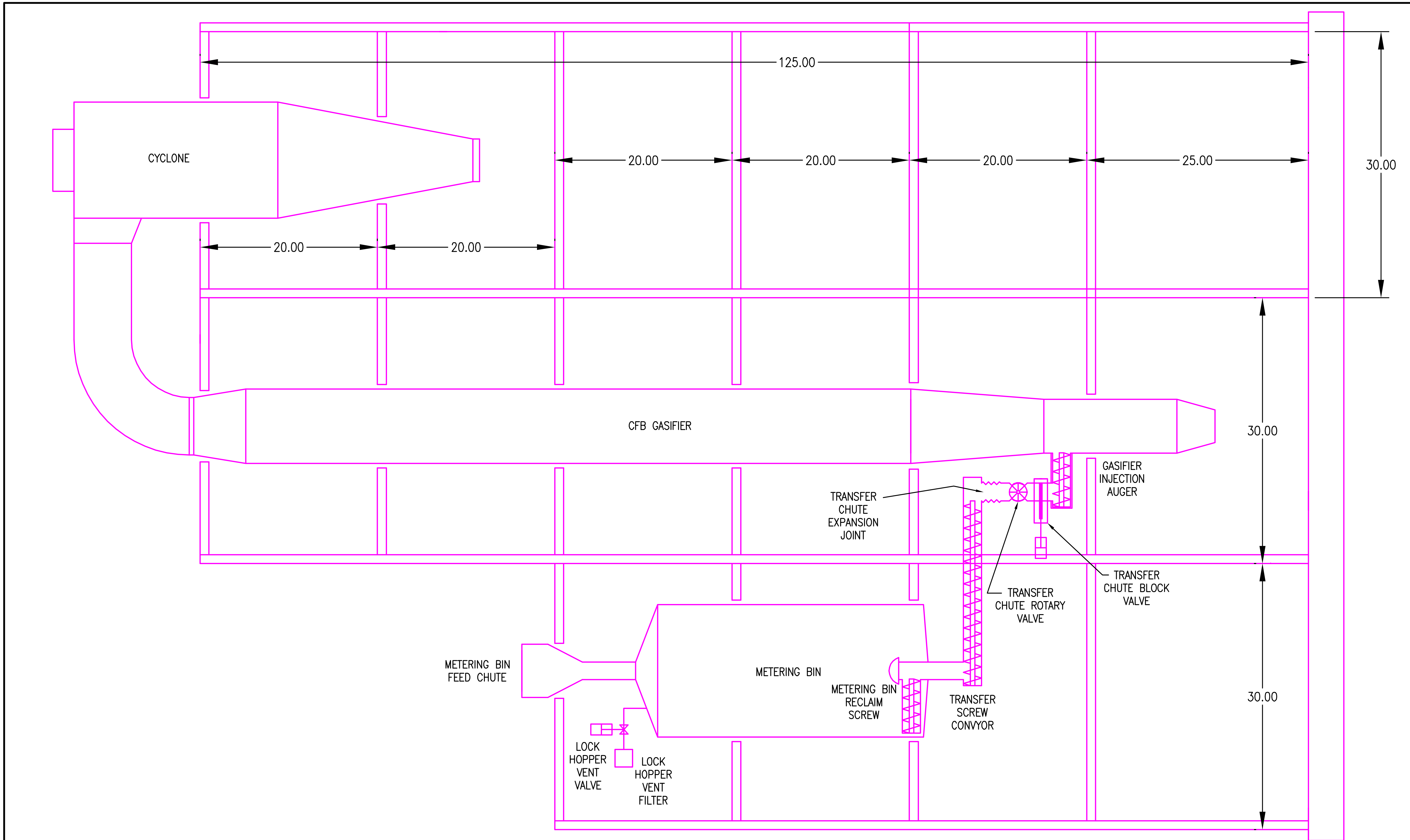
GOLDEN, COLORADO

LOW PRESSURE BIOMASS FEED SYSTEM
GENERAL ARRANGEMENT – PLAN DRAWING

PROJ NO.: 30300.00
DWG NO.: GA–4–01
DATE: 08/03/12



REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD
							08/03/12	FOR INFORMATION ONLY	JRY		

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GOLDEN, COLORADO

LOW PRESSURE BIOMASS FEED SYSTEM
GENERAL ARRANGEMENT – ELEVATION DRAWING

PROJ NO.: 30300.00

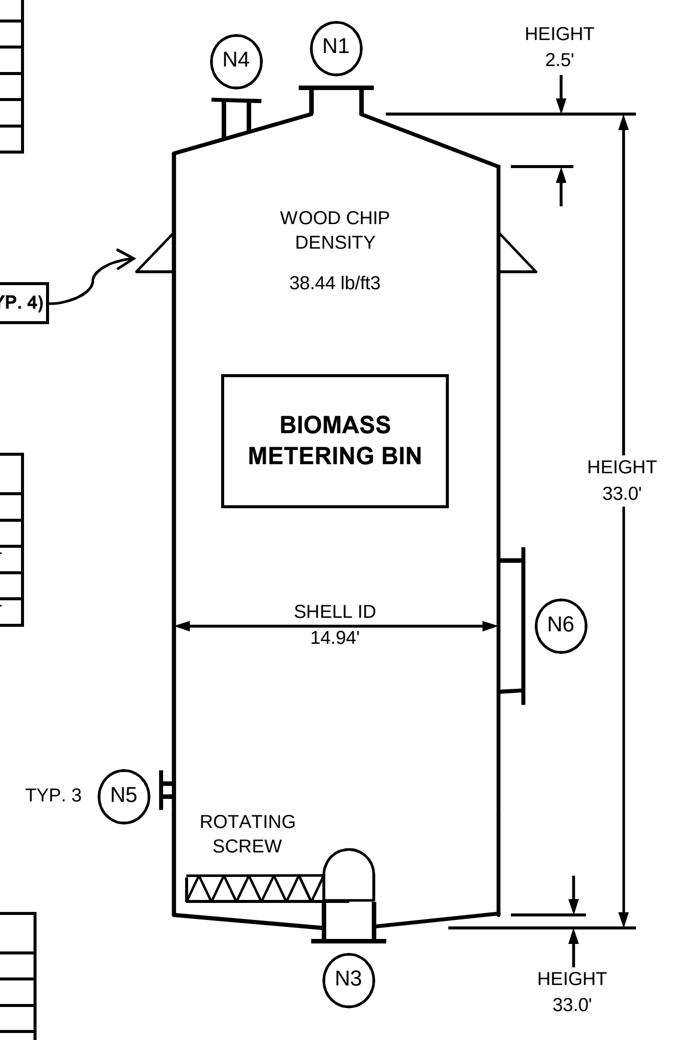
DWG NO.: GA-4-02

DATE: 08/03/12

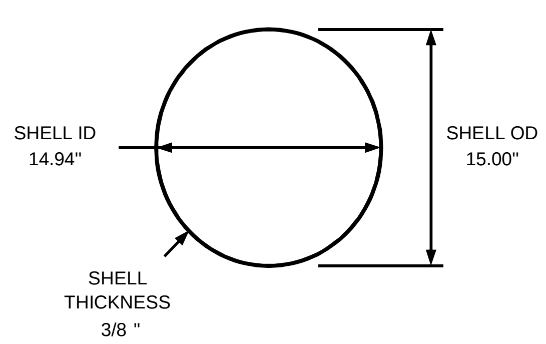
CONE TOP	
HEIGHT -	2.5'
OD -	15' X 2'
SURFACE AREA	186 SQFT
WEIGHT -	2,835 LBS
OPEN VOLUME -	167 CUFT

CYLINDER	
HEIGHT -	30.0'
OD -	15.0
SURFACE AREA	1,414 SQFT
WEIGHT -	21,585 LBS
OPEN VOLUME -	5,257 CUFT

CONE BOTTOM	
HEIGHT -	0.5'
OD -	15' X 2'
SURFACE AREA	174 SQFT
WEIGHT -	2,651 LBS
OPEN VOLUME -	33 CUFT



CYLINDER



DESIGN DATA

CONSTRUCTION CODE	ASME BOILER & PRESSURE VESSEL CODE SECTION VIII - DIVISION 1 PRESSURE VESSELS - NOT CODE STAMPED
PRESSURE - OPERATING	25.0 PSIG
PRESSURE - DESIGN	30.0 PSIG
TEMPERATURE - OPERATING	250.0 °F
TEMPERATURE - DESIGN	288.0 °F
STEEL SHELL CORROSION ALLOWANCE	0.125"
STEEL SHELL EXTERIOR - TOTAL SURFACE AREA	1,774 SQFT
VESSEL (W/NOZZLES & SUPPORT LUGS) - TOTAL WEIGHT	41,305 LBS

MATERIALS OF CONSTRUCTION

SHELL	ASME SA-516, GRADE 70 - CARBON STEEL
STRUCTURAL STEEL - LUGS	FLANGE: ASME SA-36
NOZZLES	FLANGE: 0.84
	EXTENSION: 0"-24" NOZZLES - ASME SA-106, GRADE B, SEAMLESS PIPE
	EXTENSION: 26'-96" NOZZLES - ASME SA-516, GRADE 70, WELDED PIPE

NOZZLE SCHEDULE

MARK	SIZE	DESCRIPTION	QTY	PRESSURE CLASS	PROTECTION	LENGTH	NOZZLE WEIGHT	BLIND FLANGE WEIGHT
N1	24"	TOP BIOMASS INLET	1	900#		14"	2,143 LBS	
N2								
N3	24"	BOTTOM BIOMASS DISCH	1	900#		14"	2,143 LBS	
N4								
N5	2"	LEVEL SWITCH	3	900#		7"	25 LBS	
N6	30"	MANWAY	1	900#		14"	2,146 LBS	3,758 LBS
N7								
N8								
N9								
N10								
N11								
N12								
N13								
N14								

REV.	DATE	DESCRIPTION	DRN	CKD	APRVD	REV.	DATE	DESCRIPTION	DRN	CKD	APRVD

NREL
Harris Group Inc.
Engineering for Optimum Performance®

NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO
LP BIOMASS FEED SYSTEM - EQUIPMENT DRAWING
BIOMASS METERING BIN

PROJ NO.: 30300.00
DWG NO.: EQ-4-01
DATE: 08/03/12

APPENDIX H-1
DETAILED ESTIMATE
CAPITAL COST ESTIMATE DETAILS
CFB GASIFIER MODEL

Harris Group Inc.
Engineering for Optimum Performance®

CAPITAL COST ESTIMATE

NATIONAL RENEWABLE ENERGY LABORATORY
CFB GASIFICATION MODEL
GOLDEN, COLORADO

HARRIS GROUP PROJECT NO.: 30300.00

DATE: 08/03/2012

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL: QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR: L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
11			**SUMMARY BY WORK CATEGORY**	**% of TDC**										
12	1		Civil / Earthwork	2.7%			0	683,100		3,920	85.02	333,300	150,000	1,166,400
13	2b		Buildings	18.9%			0	4,652,500		38,461	85.00	3,269,100	300,000	8,221,600
14	2e		Equipment Foundations / Supports	0.1%			0	12,900		390	85.09	33,200	0	46,100
15	3		Piping	0.6%			0	131,400		1,490	84.96	126,600	0	258,000
16	4		Electrical	1.0%			0	111,200		1,087	85.06	92,500	250,000	453,700
17	5		Instrumentation	3.00%			0	1,304,500		-		0	0	1,304,500
18	6		Process Insulation / Painting	0.1%			0	13,500		582	53.23	31,000	0	44,500
19	7		Equipment	73.6%			0	28,844,800		36,950	85.06	3,142,900	0	31,987,700
20	8		Demolition	0.0%			0	0		-		0	0	0
21			**Total Direct Cost (TDC)**				**0**	**35,753,900**		**82,881**	**84.80**	**7,028,600**	**700,000**	**43,482,500**
22														
23			Contractor Premium Pay									0		0
24			Contractor's Indirects as % of labor									0		0
25			Contractor's markup as % of matls & subs									0		0
26			**Total Construction Cost (TCC)**				**0**	**35,753,900**		**82,881**	**84.80**	**7,028,600**	**700,000**	**43,482,500**
27				**% of TCC**										
28			Engineering (Consultant)	10.0%										4,348,300
29			Owner Engineering	2.0%										869,700
30			Pre-Project Cost	0.5%										217,400
31			Other Outside Engineering Services/Construction Mngnt	2.0%										869,700
32			Environmental or Legislative Costs	1.0%										434,800
33			Capitalized Spares	3.0%										1,304,500
34			Sales Taxes	3.5%										1,521,900
35			Construction Insurance	0.0%										0
36			Freight	3.0%										1,304,500
37			**Total Indirect Cost (TIC)**	25.0%										10,870,800
38														
39			**Total Direct and Indirect Costs (TD&IC)**											**54,353,300**
40				**% of TD&IC**										
41			Contingency	15.0%										8,153,000
42			**Total Process Plant & Equipment (PP&E)**											**62,506,300**
43				**% of TD&IC**										
44			Escalation	0%										0
45			Capitalized Interest	0%										0
46			Deferred Start-Up Costs	0%										0
47			Working Capital	0%										0
48			Operator Training and Start-up	2%										1,087,100
49			**Grand Total**	**[Range: Lower -15% = $54,054,000; Upper +30% = $82,671,000]**										**63,593,400**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL: QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR: L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
50														
51			**ESTIMATE INPUTS/ASSUMPTIONS**	**UNIT**	**QTY**									
52														
53			Rounding Factor (Round values to this many places)	--	-2									
54			Grand Total Lower Range Multiplier	--	0.85									
55			Grand Total Upper Range Multiplier	--	1.3									
56			Labor Rate	$ / hr	85.00									
57														
58			**CIVIL/EARTHWORK (GASIFIER SITE ONLY)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
59	1		Site Clearing - Clear & Grub	acre	1.00	3,020.00		3,000	92.571	93	85.00	7,900		10,900
60	1		Site Grading - Fill & Compaction	yd^3	4,440	1.46		6,500	0.018	80	85.00	6,800		13,300
61	1		• Site - Width	ft	200									
62	1		• Site - Length	ft	200									
63	1		• Site Clearing - Cut Depth	ft	3.0									
64	1													
65	1		Foundation Preparation - Excavation	yd^3	797	1.50		1,200	0.150	120	85.00	10,200		11,400
66	1		Foundation Preparation - Backfill	yd^3	199	20.00		4,000	0.060	12	85.00	1,000		5,000
67	1		• Excavation - Depth	ft	2.60									
68	1		• Backfill - Depth	ft	0.65									
69	1		• Bay-1 - Qty	each	1									
70	1		• Bay-1 - Width	ft	35									
71	1		• Bay-1 - Length	ft	40									
72	1		• Bay-2 - Qty	each	11									
73	1		• Bay-2 - Width	ft	25									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
74	1		• Bay-2 - Length	ft	25									
75	1													
76	1		Site Grading & Foundation Preparation - Equipment Rental	lot	1	100,000.00							100,000	100,000
77	1													
78	1		Piles (16" Diameter)	each	281	2,340.00		658,400	12.000	3376	85.00	287,000		945,400
79	1		Piles - Equipment Rental	lot	1	50,000.00							50,000	50,000
80	1		• Pile - Density	pile / ft^2	0.034									
81	1		• Pile - Length	ft	60									
82	1		• Casing	included										
83	1													
84	1		Concrete - Miscellaneous	yd^3	20.0	500.00		10,000	12.000	240	85.00	20,400		30,400
85	1													
86	1		Roads	lot	0	0.00							0	0
87	1		Paving	lot	0	0.00							0	0
88	1		Retention Ponds	lot	0	0.00							0	0
89	1		Ditches / Culverts	lot	0	0.00							0	0
90	1		Containment Berms	lot	0	0.00							0	0
91	1		Sumps	lot	0	0.00							0	0
92	1		Hydrants	lot	0	0.00							0	0
93	1													
94			**BUILDINGS**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
95	2b		Concrete Slab - Pile Cap / Foundation	yd^3	766	250.00		191,600	6.000	4597	85.00	390,800		582,400
96	2b		• Concrete Slab - Thickness	in	30									
97	2b													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
98	2b		Concrete Slab - Elevated - Bay-1	yd^3	26	400.00		10,400	10.000	259	85.00	22,000		32,400
99	2b		• Concrete Slab - Thickness	in	6									
100	2b													
101	2b		Steel - Structural Steel	short ton	841	3,180.00		2,675,700	21.000	17,670	85.00	1,501,900		4,177,600
102	2b		Steel - Miscellaneous	short ton	59	4,740.00		279,200	68.000	4,005	85.00	340,400		619,600
103	2b		Steel - Grating & Guardrail	short ton	280	4,740.00		1,328,100	34.000	9,526	85.00	809,700		2,137,800
104	2b		Steel - Access Stairs	short ton	35	4,740.00		167,500	68.000	2,403	85.00	204,300		371,800
105	2b		• Total Weight of Equipment in Building	short ton	6,097									
106	2b		• Ratio of Building Structural Steel Wt to Equip Wt	--	0.138									
107	2b		• Ratio of Misc Steel Wt to Building Structural Steel Wt	--	0.070									
108	2b		• Ratio of Grating & Guardrail Steel Wt to Bldg Structural Steel Wt	--	0.333									
109	2b		• Ratio of Access Stairs Steel Wt to Bldg Structural Steel Wt	--	0.042									
110	2b		• Galvanized coating	included										
111	2b													
112	2b		Steel Handling - Equipment Rental	lot	1	300,000.00							300,000	300,000
113	2b													
114	2b		Masonry, Carpentry, Paint	lot	0	0.00							0	0
115	2b		Sprinklers	lot	0	0.00							0	0
116	2b		Roofing	lot	0	0.00							0	0
117	2b		Siding	lot	0	0.00							0	0
118	2b													
119			**EQUIPMENT FOUNDATIONS/SUPPORTS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
120	2e		Large Equipment Pedistals	yd^3	42.0	307		12,900	9.290	390	85.00	33,200		46,100
121	2b		• Combustion Air Blowers	each	2									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
122	2b		• Bed Media Makeup Blowers	each	2									
123	2b		• Bed Media Feeders	each	2									
124	2e		• Large Equipment Pedistal Length	ft	8.0									
125	2e		• Large Equipment Pedistal Width	ft	8.0									
126	2e		• Large Equipment Pedistal Thickness	in	36.0									
127	2e													
128			**PIPING INCLUDING FITTINGS (NATURAL GAS, PROCESS WATER, COOLING WATER, INERT GAS, PROCESS AIR, AND STEAM)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
129	3		Isolation Valves per 100 Linear Feet of Pipe	each	4									
130	3		Check Valves per 100 Linear Feet of Pipe	each	2									
131	3													
132	3		1" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	500	7.01		3,500	0.445	223	85.00	18,900		22,400
133	3		1" Valves • Carbon Steel • 150# • Wedge Gate	each	20	710		14,200	0.860	17	85.00	1,500		15,700
134	3		1" Valves • Carbon Steel • 150# • Check	each	10	660		6,600	0.860	9	85.00	700		7,300
135	3													
136	3		2" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	200	9.38		1,900	0.726	145	85.00	12,300		14,200
137	3		2" Valves • Carbon Steel • 150# • Wedge Gate	each	8	710		5,700	0.860	7	85.00	600		6,300

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
138	3		2" Valves • Carbon Steel • 150# • Check	each	4	660		2,600	0.860	3	85.00	300		2,900
139	3													
140	3		3" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	200	12.03		2,400	0.821	164	85.00	14,000		16,400
141	3		3" Valves • Carbon Steel • 150# • Wedge Gate	each	8	1,000		8,000	1.250	10	85.00	900		8,900
142	3		3" Valves • Carbon Steel • 150# • Check	each	4	780		3,100	1.250	5	85.00	400		3,500
143	3													
144	3		4" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	200	15.82		3,200	0.907	181	85.00	15,400		18,600
145	3		4" Valves • Carbon Steel • 150# • Wedge Gate	each	8	1,250		10,000	1.530	12	85.00	1,000		11,000
146	3		4" Valves • Carbon Steel • 150# • Check	each	4	1,125		4,500	1.530	6	85.00	500		5,000
147	3													
148	3		6" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	450	24.06		10,800	1.302	586	85.00	49,800		60,600
149	3		6" Valves • Carbon Steel • 150# • Wedge Gate	each	18	1,850		33,300	2.000	36	85.00	3,100		36,400

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
150	3		6" Valves • Carbon Steel • 150# • Check	each	9	1,750		15,800	2.000	18	85.00	1,500		17,300
151	3													
152	3		Eye Wash / Shower Stations	each	3	1,150		3,500	13.500	41	85.00	3,400		6,900
153	3		Hose Stations	each	2	1,150		2,300	13.500	27	85.00	2,300		4,600
154	3		Fire Water Piping	lot	0	-		0		-	85.00	0		0
155	3													
156			**ELECTRICAL**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
157	4		5 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	2	3,780		7,600	50.460	101	85.00	8,600		16,200
158	4		10 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	2	3,929		7,900	52.230	104	85.00	8,900		16,800
159	4		25 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	3	5,762		17,300	64.170	193	85.00	16,400		33,700
160	4		50 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	4	8,421		33,700	88.770	355	85.00	30,200		63,900
161	4		100 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	11,906		0	127.770	-	85.00	0		0
162	4		200 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	2	22,350		44,700	167.220	334	85.00	28,400		73,100

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
163	4		250 HP Motor Wiring • 200 ft of Wire • Medium Voltage • 1C Conduit • Wire Terminations	each	0	32,313		0	160.890	-	85.00	0		0
164	4													
165	4		Control Cabling, Terminations, Conduit	lot	1	100,000							100,000	100,000
166	4		Lighting	lot	1	100,000							100,000	100,000
167	4		Control System UPS	lot	1	25,000							25,000	25,000
168	4		Lightning Protection	lot	1	25,000							25,000	25,000
169	4		Motors	included										
170	4		Medium/High Voltage Feeder	lot	0	0							0	0
171	4		Unit Substation(s)	lot	0	0							0	0
172	4		Power Distribution To MCC Room	lot	0	0							0	0
173	4		Power Distribution To Control Rack Room	lot	0	0							0	0
174	4													
175			**INSTRUMENTATION**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
176	5		Field Instruments, Installation & Wiring	lot	1	1,304,474		1,304,500						1,304,500
177	5		• Actuated Valve Hook Up	included										
178	5		• Controls Software & Hardware (PLC Ctrl System w/HMI)	included										
179	5		• I/O Racks	included										
180	5		• Remote Termination	included										
181	5													
182			**PROCESS INSULATION / PAINTING**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
183	6		Cal Sil, 1-1/2" Wall, 4" Ips Al Jkt (Steam Piping Only) (Assume Only Steam Piping Is Insulated)	linear ft	200	7.3		1,500	0.343	69	85.00	5,800		7,300

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
184	6		Paint Finish Coat • Temperature Indicating Paint • For use on Reactors, Duct & Cyclones	ft^2	57,084	0.210		12,000	0.009	514	49.00	25,200		37,200
185	6		Equipment Insulation	lot	0	0.00							0	0
186	6													
187			**EQUIPMENT**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
188	7		Equipment Installation Labor Hours As a Function of Equipment Weight	hrs / ston	6.0									
189	7													
190	7		BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1											
191	7		Biomass Line-1 - Weigh Bin	1		210,000		210,000	240	240	85.00	20,400		230,400
192	7		Biomass Line-1 - Weigh Bin No.1 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
193	7		Biomass Line-1 - Weigh Bin No.1 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
194	7		Biomass Line-1 - Weigh Bin No.2 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
195	7		Biomass Line-1 - Weigh Bin No.2 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
196	7		Biomass Line-1 - Weigh Bin Vent Filter	1	INCL	0		0	-	-	85.00	0		0
197	7		Biomass Line-1 - Lock Hopper	1		75,000		75,000	60	60	85.00	5,100		80,100
198	7		Biomass Line-1 - Lock Hopper Inlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
199	7		Biomass Line-1 - Lock Hopper Outlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
200	7		Biomass Line-1 - Pressurized Metering Bin	1		120,000		120,000	120	120	85.00	10,200		130,200
201	7		Biomass Line-1 - Pressurized Metering Bin Live Bottom Screws	1	INCL	0		0	-	-	85.00	0		0
202	7		Biomass Line-1 - Pressurized Metering Bin Live Bottom Screws Motor	1	INCL	0		0	-	-	85.00	0		0
203	7		Biomass Line-1 - Transfer Screw	1		17,000		17,000	50	50	85.00	4,300		21,300
204	7		Biomass Line-1 - Transfer Screw Motor	1	INCL	0		0	-	-	85.00	0		0
205	7		Biomass Line-1 - Gasifier Injection Screw	1		34,000		34,000	60	60	85.00	5,100		39,100
206	7		Biomass Line-1 - Gasifier Injection Screw Motor	1	INCL	0		0	-	-	85.00	0		0
207	7		BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2											

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
208	7		Biomass Line-2 - Weigh Bin	1		210,000		210,000	240	240	85.00	20,400		230,400
209	7		Biomass Line-2 - Weigh Bin No.1 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
210	7		Biomass Line-2 - Weigh Bin No.1 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
211	7		Biomass Line-2 - Weigh Bin No.2 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
212	7		Biomass Line-2 - Weigh Bin No.2 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
213	7		Biomass Line-2 - Weigh Bin Vent Filter	1	INCL	0		0	-	-	85.00	0		0
214	7		Biomass Line-2 - Lock Hopper	1		75,000		75,000	60	60	85.00	5,100		80,100
215	7		Biomass Line-2 - Lock Hopper Inlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
216	7		Biomass Line-2 - Lock Hopper Outlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
217	7		Biomass Line-2 - Pressurized Metering Bin	1		120,000		120,000	120	120	85.00	10,200		130,200
218	7		Biomass Line-2 - Pressurized Metering Bin Live Bottom Screws	1	INCL	0		0	-	-	85.00	0		0
219	7		Biomass Line-2 - Pressurized Metering Bin Live Bottom Screws Motor	1	INCL	0		0	-	-	85.00	0		0
220	7		Biomass Line-2 - Transfer Screw	1		17,000		17,000	50	50	85.00	4,300		21,300
221	7		Biomass Line-2 - Transfer Screw Motor	1	INCL	0		0	-	-	85.00	0		0
222	7		Biomass Line-2 - Gasifier Injection Screw	1		34,000		34,000	60	60	85.00	5,100		39,100
223	7		Biomass Line-2 - Gasifier Injection Screw Motor	1	INCL	0		0	-	-	85.00	0		0
224	7		BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3											
225	7		Biomass Line-3 - Weigh Bin	1		210,000		210,000	240	240	85.00	20,400		230,400
226	7		Biomass Line-3 - Weigh Bin No.1 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
227	7		Biomass Line-3 - Weigh Bin No.1 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
228	7		Biomass Line-3 - Weigh Bin No.2 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
229	7		Biomass Line-3 - Weigh Bin No.2 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
230	7		Biomass Line-3 - Weigh Bin Vent Filter	1	INCL	0		0	-	-	85.00	0		0
231	7		Biomass Line-3 - Lock Hopper	1		75,000		75,000	60	60	85.00	5,100		80,100
232	7		Biomass Line-3 - Lock Hopper Inlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
233	7		Biomass Line-3 - Lock Hopper Outlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
234	7		Biomass Line-3 - Pressurized Metering Bin	1		120,000		120,000	120	120	85.00	10,200		130,200
235	7		Biomass Line-3 - Pressurized Metering Bin Live Bottom Screws	1	INCL	0		0	-	-	85.00	0		0
236	7		Biomass Line-3 - Pressurized Metering Bin Live Bottom Screws Motor	1	INCL	0		0	-	-	85.00	0		0
237	7		Biomass Line-3 - Transfer Screw	1		17,000		17,000	50	50	85.00	4,300		21,300
238	7		Biomass Line-3 - Transfer Screw Motor	1	INCL	0		0	-	-	85.00	0		0
239	7		Biomass Line-3 - Gasifier Injection Screw	1		34,000		34,000	60	60	85.00	5,100		39,100
240	7		Biomass Line-3 - Gasifier Injection Screw Motor	1	INCL	0		0	-	-	85.00	0		0
241	7		BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-4											
242	7		Biomass Line-4 - Weigh Bin	1		210,000		210,000	240	240	85.00	20,400		230,400
243	7		Biomass Line-4 - Weigh Bin No.1 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
244	7		Biomass Line-4 - Weigh Bin No.1 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
245	7		Biomass Line-4 - Weigh Bin No.2 Outfeed Screw	1	INCL	0		0	-	-	85.00	0		0
246	7		Biomass Line-4 - Weigh Bin No.2 Outfeed Screw Motor	1	INCL	0		0	-	-	85.00	0		0
247	7		Biomass Line-4 - Weigh Bin Vent Filter	1	INCL	0		0	-	-	85.00	0		0
248	7		Biomass Line-4 - Lock Hopper	1		75,000		75,000	60	60	85.00	5,100		80,100
249	7		Biomass Line-4 - Lock Hopper Inlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
250	7		Biomass Line-4 - Lock Hopper Outlet Shutoff Valve	1	INCL	0		0	-	-	85.00	0		0
251	7		Biomass Line-4 - Pressurized Metering Bin	1		120,000		120,000	120	120	85.00	10,200		130,200
252	7		Biomass Line-4 - Pressurized Metering Bin Live Bottom Screws	1	INCL	0		0	-	-	85.00	0		0
253	7		Biomass Line-4 - Pressurized Metering Bin Live Bottom Screws Motor	1	INCL	0		0	-	-	85.00	0		0
254	7		Biomass Line-4 - Transfer Screw	1		17,000		17,000	50	50	85.00	4,300		21,300
255	7		Biomass Line-4 - Transfer Screw Motor	1	INCL	0		0	-	-	85.00	0		0
256	7		Biomass Line-4 - Gasifier Injection Screw	1		34,000		34,000	60	60	85.00	5,100		39,100
257	7		Biomass Line-4 - Gasifier Injection Screw Motor	1	INCL	0		0	-	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
258	7		GASIFIER REACTOR & CYCLONES											
259	7		Gasifier Reactor	1		821,963		822,000	1,240	1,240	85.00	105,400		927,400
260	7		Gasifier Reactor Startup Burner	1		50,000		50,000	30	30	85.00	2,600		52,600
261	7		Duct-01 - From Gasifier Reactor To Gasifier Reactor No.1 Cyclone	1		649,975		650,000	510	510	85.00	43,400		693,400
262	7		Gasifier Reactor No.1 Cyclone	1		511,015		511,000	1,470	1,470	85.00	125,000		636,000
263	7		Line-01 - From Gasifier Reactor No.1 Cyclone To Gasifier Reactor Cyclones Solids Collection Bin	1		124,188		124,200	100	100	85.00	8,500		132,700
264	7		Gasifier Reactor Cyclones Solids Collection Bin	1		496,632		496,600	250	250	85.00	21,300		517,900
265	7		Duct-02 - From Gasifier Reactor No.1 Cyclone To Gasifier Reactor No.2 Cyclone	1		562,066		562,100	430	430	85.00	36,600		598,700
266	7		Gasifier Reactor No.2 Cyclone	1		504,655		504,700	1,440	1,440	85.00	122,400		627,100
267	7		Line-05 - From Gasifier Reactor No.2 Cyclone To Gasifier Reactor Cyclones Solids Collection Bin	1		200,579		200,600	190	190	85.00	16,200		216,800
268	7		Duct-03 - From Gasifier Reactor No.2 Cyclone To Duct-14 - From Duct-03 & Duct-13 To Syngas Reformer Reactor	1		1,235,358		1,235,400	1,460	1,460	85.00	124,100		1,359,500
269	7		Line-06 - From Gasifier Reactor Cyclones Solids Collection Bin To Char Combustion Reactor	1		279,658		279,700	330	330	85.00	28,100		307,800
270	7		Duct-17 - From Duct-15 - From Char Conbustion Reactor Air Blower To Char Combustion Reactor Startup Burner To	1		306,772		306,800	680	680	85.00	57,800		364,600
271	7		GASIFIER LOOP BED MEDIA MAKEUP SYSTEM											
272	7		Gasifier Loop Bed Media Truck Unloading Station	1		5,000		5,000	10	10	85.00	900		5,900
273	7		Line-02 - From Gasifier Loop Bed Media Truck Unloading Station To Gasifier Loop Bed Media Feed Bin	1		31,196		31,200	50	50	85.00	4,300		35,500
274	7		Gasifier Loop Bed Media Feed Bin	1		109,246		109,200	70	70	85.00	6,000		115,200
275	7		Gasifier Loop Bed Media Makeup Blower	1		35,000		35,000	10	10	85.00	900		35,900
276	7		Gasifier Loop Bed Media Makeup Blower Motor	1	INCL	0		0	-	-	85.00	0		0
277	7		Line-03 - From Gasifier Loop Bed Media Makeup Blower To Char Combustion Reactor	1		41,937		41,900	70	70	85.00	6,000		47,900
278	7		CHAR COMBUSTION REACTOR											
279	7		Char Combustion Reactor	1		896,893		896,900	1,140	1,140	85.00	96,900		993,800
280	7		Char Combustion Reactor Air Heater	1		159,000		159,000	80	80	85.00	6,800		165,800
281	7		Char Conbustion Reactor Air Blower	1		262,500		262,500	60	60	85.00	5,100		267,600
282	7		Char Conbustion Reactor Air Blower Motor	1	INCL	0		0	-	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
283	7		Char Combustion Reactor Startup Burner	1		50,000		50,000	30	30	85.00	2,600		52,600
284	7		Duct-15 - From Char Conbustion Reactor Air Blower To Char Combustion Reactor Startup Burner	1		484,442		484,400	360	360	85.00	30,600		515,000
285	7		CHAR COMBUSTION CYCLONES											
286	7		Duct-04 - From Char Combustion Reactor To Char Combustion Reactor No.1 Cyclone	1		768,435		768,400	540	540	85.00	45,900		814,300
287	7		Char Combustion Reactor No.1 Cyclone	1		785,028		785,000	2,280	2,280	85.00	193,800		978,800
288	7		Line-07 - From Char Combustion Reactor No.1 Cyclone To Char Combustion Reactor No.1 Cyclone Solids Collection Bin	1		246,648		246,600	230	230	85.00	19,600		266,200
289	7		Char Combustion Reactor No.1 Cyclone Solids Collection Bin	1		490,073		490,100	250	250	85.00	21,300		511,400
290	7		Line-08 - From Char Combustion Reactor No.1 Cyclone Solids Collection Bin To Gasifier Reactor	1		279,658		279,700	330	330	85.00	28,100		307,800
291	7		Duct-05 - From Char Combustion Reactor No.1 Cyclone To Char Combustion Reactor No.2 Cyclone	1		718,530		718,500	490	490	85.00	41,700		760,200
292	7		Char Combustion Reactor No.2 Cyclone	1		780,928		780,900	2,260	2,260	85.00	192,100		973,000
293	7		Line-09 - From Char Combustion Reactor No.2 Cyclone To Char Combustion Loop Depleted Bed Media & Ash Cooling	1		189,828		189,800	210	210	85.00	17,900		207,700
294	7		Duct-06 - From Char Combustion Reactor No.2 Cyclone To Battery Limit (Flue Gas)	1		644,279		644,300	440	440	85.00	37,400		681,700
295	7		CHAR COMBUSTION BED MEDIA & ASH DISPOSAL											
296	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor	1		20,000		20,000	20	20	85.00	1,700		21,700
297	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
298	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder	1		7,000		7,000	10	10	85.00	900		7,900
299	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder Motor	1	INCL	0		0	-	-	85.00	0		0
300	7		Line-19 - From Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor To Gasifier Loop Depleted Bed	1		14,367		14,400	10	10	85.00	900		15,300
301	7		Gasifier Loop Depleted Bed Media & Ash Storage Bin	1		109,246		109,200	70	70	85.00	6,000		115,200
302	7		SYNGAS REFORMER & CYCLONES											
303	7		Duct-13 - From Supplemental Gas Battery Limits To Syngas Reformer Reactor	1		541,728		541,700	400	400	85.00	34,000		575,700
304	7		Duct-14 - From Duct-03 & Duct-13 To Syngas Reformer Reactor	1		702,848		702,800	490	490	85.00	41,700		744,500
305	7		Syngas Reformer Reactor	1		1,522,654		1,522,700	1,810	1,810	85.00	153,900		1,676,600
306	7		Duct-07 - From Syngas Reformer Reactor To Syngas Reformer Reactor No.1 Cyclone	1		1,199,771		1,199,800	1,060	1,060	85.00	90,100		1,289,900
307	7		Syngas Reformer Reactor No.1 Cyclone	1		992,813		992,800	2,900	2,900	85.00	246,500		1,239,300

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
308	7		Line-10 - From Syngas Reformer Reactor No.1 Cyclone To Syngas Reformer Reactor Cyclones Solids Collection Bin	1		179,003		179,000	130	130	85.00	11,100		190,100
309	7		Syngas Reformer Reactor Cyclones Solids Collection Bin	1		498,006		498,000	250	250	85.00	21,300		519,300
310	7		Duct-08 - From Syngas Reformer Reactor No.1 Cyclone To Syngas Reformer Reactor No.2 Cyclone	1		1,199,771		1,199,800	1,060	1,060	85.00	90,100		1,289,900
311	7		Syngas Reformer Reactor No.2 Cyclone	1		992,813		992,800	2,900	2,900	85.00	246,500		1,239,300
312	7		Line-14 - From Syngas Reformer Reactor No.2 Cyclone To Syngas Reformer Reactor Cyclones Solids Collection Bin	1		183,783		183,800	180	180	85.00	15,300		199,100
313	7		Duct-09 - From Syngas Reformer Reactor No.2 Cyclone To Battery Limit (Reformed Syngas)	1		1,199,771		1,199,800	1,060	1,060	85.00	90,100		1,289,900
314	7		Line-15 - From Syngas Reformer Reactor Cyclones Solids Collection Bin To Reformer Bed Media Heating Reactor	1		326,966		327,000	380	380	85.00	32,300		359,300
315	7		REFORMER LOOP BED MEDIA MAKEUP SYSTEM											
316	7		Reformer Loop Bed Media Truck Unloading Station	1		5,000		5,000	10	10	85.00	900		5,900
317	7		Line-11 - From Reformer Loop Bed Media Truck Unloading Station To Reformer Loop Bed Media Feed Bin	1		33,835		33,800	50	50	85.00	4,300		38,100
318	7		Reformer Loop Bed Media Feed Bin	1		109,246		109,200	70	70	85.00	6,000		115,200
319	7		Reformer Loop Bed Media Makeup Blower	1		35,000		35,000	10	10	85.00	900		35,900
320	7		Reformer Loop Bed Media Makeup Blower Motor	1	INCL	0		0	-	-	85.00	0		0
321	7		Line-12 - From Reformer Loop Bed Media Makeup Blower To Reformer Bed Media Heating Reactor	1		44,576		44,600	70	70	85.00	6,000		50,600
322	7		REFORMER BED MEDIA HEATING REACTOR											
323	7		Reformer Bed Media Heating Reactor	1		593,440		593,400	810	810	85.00	68,900		662,300
324	7		Reformer Bed Media Heating Reactor Air Heater	1		159,000		159,000	80	80	85.00	6,800		165,800
325	7		Reformer Bed Media Heating Reactor Air Blower	1		262,500		262,500	60	60	85.00	5,100		267,600
326	7		Reformer Bed Media Heating Reactor Air Blower Motor	1	INCL	0		0	-	-	85.00	0		0
327	7		Reformer Bed Media Heating Reactor Burner	1		75,000		75,000	30	30	85.00	2,600		77,600
328	7		Duct-16 - From Reformer Bed Media Heating Reactor Air Heater To Reformer Bed Media Heating Reactor	1		208,339		208,300	180	180	85.00	15,300		223,600
329	7		REFORMER BED MEDIA HEATING CYCLONES											
330	7		Duct-10 - From Reformer Bed Media Heating Reactor To Reformer Bed Media Heating Reactor No.1 Cyclone	1		438,507		438,500	480	480	85.00	40,800		479,300
331	7		Reformer Bed Media Heating Reactor No.1 Cyclone	1		193,670		193,700	530	530	85.00	45,100		238,800
332	7		Line-16 - From Reformer Bed Media Heating Reactor No.1 Cyclone To Reformer Bed Media Heating Reactor No.1	1		183,783		183,800	180	180	85.00	15,300		199,100

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
333	7		Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin	1		491,894		491,900	250	250	85.00	21,300		513,200
334	7		Line-17 - From Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin To Syngas Reformer Reactor	1		326,966		327,000	380	380	85.00	32,300		359,300
335	7		Duct-11 - From Reformer Bed Media Heating Reactor No.1 Cyclone To Reformer Bed Media Heating Reactor No.2	1		438,507		438,500	480	480	85.00	40,800		479,300
336	7		Reformer Bed Media Heating Reactor No.2 Cyclone	1		193,670		193,700	530	530	85.00	45,100		238,800
337	7		Line-18 - From Reformer Bed Media Heating Reactor No.2 Cyclone To Reformer Loop Depleted Bed Media Cooling Screw	1		218,098		218,100	260	260	85.00	22,100		240,200
338	7		Duct-12 - From Reformer Bed Media Heating Reactor No.2 Cyclone To Battery Limit (Flue Gas)	1		438,507		438,500	480	480	85.00	40,800		479,300
339	7		REFORMER HEATER BED MEDIA & ASH DISPOSAL											
340	7		Reformer Loop Depleted Bed Media Cooling Screw Conveyor	1		20,000		20,000	20	20	85.00	1,700		21,700
341	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
342	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder	1		7,000		7,000	10	10	85.00	900		7,900
343	7		Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor Outlet Pocket Feeder Motor	1	INCL	0		0	-	-	85.00	0		0
344	7		Line-20 - From Reformer Loop Depleted Bed Media Cooling Screw Conveyor To Reformer Loop Depleted Bed Media	1		17,006		17,000	10	10	85.00	900		17,900
345	7		Reformer Loop Depleted Bed Media Storage Bin	1		109,246		109,200	70	70	85.00	6,000		115,200
346	7		FLARE SYSTEM											
347	7		Stack Flare Burner	1		6,000		6,000	10	10	85.00	900		6,900
348	7													
349	7													
350	7													
351	7													
352	7													
353	7		Inert Gas System	lot	0	0.00							0	0
354	7		Flue Gas ID Fans (Including Drives)	lot	0	0.00							0	0
355	7		Flue Gas Scrubbers (Including Scrubber, Separator, Pump, Piping)	lot	0	0.00							0	0
356	7		Stack	lot	0	0.00							0	0
357	7		Cooling Tower/Cooling System	lot	0	0.00							0	0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
358	7													
359			**DEMOLITION**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
360	8		Demolition	lot	0	0.00							0	0
361														
			Total Direct Cost (TDC)				**0**	**35,753,900**		**82,881**	**84.80**	**7,028,600**	**700,000**	**43,482,500**

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APPENDIX H-2
DETAILED ESTIMATE
CAPITAL COST ESTIMATE DETAILS
BFB GASIFIER MODEL

Harris Group Inc.
Engineering for Optimum Performance®

CAPITAL COST ESTIMATE

NATIONAL RENEWABLE ENERGY LABORATORY
BFB BIOMASS GASIFICATION SYSTEM
GOLDEN, COLORADO

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

HARRIS GROUP PROJECT NO.: 30300.00

DATE: 08/03/2012

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
11			**SUMMARY BY WORK CATEGORY**	**% of TDC**										
12	1		Civil / Earthwork	8.6%			0	222,200		1,276	84.95	108,400	60,000	390,600
13	2b		Buildings	14.6%			0	269,600		3,064	84.99	260,400	130,000	660,000
14	2e		Equipment Foundations / Supports	0.2%			0	2,100		65	84.58	5,500	0	7,600
15	3		Piping	1.0%			0	24,000		275	85.08	23,400	0	47,400
16	4		Electrical	6.1%			0	14,200		153	85.00	13,000	250,000	277,200
17	5		Instrumentation	3.0%			0	135,700		-		0	0	135,700
18	6		Process Insulation / Painting	0.2%			0	2,100		95	74.40	7,100	0	9,200
19	7		Equipment	66.2%			0	2,842,200		1,810	85.41	154,600	0	2,996,800
20	8		Demolition	0.0%			0	0		-		0	0	0
21			**Total Direct Cost (TDC)**				**0**	**3,512,100**		**6,738**	**84.95**	**572,400**	**440,000**	**4,524,500**
22														
23			Contractor Premium Pay									0		0
24			Contractor's Indirects as % of labor									0		0
25			Contractor's markup as % of matls & subs									0		0
26			**Total Construction Cost (TCC)**				**0**	**3,512,100**		**6,738**	**84.95**	**572,400**	**440,000**	**4,524,500**
27				**% of TCC**										
28			Engineering (Consultant)	10.0%										452,500
29			Owner Engineering	2.0%										90,500
30			Pre-Project Cost	0.5%										22,600
31			Other Outside Engineering Services/Construction Mngnt	2.0%										90,500
32			Environmental or Legislative Costs	1.0%										45,200
33			Capitalized Spares	3.0%										135,700
34			Sales Taxes	3.5%										158,400
35			Construction Insurance	0.0%										0
36			Freight	3.0%										135,700
37			**Total Indirect Cost (TIC)**	25.0%										1,131,100
38														
39			**Total Direct and Indirect Costs (TD&IC)**											**5,655,600**
40				**% of TD&IC**										
41			Contingency	15.0%										848,300
42			**Total Process Plant & Equipment (PP&E)**											**6,503,900**
43				**% of TD&IC**										
44			Escalation	0%										0
45			Capitalized Interest	0%										0
46			Deferred Start-Up Costs	0%										0
47			Working Capital	0%										0
48			Operator Training and Start-up	2%										113,100
49			**Grand Total**	**[Range: Lower -15% = $5,624,000; Upper +30% = $8,602,000]**										**6,617,000**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
50														
51			**ESTIMATE INPUTS/ASSUMPTIONS**	**UNIT**	**QTY**									
52														
53			Rounding Factor (Round values to this many places)	--	-2									
54			Grand Total Lower Range Multiplier	--	0.85									
55			Grand Total Upper Range Multiplier	--	1.3									
56			Labor Rate	$ / hr	85.00									
57														
58			**CIVIL/EARTHWORK (GASIFIER SITE ONLY)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
59	1		Site Clearing - Clear & Grub	acre	0.06	3,020.00		200	92.571	6	85.00	500		700
60	1		Site Grading - Fill & Compaction	yd^3	310	1.46		500	0.018	6	85.00	500		1,000
61	1		• Site - Width	ft	31									
62	1		• Site - Length	ft	91									
63	1		• Site Clearing - Cut Depth	ft	3.0									
64	1													
65	1		Foundation Preparation - Excavation	yd^3	260	1.50		400	0.150	39	85.00	3,300		3,700
66	1		Foundation Preparation - Backfill	yd^3	65	20.00		1,300	0.060	4	85.00	300		1,600
67	1		• Excavation - Depth	ft	2.60									
68	1		• Backfill - Depth	ft	0.65									
69	1		• Bay-1 - Qty	each	3									
70	1		• Bay-1 - Width	ft	30									
71	1		• Bay-1 - Length	ft	30									
72	1		• Bay-2 - Qty	each	0									
73	1		• Bay-2 - Width	ft	0									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
74	1		• Bay-2 - Length	ft	0									
75	1													
76	1		Site Grading & Foundation Preparation - Equipment Rental	lot	1	40,000.00							40,000	40,000
77	1													
78	1		Piles (16" Diameter)	each	92	2,340.00		214,800	12.000	1102	85.00	93,600		308,400
79	1		Piles - Equipment Rental	lot	1	20,000.00							20,000	20,000
80	1		• Pile - Density	pile / ft^2	0.034									
81	1		• Pile - Length	ft	60									
82	1		• Casing	included										
83	1													
84	1		Concrete - Miscellaneous	yd^3	10.0	500.00		5,000	12.000	120	85.00	10,200		15,200
85	1													
86	1		Roads	lot	0	0.00							0	0
87	1		Paving	lot	0	0.00							0	0
88	1		Retention Ponds	lot	0	0.00							0	0
89	1		Ditches / Culverts	lot	0	0.00							0	0
90	1		Containment Berms	lot	0	0.00							0	0
91	1		Sumps	lot	0	0.00							0	0
92	1		Hydrants	lot	0	0.00							0	0
93	1													
94			**BUILDINGS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
95	2b		Concrete Slab - Pile Cap / Foundation	yd^3	250	250.00		62,500	6.000	1500	85.00	127,500		190,000
96	2b		• Concrete Slab - Thickness	in	30									
97	2b													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
98	2b		Concrete Slab - Elevated - Bay-1	qty	0									
99	2b		Concrete Slab - Elevated - Bay-1	yd^3	0	400.00		0	10.000	0	85.00	0		0
100	2b		• Concrete Slab - Thickness	in	6									
101	2b													
102	2b		Steel - Structural Steel	short ton	39	3,180.00		124,500	21.000	822	85.00	69,900		194,400
103	2b		Steel - Miscellaneous	short ton	3	4,740.00		13,000	68.000	186	85.00	15,800		28,800
104	2b		Steel - Grating & Guardrail	short ton	13	4,740.00		61,800	34.000	443	85.00	37,700		99,500
105	2b		Steel - Access Stairs	short ton	2	4,740.00		7,800	68.000	112	85.00	9,500		17,300
106	2b		• Total Weight of Equipment in Building	short ton	284									
107	2b		• Ratio of Building Structural Steel Wt to Equip Wt	--	0.138									
108	2b		• Ratio of Misc Steel Wt to Building Structural Steel Wt	--	0.070									
109	2b		• Ratio of Grating & Guardrail Steel Wt to Bldg Structural Steel Wt	--	0.333									
110	2b		• Ratio of Access Stairs Steel Wt to Bldg Structural Steel Wt	--	0.042									
111	2b		• Galvanized coating	included										
112	2b													
113	2b		Steel Handling - Equipment Rental	lot	1	130,000.00							130,000	130,000
114	2b													
115	2b		Masonry, Carpentry, Paint	lot	0	0.00							0	0
116	2b		Sprinklers	lot	0	0.00							0	0
117	2b		Roofing	lot	0	0.00							0	0
118	2b		Siding	lot	0	0.00							0	0
119	2b													
120			**EQUIPMENT FOUNDATIONS/SUPPORTS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
121	2e		Large Equipment Pedistals	yd^3	7.0	307		2,100	9.290	65	85.00	5,500		7,600

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
122	2b		• Bed Media Transporter	each	1									
123	2b		• Not Used	each	0									
124	2b		• Not Used	each	0									
125	2e		• Large Equipment Pedistal Length	ft	8.0									
126	2e		• Large Equipment Pedistal Width	ft	8.0									
127	2e		• Large Equipment Pedistal Thickness	in	36.0									
128	2e													
129			**PIPING INCLUDING FITTINGS (NATURAL GAS, PROCESS WATER, COOLING WATER, INERT GAS, PROCESS AIR, AND STEAM)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
130	3		Isolation Valves per 100 Linear Feet of Pipe	each	4									
131	3		Check Valves per 100 Linear Feet of Pipe	each	2									
132	3													
133	3		1" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	150	7.01		1,100	0.445	67	85.00	5,700		6,800
134	3		1" Valves • Carbon Steel • 150# • Wedge Gate	each	6	710		4,300	0.860	5	85.00	400		4,700
135	3		1" Valves • Carbon Steel • 150# • Check	each	3	660		2,000	0.860	3	85.00	200		2,200
136	3													
137	3		2" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	60	9.38		600	0.726	44	85.00	3,700		4,300
138	3		2" Valves • Carbon Steel • 150# • Wedge Gate	each	2.4	710		1,700	0.860	2	85.00	200		1,900

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
139	3		2" Valves • Carbon Steel • 150# • Check	each	1.2	660		800	0.860	1	85.00	100		900
140	3													
141	3		3" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	12.03		0	0.821	-	85.00	0		0
142	3		3" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,000		0	1.250	-	85.00	0		0
143	3		3" Valves • Carbon Steel • 150# • Check	each	0	780		0	1.250	-	85.00	0		0
144	3													
145	3		4" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	100	15.82		1,600	0.907	91	85.00	7,700		9,300
146	3		4" Valves • Carbon Steel • 150# • Wedge Gate	each	4	1,250		5,000	1.530	6	85.00	500		5,500
147	3		4" Valves • Carbon Steel • 150# • Check	each	2	1,125		2,300	1.530	3	85.00	300		2,600
148	3													
149	3		6" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	24.06		0	1.302	-	85.00	0		0
150	3		6" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,850		0	2.000	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
151	3		6" Valves • Carbon Steel • 150# • Check	each	0	1,750		0	2.000	-	85.00	0		0
152	3													
153	3		Eye Wash / Shower Stations	each	2	1,150		2,300	13.500	27	85.00	2,300		4,600
154	3		Hose Stations	each	2	1,150		2,300	13.500	27	85.00	2,300		4,600
155	3		Fire Water Piping	lot	0	-		0		-	85.00	0		0
156	3													
157			**ELECTRICAL**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
158	4		5 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	3,780		0	50.460	-	85.00	0		0
159	4		10 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	3,929		0	52.230	-	85.00	0		0
160	4		25 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	5,762		5,800	64.170	64	85.00	5,500		11,300
161	4		50-70 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	8,421		8,400	88.770	89	85.00	7,500		15,900
162	4		100 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	11,906		0	127.770	-	85.00	0		0
163	4		200 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	22,350		0	167.220	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
164	4		250 HP Motor Wiring • 200 ft of Wire • Medium Voltage • 1C Conduit • Wire Terminations	each	0	32,313		0	160.890	-	85.00	0		0
165	4													
166	4		Control Cabling, Terminations, Conduit	lot	1	100,000							100,000	100,000
167	4		Lighting	lot	1	100,000							100,000	100,000
168	4		Control System UPS	lot	1	25,000							25,000	25,000
169	4		Lightning Protection	lot	1	25,000							25,000	25,000
170	4		Motors	included										
171	4		Medium/High Voltage Feeder	lot	0	0							0	0
172	4		Unit Substation(s)	lot	0	0							0	0
173	4		Power Distribution To MCC Room	lot	0	0							0	0
174	4		Power Distribution To Control Rack Room	lot	0	0							0	0
175	4													
176			**INSTRUMENTATION**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
177	5		Field Instruments, Installation & Wiring	lot	1	135,736		135,700						135,700
178	5		• Actuated Valve Hook Up	included										
179	5		• Controls Software & Hardware (PLC Ctrl System w/HMI)	included										
180	5		• I/O Racks	included										
181	5		• Remote Termination	included										
182	5													
183			**PROCESS INSULATION / PAINTING**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
184	6		Cal Sil, 1-1/2" Wall, 4" Ips Al Jkt (Steam Piping Only) (Assume Only Steam Piping Is Insulated)	linear ft	200	7.3		1,500	0.343	69	85.00	5,800		7,300

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
185	6		Paint Finish Coat • Temperature Indicating Paint • For use on Reactors, Duct & Cyclones	ft^2	2,979	0.210		600	0.009	27	49.00	1,300		1,900
186	6		Equipment Insulation	lot	0	0.00							0	0
187	6													
188			**EQUIPMENT**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
189	7		Equipment Installation Labor Hours As a Function of Equipment Weight	hrs / ston	6.0									
190	7													
191	7		GASIFIER REACTOR & CYCLONE											
192	7		Gasifier Reactor	1		546,361		546,400	690	690	85.00	58,700		605,100
193	7		Gasifier Reactor Startup Burner	1		150,000		150,000	10	10	85.00	900		150,900
194	7		Duct-01 (Refractory Lined) - From Gasifier Reactor To Gasifier Cyclone	1		161,893		161,900	60	60	85.00	5,100		167,000
195	7		Gasifier Cyclone	1		160,924		160,900	240	240	85.00	20,400		181,300
196	7		Line-01 (Refractory Lined) - From Gasifier Cyclone To Gasifier Reactor	1		191,879		191,900	140	140	85.00	11,900		203,800
197	7		Duct-02 (Refractory Lined) - From Gasifier Cyclone To Battery Limit	1		201,035		201,000	100	100	85.00	8,500		209,500
198	7		Line-02 (Refractory Lined) - From Gasifier Reactor To Ash Cooling Screw Conveyor	1		130,945		130,900	60	60	85.00	5,100		136,000
199	7		BED MEDIA MAKEUP SYSTEM											
200	7		Bed Media Truck Unloading Station	1		8,500		8,500	10	10	85.00	900		9,400
201	7		Piping - From Bed Media Truck Unloading Station To Bed Media Storage Bin	1	INCL	0		0	-	-	85.00	0		0
202	7		Bed Media Storage Bin	1		105,819		105,800	50	50	85.00	4,300		110,100
203	7		Bed Media Nitrogen Tank	1		83,111		83,100	50	50	85.00	4,300		87,400
204	7		Piping - From Bed Media Nitrogen Tank To Bed Media Pneumatic Transporter	1		2,500		2,500	10	10	85.00	900		3,400
205	7		Bed Media Pneumatic Transporter	1		250,000		250,000	10	10	85.00	900		250,900
206	7		Piping - From Bed Media Pneumatic Transporter To Gasifier Reactor	1	INCL	0		0	-	-	85.00	0		0
207	7		ASH REMOVAL SYSTEM											
208	7		Ash Cooling Screw Conveyor	1		159,497		159,500	50	50	85.00	4,300		163,800

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
209	7		Ash Cooling Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
210	7		Piping - From Ash Cooling Screw Conveyor To Ash Discharge Hopper	1		5,000		5,000	10	10	85.00	900		5,900
211	7		Ash Discharge Hopper	1		165,732		165,700	90	90	85.00	7,700		173,400
212	7		Ash Lock Hopper Inlet Block Valve	1		15,000		15,000	10	10	85.00	900		15,900
213	7		Piping - From Ash Discharge Hopper To Ash Lock Hopper	1		5,000		5,000	10	10	85.00	900		5,900
214	7		Ash Lock Hopper	1		165,185		165,200	90	90	85.00	7,700		172,900
215	7		Ash Lock Hopper Discharge Screw Conveyor	1		310,935		310,900	100	100	85.00	8,500		319,400
216	7		Ash Lock Hopper Discharge Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
217	7		Ash Lock Hopper Outlet Block Valve	1		15,000		15,000	10	10	85.00	900		15,900
218	7		Piping - From Ash Lock Hopper To Battery Limit	1		8,000		8,000	10	10	85.00	900		8,900
219	7		0											
220	7		0											
221	7		0											
222	7		0											
223	7		0											
224	7		0											
225	7		0											
226	7		0											
227	7		0											
228	7		0											
229	7													
230	7		Inert Gas System	lot	0	0.00							0	0
231	7		Flue Gas ID Fans (Including Drives)	lot	0	0.00							0	0
232	7		Flue Gas Scrubbers (Including Scrubber, Separator, Pump, Piping)	lot	0	0.00							0	0
233	7		Stack	lot	0	0.00							0	0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
234	7		Cooling Tower/Cooling System	lot	0	0.00							0	0
235	7													
236			**DEMOLITION**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
237	8		Demolition	lot	0	0.00							0	0
238														
			Total Direct Cost (TDC)				**0**	**3,512,100**		**6,738**	**84.95**	**572,400**	**440,000**	**4,524,500**

APPENDIX H-3
DETAILED ESTIMATE
CAPITAL COST ESTIMATE DETAILS
HP BIOMASS FEED SYSTEM MODEL MODEL

Harris Group Inc.
Engineering for Optimum Performance®

CAPITAL COST ESTIMATE

NATIONAL RENEWABLE ENERGY LABORATORY
HP BIOMASS FEED SYSTEM - SINGLE LINE
GOLDEN, COLORADO

HARRIS GROUP PROJECT NO.: 30300.00

DATE: 08/03/2012

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
11			**SUMMARY BY WORK CATEGORY**	**% of TDC**										
12	1		Civil / Earthwork	0.0%			0	0		-		0	0	0
13	2b		Buildings	0.0%			0	0		-		0	0	0
14	2e		Equipment Foundations / Supports	0.0%			0	0		-		0	0	0
15	3		Piping	1.9%			0	25,200		317	85.23	27,000	0	52,200
16	4		Electrical	2.5%			0	9,700		116	85.05	9,900	49,000	68,600
17	5		Instrumentation	3.0%			0	81,800		-		0	0	81,800
18	6		Process Insulation / Painting	0.0%			0	0		-		0	0	0
19	7		Equipment	92.6%			0	2,455,000		800	85.63	68,500	0	2,523,500
20	8		Demolition	0.0%			0	0		-		0	0	0
21			**Total Direct Cost (TDC)**				**0**	**2,571,700**		**1,233**	**85.47**	**105,400**	**49,000**	**2,726,100**
22														
23			Contractor Premium Pay									0		0
24			Contractor's Indirects as % of labor									0		0
25			Contractor's markup as % of matls & subs									0		0
26			**Total Construction Cost (TCC)**				**0**	**2,571,700**		**1,233**	**85.47**	**105,400**	**49,000**	**2,726,100**
27				**% of TCC**										
28			Engineering (Consultant)	10.0%										272,600
29			Owner Engineering	2.0%										54,500
30			Pre-Project Cost	0.5%										13,600
31			Other Outside Engineering Services/Construction Mngnt	2.0%										54,500
32			Environmental or Legislative Costs	1.0%										27,300
33			Capitalized Spares	3.0%										81,800
34			Sales Taxes	3.5%										95,400
35			Construction Insurance	0.0%										0
36			Freight	3.0%										81,800
37			**Total Indirect Cost (TIC)**	25.0%										681,500
38														
39			**Total Direct and Indirect Costs (TD&IC)**											**3,407,600**
40				**% of TD&IC**										
41			Contingency	15.0%										511,100
42			**Total Process Plant & Equipment (PP&E)**											**3,918,700**
43				**% of TD&IC**										
44			Escalation	0%										0
45			Capitalized Interest	0%										0
46			Deferred Start-Up Costs	0%										0
47			Working Capital	0%										0
48			Operator Training and Start-up	2%										68,200
49			**Grand Total**	**[Range: Lower -15% = $3,389,000; Upper +30% = $5,183,000]**										**3,986,900**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
50														
51			**ESTIMATE INPUTS/ASSUMPTIONS**	UNIT	QTY									
52														
53			Rounding Factor (Round values to this many places)	--	-2									
54			Grand Total Lower Range Multiplier	--	0.85									
55			Grand Total Upper Range Multiplier	--	1.3									
56			Labor Rate	$ / hr	85.00									
57														
58			**CIVIL/EARTHWORK (GASIFIER SITE ONLY)**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
59	1		Site Clearing - Clear & Grub	acre	0.00	3,020.00		0	92.571	-	85.00	0		0
60	1		Site Grading - Fill & Compaction	yd^3	0	1.46		0	0.018	-	85.00	0		0
61	1		• Site - Width	ft	0									
62	1		• Site - Length	ft	0									
63	1		• Site Clearing - Cut Depth	ft	0.0									
64	1													
65	1		Foundation Preparation - Excavation	yd^3	0	1.50		0	0.150	-	85.00	0		0
66	1		Foundation Preparation - Backfill	yd^3	0	20.00		0	0.060	-	85.00	0		0
67	1		• Excavation - Depth	ft	0.00									
68	1		• Backfill - Depth	ft	0.00									
69	1		• Bay-1 - Qty	each	0									
70	1		• Bay-1 - Width	ft	0									
71	1		• Bay-1 - Length	ft	0									
72	1		• Bay-2 - Qty	each	0									
73	1		• Bay-2 - Width	ft	0									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
74	1		• Bay-2 - Length	ft	0									
75	1													
76	1		Site Grading & Foundation Preparation - Equipment Rental	lot	0	40,000.00							0	0
77	1													
78	1		Piles (16" Diameter)	each	0	2,340.00		0	12.000	0	85.00	0		0
79	1		Piles - Equipment Rental	lot	0	20,000.00							0	0
80	1		• Pile - Density	pile / ft^2	0.034									
81	1		• Pile - Length	ft	0									
82	1		• Casing	included										
83	1													
84	1		Concrete - Miscellaneous	yd^3	0.0	500.00		0	12.000	0	85.00	0		0
85	1													
86	1		Roads	lot	0	0.00							0	0
87	1		Paving	lot	0	0.00							0	0
88	1		Retention Ponds	lot	0	0.00							0	0
89	1		Ditches / Culverts	lot	0	0.00							0	0
90	1		Containment Berms	lot	0	0.00							0	0
91	1		Sumps	lot	0	0.00							0	0
92	1		Hydrants	lot	0	0.00							0	0
93	1													
94			**BUILDINGS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
95	2b		Concrete Slab - Pile Cap / Foundation	yd^3	0	250.00		0	6.000	0	85.00	0		0
96	2b		• Concrete Slab - Thickness	in	0									
97	2b													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
98	2b		Concrete Slab - Elevated - Bay-1	yd^3	0	400.00		0	10.000	0	85.00	0		0
99	2b		• Concrete Slab - Thickness	in	0									
100	2b													
101	2b		Steel - Structural Steel	short ton	0	3,180.00		0	21.000	-	85.00	0		0
102	2b		Steel - Miscellaneous	short ton	0	4,740.00		0	68.000	-	85.00	0		0
103	2b		Steel - Grating & Guardrail	short ton	0	4,740.00		0	34.000	-	85.00	0		0
104	2b		Steel - Access Stairs	short ton	0	4,740.00		0	68.000	-	85.00	0		0
105	2b		• Total Weight of Equipment in Building	short ton	0									
106	2b		• Ratio of Building Structural Steel Wt to Equip Wt	--	0.138									
107	2b		• Ratio of Misc Steel Wt to Building Structural Steel Wt	--	0.070									
108	2b		• Ratio of Grating & Guardrail Steel Wt to Bldg Structural Steel Wt	--	0.333									
109	2b		• Ratio of Access Stairs Steel Wt to Bldg Structural Steel Wt	--	0.042									
110	2b		• Galvanized coating	included										
111	2b													
112	2b		Steel Handling - Equipment Rental	lot	0	130,000.00							0	0
113	2b													
114	2b		Masonry, Carpentry, Paint	lot	0	0.00							0	0
115	2b		Sprinklers	lot	0	0.00							0	0
116	2b		Roofing	lot	0	0.00							0	0
117	2b		Siding	lot	0	0.00							0	0
118	2b													
119			**EQUIPMENT FOUNDATIONS/SUPPORTS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
120	2e		Large Equipment Pedistals	yd^3	0.0	307		0	9.290	-	85.00	0		0
121	2b		• Bed Media Transporter	each	0									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL: QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR: L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
122	2b		• Not Used	each	0									
123	2b		• Not Used	each	0									
124	2e		• Large Equipment Pedistal Length	ft	8.0									
125	2e		• Large Equipment Pedistal Width	ft	8.0									
126	2e		• Large Equipment Pedistal Thickness	in	36.0									
127	2e													
128			**PIPING INCLUDING FITTINGS (NATURAL GAS, PROCESS WATER, COOLING WATER, INERT GAS, PROCESS AIR, AND STEAM)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
129	3		Isolation Valves per 100 Linear Feet of Pipe	each	4									
130	3		Check Valves per 100 Linear Feet of Pipe	each	2									
131	3													
132	3		1" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	7.01		0	0.445	-	85.00	0		0
133	3		1" Valves • Carbon Steel • 150# • Wedge Gate	each	0	710		0	0.860	-	85.00	0		0
134	3		1" Valves • Carbon Steel • 150# • Check	each	0	660		0	0.860	-	85.00	0		0
135	3													
136	3		2" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	9.38		0	0.726	-	85.00	0		0
137	3		2" Valves • Carbon Steel • 150# • Wedge Gate	each	0	710		0	0.860	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
138	3		2" Valves • Carbon Steel • 150# • Check	each	0	660		0	0.860	-	85.00	0		0
139	3													
140	3		3" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	12.03		0	0.821	-	85.00	0		0
141	3		3" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,000		0	1.250	-	85.00	0		0
142	3		3" Valves • Carbon Steel • 150# • Check	each	0	780		0	1.250	-	85.00	0		0
143	3													
144	3		4" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	250	15.82		4,000	0.907	227	85.00	19,300		23,300
145	3		4" Valves • Carbon Steel • 150# • Wedge Gate	each	10	1,250		12,500	1.530	15	85.00	1,300		13,800
146	3		4" Valves • Carbon Steel • 150# • Check	each	5	1,125		5,600	1.530	8	85.00	700		6,300
147	3													
148	3		6" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	24.06		0	1.302	-	85.00	0		0
149	3		6" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,850		0	2.000	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
150	3		6" Valves • Carbon Steel • 150# • Check	each	0	1,750		0	2.000	-	85.00	0		0
151	3													
152	3		8" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	50	24.06		1,200	1.302	65	85.00	5,500		6,700
153	3		8" Valves • Carbon Steel • 150# • Wedge Gate	each	1	1,850		1,900	2.000	2	85.00	200		2,100
154	3		8" Valves • Carbon Steel • 150# • Check	each	0	1,750		0	2.000	-	85.00	0		0
155	3													
156	3		Eye Wash / Shower Stations	each	0	1,150		0	13.500	-	85.00	0		0
157	3		Hose Stations	each	0	1,150		0	13.500	-	85.00	0		0
158	3		Fire Water Piping	lot	0	-		0		-	85.00	0		0
159	3													
160			**ELECTRICAL**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
161	4		5 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	3,780		0	50.460	-	85.00	0		0
162	4		10 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	3,929		3,900	52.230	52	85.00	4,400		8,300
163	4		15 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	55.000	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
164	4		20 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	60.000	-	85.00	0		0
165	4		25 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	5,762		5,800	64.170	64	85.00	5,500		11,300
166	4		30 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	72.000	-	85.00	0		0
167	4		50 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	8,421		0	78.000	-	85.00	0		0
168	4		75 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	8,421		0	88.770	-	85.00	0		0
169	4		100 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	11,906		0	127.770	-	85.00	0		0
170	4		200 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	22,350		0	167.220	-	85.00	0		0
171	4		250 HP Motor Wiring • 200 ft of Wire • Medium Voltage • 1C Conduit • Wire Terminations	each	0	32,313		0	160.890	-	85.00	0		0
172	4													
173	4		Control Cabling, Terminations, Conduit	each	2	12,000							24,000	24,000
174	4		Lighting	lot	0	100,000							0	0
175	4		Control System UPS	lot	0	25,000							0	0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
176	4		Lightning Protection	lot	1	25,000							25,000	25,000
177	4		Motors	included										
178	4		Medium/High Voltage Feeder	lot	0	0							0	0
179	4		Unit Substation(s)	lot	0	0							0	0
180	4		Power Distribution To MCC Room	lot	0	0							0	0
181	4		Power Distribution To Control Rack Room	lot	0	0							0	0
182	4													
183			**INSTRUMENTATION**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
184	5		Field Instruments, Installation & Wiring	lot	1	81,782		81,800						81,800
185	5		• Actuated Valve Hook Up	included										
186	5		• Controls Software & Hardware (PLC Ctrl System w/HMI)	included										
187	5		• I/O Racks	included										
188	5		• Remote Termination	included										
189	5													
190			**PROCESS INSULATION / PAINTING**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
191	6		Cal Sil, 1-1/2" Wall, 4" Ips Al Jkt (Steam Piping Only) (Assume Only Steam Piping Is Insulated)	linear ft	0	7.3		0	0.343	-	85.00	0		0
192	6		Paint Finish Coat • Temperature Indicating Paint • For use on Reactors, Duct & Cyclones	ft^2	0	0.210		0	0.009	-	49.00	0		0
193	6		Equipment Insulation	lot	0	0.00							0	0
194	6													
195			**EQUIPMENT**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
196	7		Equipment Installation Labor Hours As a Function of Equipment Weight	hrs / ston	6.0									
197	7													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
198	7		BIOMASS FEED LINE											
199	7		Biomass Lock Hopper Feed Equipment	1		250,000		250,000	-	-	85.00	0		250,000
200	7		Biomass Lock Hopper Feed Chute	1		15,000		15,000	10	10	85.00	900		15,900
201	7		Biomass Lock Hopper Inlet Block Valve	1		75,000		75,000	10	10	85.00	900		75,900
202	7		Biomass Lock Hopper	1		176,400		176,400	120	120	85.00	10,200		186,600
203	7		Biomass Lock Hopper Bottom Reclaimer	1		232,100		232,100	80	80	85.00	6,800		238,900
204	7		Biomass Lock Hopper Rotating Dischrage Screw Motor	1	INCL	0		0	-	-	85.00	0		0
205	7		Biomass Lock Hopper Outlet Block Valve	1		75,000		75,000	10	10	85.00	900		75,900
206	7		Biomass Lock Hopper Vent Filter	1		15,000		15,000	10	10	85.00	900		15,900
207	7		Biomass Lock Hopper Vent Filter Valve	1		15,000		15,000	10	10	85.00	900		15,900
208	7		Biomass Metering Bin	1		197,100		197,100	130	130	85.00	11,100		208,200
209	7		Biomass Metering Bin Rotating Dischrage Screw	1		248,300		248,300	80	80	85.00	6,800		255,100
210	7		Biomass Metering Bin Rotating Dischrage Screw Motor	1	INCL	0		0	-	-	85.00	0		0
211	7		Biomass Transfer Screw Conveyor	1		764,300		764,300	230	230	85.00	19,600		783,900
212	7		Biomass Transfer Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
213	7		Biomass Transfer Screw Conveyor Discharge Expansion Joint	1		57,500		57,500	10	10	85.00	900		58,400
214	7		Biomass Transfer Screw Conveyor Discharge Chute	1		15,000		15,000	10	10	85.00	900		15,900
215	7		Biomass Transfer Screw Conveyor Discharge Chute Block Valve	1		75,000		75,000	10	10	85.00	900		75,900
216	7		Gasifier Injection Auger	1		244,300		244,300	80	80	85.00	6,800		251,100
217	7		Gasifier Injection Auger Motor	1	INCL	0		0	-	-	85.00	0		0
218	7		0											
219	7		0											
220	7		0											
221	7		0											
222	7		0											

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
223	7		0											
224	7		0											
225	7		0											
226	7		0											
227	7		0											
228	7		0											
229	7		0											
230	7		0											
231	7		0											
232	7		0											
233	7		0											
234	7		0											
235	7		0											
236	7		0											
237	7													
238	7		Inert Gas System	lot	0	0.00							0	0
239	7		Flue Gas ID Fans (Including Drives)	lot	0	0.00							0	0
240	7		Flue Gas Scrubbers (Including Scrubber, Separator, Pump, Piping)	lot	0	0.00							0	0
241	7		Stack	lot	0	0.00							0	0
242	7		Cooling Tower/Cooling System	lot	0	0.00							0	0
243	7													
244			**DEMOLITION**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
245	8		Demolition	lot	0	0.00							0	0
246														
			Total Direct Cost (TDC)				**0**	**2,571,700**		**1,233**	**85.47**	**105,400**	**49,000**	**2,726,100**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		

APPENDIX H-4
DETAILED ESTIMATE
CAPITAL COST ESTIMATE DETAILS
LP BIOMASS FEED SYSTEM MODEL

Harris Group Inc.
Engineering for Optimum Performance®

CAPITAL COST ESTIMATE

NATIONAL RENEWABLE ENERGY LABORATORY
LP BIOMASS FEED SYSTEM - SINGLE LINE
GOLDEN, COLORADO

HARRIS GROUP PROJECT NO.: 30300.00

DATE: 08/03/2012

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
11			**SUMMARY BY WORK CATEGORY**	**% of TDC**										
12	1		Civil / Earthwork	0.0%			0	0		-		0	0	0
13	2b		Buildings	0.0%			0	0		-		0	0	0
14	2e		Equipment Foundations / Supports	0.0%			0	0		-		0	0	0
15	3		Piping	2.4%			0	25,200		317	85.23	27,000	0	52,200
16	4		Electrical	3.2%			0	9,700		116	85.05	9,900	49,000	68,600
17	5		Instrumentation	3.0%			0	64,300		-		0	0	64,300
18	6		Process Insulation / Painting	0.0%			0	0		-		0	0	0
19	7		Equipment	91.4%			0	1,911,100		560	85.54	47,900	0	1,959,000
20	8		Demolition	0.0%			0	0		-		0	0	0
21			**Total Direct Cost (TDC)**				**0**	**2,010,300**		**993**	**85.38**	**84,800**	**49,000**	**2,144,100**
22														
23			Contractor Premium Pay									0		0
24			Contractor's Indirects as % of labor									0		0
25			Contractor's markup as % of matls & subs									0		0
26			**Total Construction Cost (TCC)**				**0**	**2,010,300**		**993**	**85.38**	**84,800**	**49,000**	**2,144,100**
27				**% of TCC**										
28			Engineering (Consultant)	10.0%										214,400
29			Owner Engineering	2.0%										42,900
30			Pre-Project Cost	0.5%										10,700
31			Other Outside Engineering Services/Construction Mngnt	2.0%										42,900
32			Environmental or Legislative Costs	1.0%										21,400
33			Capitalized Spares	3.0%										64,300
34			Sales Taxes	3.5%										75,000
35			Construction Insurance	0.0%										0
36			Freight	3.0%										64,300
37			**Total Indirect Cost (TIC)**	25.0%										535,900
38														
39			**Total Direct and Indirect Costs (TD&IC)**											**2,680,000**
40				**% of TD&IC**										
41			Contingency	15.0%										402,000
42			**Total Process Plant & Equipment (PP&E)**											**3,082,000**
43				**% of TD&IC**										
44			Escalation	0%										0
45			Capitalized Interest	0%										0
46			Deferred Start-Up Costs	0%										0
47			Working Capital	0%										0
48			Operator Training and Start-up	2%										53,600
49			**Grand Total**	**[Range: Lower -15% = $2,665,000; Upper +30% = $4,076,000]**										**3,135,600**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
50														
51			**ESTIMATE INPUTS/ASSUMPTIONS**	UNIT	QTY									
52														
53			Rounding Factor (Round values to this many places)	--	-2									
54			Grand Total Lower Range Multiplier	--	0.85									
55			Grand Total Upper Range Multiplier	--	1.3									
56			Labor Rate	$ / hr	85.00									
57														
58			**CIVIL/EARTHWORK (GASIFIER SITE ONLY)**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
59	1		Site Clearing - Clear & Grub	acre	0.00	3,020.00		0	92.571	-	85.00	0		0
60	1		Site Grading - Fill & Compaction	yd^3	0	1.46		0	0.018	-	85.00	0		0
61	1		• Site - Width	ft	0									
62	1		• Site - Length	ft	0									
63	1		• Site Clearing - Cut Depth	ft	0.0									
64	1													
65	1		Foundation Preparation - Excavation	yd^3	0	1.50		0	0.150	-	85.00	0		0
66	1		Foundation Preparation - Backfill	yd^3	0	20.00		0	0.060	-	85.00	0		0
67	1		• Excavation - Depth	ft	0.00									
68	1		• Backfill - Depth	ft	0.00									
69	1		• Bay-1 - Qty	each	0									
70	1		• Bay-1 - Width	ft	0									
71	1		• Bay-1 - Length	ft	0									
72	1		• Bay-2 - Qty	each	0									
73	1		• Bay-2 - Width	ft	0									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
74	1		• Bay-2 - Length	ft	0									
75	1													
76	1		Site Grading & Foundation Preparation - Equipment Rental	lot	0	40,000.00							0	0
77	1													
78	1		Piles (16" Diameter)	each	0	2,340.00		0	12.000	0	85.00	0		0
79	1		Piles - Equipment Rental	lot	0	20,000.00							0	0
80	1		• Pile - Density	pile / ft^2	0.034									
81	1		• Pile - Length	ft	0									
82	1		• Casing	included										
83	1													
84	1		Concrete - Miscellaneous	yd^3	0.0	500.00		0	12.000	0	85.00	0		0
85	1													
86	1		Roads	lot	0	0.00							0	0
87	1		Paving	lot	0	0.00							0	0
88	1		Retention Ponds	lot	0	0.00							0	0
89	1		Ditches / Culverts	lot	0	0.00							0	0
90	1		Containment Berms	lot	0	0.00							0	0
91	1		Sumps	lot	0	0.00							0	0
92	1		Hydrants	lot	0	0.00							0	0
93	1													
94			**BUILDINGS**	UNIT	QTY	UNIT PRICE	OWNER FURNISHED	CONTRACTOR FURNISHED	LABOR HOURS / UNIT	TOTAL LABOR HOURS	LABOR RATE	TOTAL LABOR COST	SUBCONTR TOTAL (Lab & Mat)	TOTAL
95	2b		Concrete Slab - Pile Cap / Foundation	yd^3	0	250.00		0	6.000	0	85.00	0		0
96	2b		• Concrete Slab - Thickness	in	0									
97	2b													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
98	2b		Concrete Slab - Elevated - Bay-1	yd^3	0	400.00		0	10.000	0	85.00	0		0
99	2b		• Concrete Slab - Thickness	in	0									
100	2b													
101	2b		Steel - Structural Steel	short ton	0	3,180.00		0	21.000	-	85.00	0		0
102	2b		Steel - Miscellaneous	short ton	0	4,740.00		0	68.000	-	85.00	0		0
103	2b		Steel - Grating & Guardrail	short ton	0	4,740.00		0	34.000	-	85.00	0		0
104	2b		Steel - Access Stairs	short ton	0	4,740.00		0	68.000	-	85.00	0		0
105	2b		• Total Weight of Equipment in Building	short ton	0									
106	2b		• Ratio of Building Structural Steel Wt to Equip Wt	--	0.138									
107	2b		• Ratio of Misc Steel Wt to Building Structural Steel Wt	--	0.070									
108	2b		• Ratio of Grating & Guardrail Steel Wt to Bldg Structural Steel Wt	--	0.333									
109	2b		• Ratio of Access Stairs Steel Wt to Bldg Structural Steel Wt	--	0.042									
110	2b		• Galvanized coating	included										
111	2b													
112	2b		Steel Handling - Equipment Rental	lot	0	130,000.00							0	0
113	2b													
114	2b		Masonry, Carpentry, Paint	lot	0	0.00							0	0
115	2b		Sprinklers	lot	0	0.00							0	0
116	2b		Roofing	lot	0	0.00							0	0
117	2b		Siding	lot	0	0.00							0	0
118	2b													
119			**EQUIPMENT FOUNDATIONS/SUPPORTS**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
120	2e		Large Equipment Pedistals	yd^3	0.0	307		0	9.290	-	85.00	0		0
121	2b		• Bed Media Transporter	each	0									

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
122	2b		• Not Used	each	0									
123	2b		• Not Used	each	0									
124	2e		• Large Equipment Pedistal Length	ft	8.0									
125	2e		• Large Equipment Pedistal Width	ft	8.0									
126	2e		• Large Equipment Pedistal Thickness	in	36.0									
127	2e													
128			**PIPING INCLUDING FITTINGS (NATURAL GAS, PROCESS WATER, COOLING WATER, INERT GAS, PROCESS AIR, AND STEAM)**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
129	3		Isolation Valves per 100 Linear Feet of Pipe	each	4									
130	3		Check Valves per 100 Linear Feet of Pipe	each	2									
131	3													
132	3		1" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	7.01		0	0.445	-	85.00	0		0
133	3		1" Valves • Carbon Steel • 150# • Wedge Gate	each	0	710		0	0.860	-	85.00	0		0
134	3		1" Valves • Carbon Steel • 150# • Check	each	0	660		0	0.860	-	85.00	0		0
135	3													
136	3		2" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	9.38		0	0.726	-	85.00	0		0
137	3		2" Valves • Carbon Steel • 150# • Wedge Gate	each	0	710		0	0.860	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
138	3		2" Valves • Carbon Steel • 150# • Check	each	0	660		0	0.860	-	85.00	0		0
139	3													
140	3		3" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	12.03		0	0.821	-	85.00	0		0
141	3		3" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,000		0	1.250	-	85.00	0		0
142	3		3" Valves • Carbon Steel • 150# • Check	each	0	780		0	1.250	-	85.00	0		0
143	3													
144	3		4" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	250	15.82		4,000	0.907	227	85.00	19,300		23,300
145	3		4" Valves • Carbon Steel • 150# • Wedge Gate	each	10	1,250		12,500	1.530	15	85.00	1,300		13,800
146	3		4" Valves • Carbon Steel • 150# • Check	each	5	1,125		5,600	1.530	8	85.00	700		6,300
147	3													
148	3		6" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	0	24.06		0	1.302	-	85.00	0		0
149	3		6" Valves • Carbon Steel • 150# • Wedge Gate	each	0	1,850		0	2.000	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	CONTRACTOR LABOR L.H. UNIT	LABOR HOURS	RATE	TOTAL	SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
150	3		6" Valves • Carbon Steel • 150# • Check	each	0	1,750		0	2.000	-	85.00	0		0
151	3													
152	3		8" Piping • Carbon Steel • Standard Weight • w/Fittings • No Valves	ft	50	24.06		1,200	1.302	65	85.00	5,500		6,700
153	3		8" Valves • Carbon Steel • 150# • Wedge Gate	each	1	1,850		1,900	2.000	2	85.00	200		2,100
154	3		8" Valves • Carbon Steel • 150# • Check	each	0	1,750		0	2.000	-	85.00	0		0
155	3													
156	3		Eye Wash / Shower Stations	each	0	1,150		0	13.500	-	85.00	0		0
157	3		Hose Stations	each	0	1,150		0	13.500	-	85.00	0		0
158	3		Fire Water Piping	lot	0	-		0		-	85.00	0		0
159	3													
160			**ELECTRICAL**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
161	4		5 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	3,780		0	50.460	-	85.00	0		0
162	4		10 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	3,929		3,900	52.230	52	85.00	4,400		8,300
163	4		15 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	55.000	-	85.00	0		0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
164	4		20 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	60.000	-	85.00	0		0
165	4		25 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	1	5,762		5,800	64.170	64	85.00	5,500		11,300
166	4		30 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	5,762		0	72.000	-	85.00	0		0
167	4		50 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	8,421		0	78.000	-	85.00	0		0
168	4		75 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	8,421		0	88.770	-	85.00	0		0
169	4		100 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	11,906		0	127.770	-	85.00	0		0
170	4		200 HP Motor Wiring • 200 ft of Wire • Low Voltage • 1C Conduit • Wire Terminations	each	0	22,350		0	167.220	-	85.00	0		0
171	4		250 HP Motor Wiring • 200 ft of Wire • Medium Voltage • 1C Conduit • Wire Terminations	each	0	32,313		0	160.890	-	85.00	0		0
172	4													
173	4		Control Cabling, Terminations, Conduit	each	2	12,000							24,000	24,000
174	4		Lighting	lot	0	100,000							0	0
175	4		Control System UPS	lot	0	25,000							0	0

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
176	4		Lightning Protection	lot	1	25,000							25,000	25,000
177	4		Motors	included										
178	4		Medium/High Voltage Feeder	lot	0	0							0	0
179	4		Unit Substation(s)	lot	0	0							0	0
180	4		Power Distribution To MCC Room	lot	0	0							0	0
181	4		Power Distribution To Control Rack Room	lot	0	0							0	0
182	4													
183			**INSTRUMENTATION**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
184	5		Field Instruments, Installation & Wiring	lot	1	64,324		64,300						64,300
185	5		• Actuated Valve Hook Up	included										
186	5		• Controls Software & Hardware (PLC Ctrl System w/HMI)	included										
187	5		• I/O Racks	included										
188	5		• Remote Termination	included										
189	5													
190			**PROCESS INSULATION / PAINTING**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
191	6		Cal Sil, 1-1/2" Wall, 4" Ips Al Jkt (Steam Piping Only) (Assume Only Steam Piping Is Insulated)	linear ft	0	7.3		0	0.343	-	85.00	0		0
192	6		Paint Finish Coat • Temperature Indicating Paint • For use on Reactors, Duct & Cyclones	ft^2	0	0.210		0	0.009	-	49.00	0		0
193	6		Equipment Insulation	lot	0	0.00							0	0
194	6													
195			**EQUIPMENT**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
196	7		Equipment Installation Labor Hours As a Function of Equipment Weight	hrs / ston	6.0									
197	7													

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
198	7		BIOMASS FEED LINE											
199	7		Biomass Metering Bin Distributor	1		250,000		250,000	-	-	85.00	0		250,000
200	7		Biomass Metering Bin Feed Chute	1		15,000		15,000	10	10	85.00	900		15,900
201	7		Biomass Metering Bin	1		196,700		196,700	130	130	85.00	11,100		207,800
202	7		Biomass Metering Bin Reclaim Screw	1		248,300		248,300	80	80	85.00	6,800		255,100
203	7		Biomass Metering Bin Reclaim Screw Motor	1	INCL	0		0	-	-	85.00	0		0
204	7		Biomass Transfer Screw Conveyor	1		764,300		764,300	230	230	85.00	19,600		783,900
205	7		Biomass Transfer Screw Conveyor Motor	1	INCL	0		0	-	-	85.00	0		0
206	7		Biomass Transfer Chute Expansion Joint	1		57,500		57,500	10	10	85.00	900		58,400
207	7		Biomass Transfer Chute	1		15,000		15,000	10	10	85.00	900		15,900
208	7		Biomass Transfer Chute Rotary Valve	1		120,000		120,000	10	10	85.00	900		120,900
209	7		Gasifier Injection Auger	1		244,300		244,300	80	80	85.00	6,800		251,100
210	7		Gasifier Injection Auger Motor	1	INCL	0		0	-	-	85.00	0		0
211	7		0											
212	7		0											
213	7		0											
214	7		0											
215	7		0											
216	7		0											
217	7		0											
218	7		0											
219	7		0											
220	7		0											
221	7		0											
222	7		0											

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		
223	7		0											
224	7		0											
225	7		0											
226	7		0											
227	7		0											
228	7		0											
229	7		0											
230	7		0											
231	7		0											
232	7		0											
233	7		0											
234	7		0											
235	7		0											
236	7		0											
237	7													
238	7		Inert Gas System	lot	0	0.00							0	0
239	7		Flue Gas ID Fans (Including Drives)	lot	0	0.00							0	0
240	7		Flue Gas Scrubbers (Including Scrubber, Separator, Pump, Piping)	lot	0	0.00							0	0
241	7		Stack	lot	0	0.00							0	0
242	7		Cooling Tower/Cooling System	lot	0	0.00							0	0
243	7													
244			**DEMOLITION**	**UNIT**	**QTY**	**UNIT PRICE**	**OWNER FURNISHED**	**CONTRACTOR FURNISHED**	**LABOR HOURS / UNIT**	**TOTAL LABOR HOURS**	**LABOR RATE**	**TOTAL LABOR COST**	**SUBCONTR TOTAL (Lab & Mat)**	**TOTAL**
245	8		Demolition	lot	0	0.00							0	0
246														
			Total Direct Cost (TDC)				**0**	**2,010,300**		**993**	**85.38**	**84,800**	**49,000**	**2,144,100**

Row	Category		DESCRIPTION	EQUIPMENT AND MATERIAL					CONTRACTOR LABOR				SUBCONTR TOTAL (Lab & Mat)	GRAND TOTAL
				QTY	UNIT	UNIT PRICE	OWNER FURN. TOTAL	CONTR. FURN TOTAL	L.H. UNIT	LABOR HOURS	RATE	TOTAL		

APPENDIX I
CAPITAL COST COMPARISON TABLE

NREL COST COMPARISONS

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: GASIFIER MODELS
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 11/02/2012

ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU*)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
14	**BIOMASS FUEL HANDLING & STORAGE SYSTEM DISTRIBUTION CONVEYOR**								
15	Biomass Delivery Equipment	• Biomass Bucket Elevator	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl
16	Biomass Delivery Equipment Motor		Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl
17	Biomass Distirbution Equipment	• Biomass Rotating Chute System	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	$750,000	$250,000
18	Biomass Distirbution Equipment Motor		Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Not Incl	Incl
19	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-1**								
20	Biomass Line-1 - Weigh Bin - Inlet Distribution Spreader	• Rotating spreader in top of bin	--	--	Incl	--	--	--	--
21	Biomass Line-1 - Weigh Bin - Inlet Distribution Spreader Motor		--	--	Incl	--	--	--	--
22									
23	Biomass Line-1 - Weigh Bin	• Weighing hopper • Atmospheric vessel	$408,348	$210,000	Incl	--	--	--	--
24	Biomass Line-1 - Weigh Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	Incl	--	--	--	--
25	Biomass Line-1 - Weigh Bin - Bottom Reclaimer - Screw Motor		--	--	Incl	--	--	--	--
26	Biomass Line-1 - Weigh Bin - Bottom Reclaimer - Pivet Motor		--	--	Incl	--	--	--	--
27	Biomass Line-1 - Weigh Bin - Outfeed Splitting Transfer Screw	• Reversible screw conveyor to split feed to two lock hoppers	--	--	Incl	--	--	--	--
28	Biomass Line-1 - Weigh Bin - Outfeed Splitting Transfer Screw Motor		--	--	Incl	--	--	--	--
29	Biomass Line-1 - Weigh Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	--	--	--	--	--
30	Biomass Line-1 - Weigh Bin - Live Bottom Discharger Screws Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	--	--	--	--	--
31	Biomass Line-1 - Weigh Bin - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
32	Biomass Line-1 - Weigh Bin - Discharge Screw Conveyor	• Reclaimer with multiple screws, which discharge to a single screw conveyor	--	Incl	--	--	--	--	--
33	Biomass Line-1 - Weigh Bin - Discharge Screw Conveyor Motor	• Single motor and drive mechanism used to drive multiple screws	--	Incl	--	--	--	--	--
34	Biomass Line-1 - Weigh Bin - Vent Filter	• Fabric filter	Incl	Incl	Incl	--	--	--	--

* ASU: Air Separation Unit

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
35									
36	Biomass Line-1 - Lock Hopper No.1 - Feed Chute		--	--	--	--	--	$15,000	$15,000
37	Biomass Line-1 - Lock Hopper No.1 - Inlet Valve	• Inlet pneumatic slide gate	--	Incl	Incl	--	--	$75,000	$75,000
38	Biomass Line-1 - Lock Hopper No.1	• Pressure vessel	Incl	$75,000	Incl	--	--	$198,100	$198,100
39	Biomass Line-1 - Lock Hopper No.1 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
40	Biomass Line-1 - Lock Hopper No.1 - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	$245,400
41	Biomass Line-1 - Lock Hopper No.1 - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	Incl
42	Biomass Line-1 - Lock Hopper No.1 - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	Incl
43	Biomass Line-1 - Lock Hopper No.2 - Inlet Valve	• Inlet pneumatic slide gate	--	--	Incl	--	--	--	--
44	Biomass Line-1 - Lock Hopper No.2	• Pressure vessel	--	--	Incl	--	--	--	--
45	Biomass Line-1 - Lock Hopper No.2 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
46	Biomass Line-1 - Lock Hopper - Discharge Conveyor	• Pressurized • Reversible screw conveyor to receive discharge from two lock hoppers	--	--	Incl	--	--	--	--
47	Biomass Line-1 - Lock Hopper - Discharge Conveyor Motor		--	--	Incl	--	--	--	--
48	Biomass Line-1 - Lock Hopper - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
49	Biomass Line-1 - Lock Hopper - Rotary Discharger Motor		Incl	--	--	--	--	--	--
50	Biomass Line-1 - Lock Hopper - Vent Filter	• Fabric filter	--	--	--	--	--	$15,000	$15,000
51	Biomass Line-1 - Lock Hopper - Vent Filter Valve		--	--	--	--	--	$15,000	$15,000
52									
53	Biomass Line-1 - Lock Hopper Weigh Bin - Inlet Valve	• Inlet pneumatic slide gate	--	--	--	Incl	--	--	--
54	Biomass Line-1 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--

NREL COST COMPARISONS

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ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
55	Biomass Line-1 - Lock Hopper Weigh Bin - Discharge Screw Conveyor	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
56	Biomass Line-1 - Lock Hopper Weigh Bin - Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
57									
58	Biomass Line-1 - Metering Bin - Inlet Valve	• Inlet pneumatic slide gate	Incl	Incl	Incl	Incl	--	$75,000	$75,000
59	Biomass Line-1 - Metering Bin	• Pressure vessel • Pressurized with nitrogen	Incl	$120,000	Incl	Incl	--	$197,100	$197,100
60	Biomass Line-1 - Metering Bin - Outlet Valve	• Outlet pneumatic slide gate	Incl	--	Incl	--	--	--	--
61	Biomass Line-1 - Metering Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	Incl	--	--	--	--
62	Biomass Line-1 - Metering Bin - Live Bottom Discharger Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	Incl	--	--	--	--
63	Biomass Line-1 - Metering Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	$245,400
64	Biomass Line-1 - Metering Bin - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	Incl
65	Biomass Line-1 - Metering Bin - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	Incl
66	Biomass Line-1 - Metering Bin - Discharge Screw Conveyor	• Screw conveyor • Pressurized	--	Incl	Incl	Incl	--	--	--
67	Biomass Line-1 - Metering Bin - Discharge Screw Conveyor Motor		--	Incl	--	Incl	--	--	--
68	Biomass Line-1 - Metering Bin - Transfer Screw Conveyor		--	$17,000	Incl	Incl	--	$761,700	$761,700
69	Biomass Line-1 - Metering Bin - Transfer Screw Conveyor Motor		--	Incl	--	Incl	--	Incl	Incl
70	Biomass Line-1 - Metering Bin - Transfer Screw Conveyor Discharge Expansion Joint		--	--	--	--	--	$57,500	$57,500
71	Biomass Line-1 - Metering Bin - Transfer Screw Outlet Chute		--	--	--	--	--	$15,000	$15,000
72	Biomass Line-1 - Metering Bin - Transfer Screw Outlet Valve	• Pneumatic slide gate	--	--	--	--	--	$75,000	$75,000
73									
74	Biomass Line-1 - Gasifier Feed Screw	• Screw conveyor • Pressurized • Water cooled	Incl	$34,000	Incl	Incl	--	$243,400	$243,400

NREL COST COMPARISONS

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
75	Biomass Line-1 - Gasifier Feed Screw Motor		Incl	Incl	Incl	Incl	--	Incl	Incl
76	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-2**								
77	Biomass Line-2 - Weigh Bin - Inlet Distribution Spreader	• Rotating spreader in top of bin	--	--	Incl	--	--	--	--
78	Biomass Line-2 - Weigh Bin - Inlet Distribution Spreader Motor		--	--	Incl	--	--	--	--
79									
80	Biomass Line-2 - Weigh Bin	• Weighing hopper • Atmospheric vessel	$408,348	$210,000	Incl	--	--	--	--
81	Biomass Line-2 - Weigh Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	Incl	--	--	--	--
82	Biomass Line-2 - Weigh Bin - Bottom Reclaimer - Screw Motor		--	--	Incl	--	--	--	--
83	Biomass Line-2 - Weigh Bin - Bottom Reclaimer - Pivet Motor		--	--	Incl	--	--	--	--
84	Biomass Line-2 - Weigh Bin - Outfeed Splitting Transfer Screw	• Reversible screw conveyor to split feed to two lock hoppers	--	--	Incl	--	--	--	--
85	Biomass Line-2 - Weigh Bin - Outfeed Splitting Transfer Screw Motor		--	--	Incl	--	--	--	--
86	Biomass Line-2 - Weigh Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	--	--	--	--	--
87	Biomass Line-2 - Weigh Bin - Live Bottom Discharger Screws Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	--	--	--	--	--
88	Biomass Line-2 - Weigh Bin - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
89	Biomass Line-2 - Weigh Bin - Discharge Screw Conveyor	• Reclaimer with multiple screws, which discharge to a single screw conveyor	--	Incl	--	--	--	--	--
90	Biomass Line-2 - Weigh Bin - Discharge Screw Conveyor Motor	• Single motor and drive mechanism used to drive multiple screws	--	Incl	--	--	--	--	--
91	Biomass Line-2 - Weigh Bin - Vent Filter	• Fabric filter	Incl	Incl	Incl	--	--	--	--
92									
93	Biomass Line-2 - Lock Hopper No.1 - Feed Chute		--	--	--	--	--	$15,000	--
94	Biomass Line-2 - Lock Hopper No.1 - Inlet Valve	• Inlet pneumatic slide gate	--	Incl	Incl	--	--	$75,000	--
95	Biomass Line-2 - Lock Hopper No.1	• Pressure vessel	Incl	$75,000	Incl	--	--	$198,100	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
96	Biomass Line-2 - Lock Hopper No.1 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
97	Biomass Line-2 - Lock Hopper No.1 - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
98	Biomass Line-2 - Lock Hopper No.1 - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
99	Biomass Line-2 - Lock Hopper No.1 - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--
100	Biomass Line-2 - Lock Hopper No.2 - Inlet Valve	• Inlet pneumatic slide gate	--	--	Incl	--	--	--	--
101	Biomass Line-2 - Lock Hopper No.2	• Pressure vessel	--	--	Incl	--	--	--	--
102	Biomass Line-2 - Lock Hopper No.2 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
103	Biomass Line-2 - Lock Hopper - Discharge Conveyor	• Pressurized • Reversible screw conveyor to receive discharge from two lock hoppers	--	--	Incl	--	--	--	--
104	Biomass Line-2 - Lock Hopper - Discharge Conveyor Motor		--	--	Incl	--	--	--	--
105	Biomass Line-2 - Lock Hopper - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
106	Biomass Line-2 - Lock Hopper - Rotary Discharger Motor		Incl	--	--	--	--	--	--
107	Biomass Line-2 - Lock Hopper - Vent Filter	• Fabric filter	--	--	--	--	--	$15,000	--
108	Biomass Line-2 - Lock Hopper - Vent Filter Valve		--	--	--	--	--	$15,000	--
109									
110	Biomass Line-2 - Lock Hopper Weigh Bin - Inlet Valve	• Inlet pneumatic slide gate	--	--	--	Incl	--	--	--
111	Biomass Line-2 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
112	Biomass Line-2 - Lock Hopper Weigh Bin - Discharge Screw Conveyor	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
113	Biomass Line-2 - Lock Hopper Weigh Bin - Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
114									
115	Biomass Line-2 - Metering Bin - Inlet Valve	• Inlet pneumatic slide gate	Incl	Incl	Incl	Incl	--	$75,000	--

NREL COST COMPARISONS

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
116	Biomass Line-2 - Metering Bin	• Pressure vessel • Pressurized with nitrogen	Incl	$120,000	Incl	Incl	--	$197,100	--
117	Biomass Line-2 - Metering Bin - Outlet Valve	• Outlet pneumatic slide gate	Incl	--	Incl	--	--	--	--
118	Biomass Line-2 - Metering Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	Incl	--	--	--	--
119	Biomass Line-2 - Metering Bin - Live Bottom Discharger Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	Incl	--	--	--	--
120	Biomass Line-2 - Metering Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
121	Biomass Line-2 - Metering Bin - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
122	Biomass Line-2 - Metering Bin - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--
123	Biomass Line-2 - Metering Bin - Discharge Screw Conveyor	• Screw conveyor • Pressurized	--	Incl	Incl	Incl	--	--	--
124	Biomass Line-2 - Metering Bin - Discharge Screw Conveyor Motor		--	Incl	--	Incl	--	--	--
125	Biomass Line-2 - Metering Bin - Transfer Screw Conveyor		--	$17,000	Incl	Incl	--	$761,700	--
126	Biomass Line-2 - Metering Bin - Transfer Screw Conveyor Motor		--	Incl	--	Incl	--	Incl	--
127	Biomass Line-2 - Metering Bin - Transfer Screw Conveyor Discharge Expansion Joint		--	--	--	--	--	$57,500	--
128	Biomass Line-2 - Metering Bin - Transfer Screw Outlet Chute		--	--	--	--	--	$15,000	--
129	Biomass Line-2 - Metering Bin - Transfer Screw Outlet Valve	• Pneumatic slide gate	--	--	--	--	--	$75,000	--
130									
131	Biomass Line-2 - Gasifier Feed Screw	• Screw conveyor • Pressurized • Water cooled	Incl	$34,000	Incl	Incl	--	$243,400	--
132	Biomass Line-2 - Gasifier Feed Screw Motor		Incl	Incl	Incl	Incl	--	Incl	--
133	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-3**								
134	Biomass Line-3 - Weigh Bin - Inlet Distribution Spreader	• Rotating spreader in top of bin	--	--	Incl	--	--	--	--
135	Biomass Line-3 - Weigh Bin - Inlet Distribution Spreader Motor		--	--	Incl	--	--	--	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
136									
137	Biomass Line-3 - Weigh Bin	• Weighing hopper • Atmospheric vessel	$408,348	$210,000	Incl	--	--	--	--
138	Biomass Line-3 - Weigh Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	Incl	--	--	--	--
139	Biomass Line-3 - Weigh Bin - Bottom Reclaimer - Screw Motor		--	--	Incl	--	--	--	--
140	Biomass Line-3 - Weigh Bin - Bottom Reclaimer - Pivet Motor		--	--	Incl	--	--	--	--
141	Biomass Line-3 - Weigh Bin - Outfeed Splitting Transfer Screw	• Reversible screw conveyor to split feed to two lock hoppers	--	--	Incl	--	--	--	--
142	Biomass Line-3 - Weigh Bin - Outfeed Splitting Transfer Screw Motor		--	--	Incl	--	--	--	--
143	Biomass Line-3 - Weigh Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	--	--	--	--	--
144	Biomass Line-3 - Weigh Bin - Live Bottom Discharger Screws Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	--	--	--	--	--
145	Biomass Line-3 - Weigh Bin - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
146	Biomass Line-3 - Weigh Bin - Discharge Screw Conveyor	• Reclaimer with multiple screws, which discharge to a single screw conveyor	--	Incl	--	--	--	--	--
147	Biomass Line-3 - Weigh Bin - Discharge Screw Conveyor Motor	• Single motor and drive mechanism used to drive multiple screws	--	Incl	--	--	--	--	--
148	Biomass Line-3 - Weigh Bin - Vent Filter	• Fabric filter	Incl	Incl	Incl	--	--	--	--
149									
150	Biomass Line-3 - Lock Hopper No.1 - Feed Chute		--	--	--	--	--	$15,000	--
151	Biomass Line-3 - Lock Hopper No.1 - Inlet Valve	• Inlet pneumatic slide gate	--	Incl	Incl	--	--	$75,000	--
152	Biomass Line-3 - Lock Hopper No.1	• Pressure vessel	Incl	$75,000	Incl	--	--	$198,100	--
153	Biomass Line-3 - Lock Hopper No.1 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
154	Biomass Line-3 - Lock Hopper No.1 - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
155	Biomass Line-3 - Lock Hopper No.1 - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
156	Biomass Line-3 - Lock Hopper No.1 - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--

NREL COST COMPARISONS

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: GASIFIER MODELS
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 11/02/2012

ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
157	Biomass Line-3 - Lock Hopper No.2 - Inlet Valve	• Inlet pneumatic slide gate	--	--	Incl	--	--	--	--
158	Biomass Line-3 - Lock Hopper No.2	• Pressure vessel	--	--	Incl	--	--	--	--
159	Biomass Line-3 - Lock Hopper No.2 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
160	Biomass Line-3 - Lock Hopper - Discharge Conveyor	• Pressurized • Reversible screw conveyor to receive discharge from two lock hoppers	--	--	Incl	--	--	--	--
161	Biomass Line-3 - Lock Hopper - Discharge Conveyor Motor		--	--	Incl	--	--	--	--
162	Biomass Line-3 - Lock Hopper - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
163	Biomass Line-3 - Lock Hopper - Rotary Discharger Motor		Incl	--	--	--	--	--	--
164	Biomass Line-3 - Lock Hopper - Vent Filter	• Fabric filter	--	--	--	--	--	$15,000	--
165	Biomass Line-3 - Lock Hopper - Vent Filter Valve		--	--	--	--	--	$15,000	--
166									
167	Biomass Line-3 - Lock Hopper Weigh Bin - Inlet Valve	• Inlet pneumatic slide gate	--	--	--	Incl	--	--	--
168	Biomass Line-3 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
169	Biomass Line-3 - Lock Hopper Weigh Bin - Discharge Screw Conveyor	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
170	Biomass Line-3 - Lock Hopper Weigh Bin - Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
171									
172	Biomass Line-3 - Metering Bin - Inlet Valve	• Inlet pneumatic slide gate	Incl	Incl	Incl	Incl	--	$75,000	--
173	Biomass Line-3 - Metering Bin	• Pressure vessel • Pressurized with nitrogen	Incl	$120,000	Incl	Incl	--	$197,100	--
174	Biomass Line-3 - Metering Bin - Outlet Valve	• Outlet pneumatic slide gate	Incl	--	Incl	--	--	--	--
175	Biomass Line-3 - Metering Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	Incl	--	--	--	--
176	Biomass Line-3 - Metering Bin - Live Bottom Discharger Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	Incl	--	--	--	--

NREL COST COMPARISONS

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
177	Biomass Line-3 - Metering Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
178	Biomass Line-3 - Metering Bin - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
179	Biomass Line-3 - Metering Bin - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--
180	Biomass Line-3 - Metering Bin - Discharge Screw Conveyor	• Screw conveyor • Pressurized	--	Incl	Incl	Incl	--	--	--
181	Biomass Line-3 - Metering Bin - Discharge Screw Conveyor Motor		--	Incl	--	Incl	--	--	--
182	Biomass Line-3 - Metering Bin - Transfer Screw Conveyor		--	$17,000	Incl	Incl	--	$761,700	--
183	Biomass Line-3 - Metering Bin - Transfer Screw Conveyor Motor		--	Incl	--	Incl	--	Incl	--
184	Biomass Line-3 - Metering Bin - Transfer Screw Conveyor Discharge Expansion Joint		--	--	--	--	--	$57,500	--
185	Biomass Line-3 - Metering Bin - Transfer Screw Outlet Chute		--	--	--	--	--	$15,000	--
186	Biomass Line-3 - Metering Bin - Transfer Screw Outlet Valve	• Pneumatic slide gate	--	--	--	--	--	$75,000	--
187									
188	Biomass Line-3 - Gasifier Feed Screw	• Screw conveyor • Pressurized • Water cooled	Incl	$34,000	Incl	Incl	--	$243,400	--
189	Biomass Line-3 - Gasifier Feed Screw Motor		Incl	Incl	Incl	Incl	--	Incl	--
190	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-4**								
191	Biomass Line-4 - Weigh Bin - Inlet Distribution Spreader	• Rotating spreader in top of bin	--	--	Incl	--	--	--	--
192	Biomass Line-4 - Weigh Bin - Inlet Distribution Spreader Motor		--	--	Incl	--	--	--	--
193									
194	Biomass Line-4 - Weigh Bin	• Weighing hopper • Atmospheric vessel	$408,348	$210,000	Incl	--	--	--	--
195	Biomass Line-4 - Weigh Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	Incl	--	--	--	--
196	Biomass Line-4 - Weigh Bin - Bottom Reclaimer - Screw Motor		--	--	Incl	--	--	--	--

NREL COST COMPARISONS

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
197	Biomass Line-4 - Weigh Bin - Bottom Reclaimer - Pivet Motor		--	--	Incl	--	--	--	--
198	Biomass Line-4 - Weigh Bin - Outfeed Splitting Transfer Screw	• Reversible screw conveyor to split feed to two lock hoppers	--	--	Incl	--	--	--	--
199	Biomass Line-4 - Weigh Bin - Outfeed Splitting Transfer Screw Motor		--	--	Incl	--	--	--	--
200	Biomass Line-4 - Weigh Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	--	--	--	--	--
201	Biomass Line-4 - Weigh Bin - Live Bottom Discharger Screws Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	--	--	--	--	--
202	Biomass Line-4 - Weigh Bin - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
203	Biomass Line-4 - Weigh Bin - Discharge Screw Conveyor	• Reclaimer with multiple screws, which discharge to a single screw conveyor	--	Incl	--	--	--	--	--
204	Biomass Line-4 - Weigh Bin - Discharge Screw Conveyor Motor	• Single motor and drive mechanism used to drive multiple screws	--	Incl	--	--	--	--	--
205	Biomass Line-4 - Weigh Bin - Vent Filter	• Fabric filter	Incl	Incl	Incl	--	--	--	--
206									
207	Biomass Line-4 - Lock Hopper No.1 - Feed Chute		--	--	--	--	--	$15,000	--
208	Biomass Line-4 - Lock Hopper No.1 - Inlet Valve	• Inlet pneumatic slide gate	--	Incl	Incl	--	--	$75,000	--
209	Biomass Line-4 - Lock Hopper No.1	• Pressure vessel	Incl	$75,000	Incl	--	--	$198,100	--
210	Biomass Line-4 - Lock Hopper No.1 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--
211	Biomass Line-4 - Lock Hopper No.1 - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
212	Biomass Line-4 - Lock Hopper No.1 - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
213	Biomass Line-4 - Lock Hopper No.1 - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--
214	Biomass Line-4 - Lock Hopper No.2 - Inlet Valve	• Inlet pneumatic slide gate	--	--	Incl	--	--	--	--
215	Biomass Line-4 - Lock Hopper No.2	• Pressure vessel	--	--	Incl	--	--	--	--
216	Biomass Line-4 - Lock Hopper No.2 - Outlet Valve	• Outlet pneumatic slide gate	--	--	Incl	--	--	--	--

NREL COST COMPARISONS

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
217	Biomass Line-4 - Lock Hopper - Discharge Conveyor	• Pressurized • Reversible screw conveyor to receive discharge from two lock hoppers	--	--	Incl	--	--	--	--
218	Biomass Line-4 - Lock Hopper - Discharge Conveyor Motor		--	--	Incl	--	--	--	--
219	Biomass Line-4 - Lock Hopper - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
220	Biomass Line-4 - Lock Hopper - Rotary Discharger Motor		Incl	--	--	--	--	--	--
221	Biomass Line-4 - Lock Hopper - Vent Filter	• Fabric filter	--	--	--	--	--	$15,000	--
222	Biomass Line-4 - Lock Hopper - Vent Filter Valve		--	--	--	--	--	$15,000	--
223									
224	Biomass Line-4 - Lock Hopper Weigh Bin - Inlet Valve	• Inlet pneumatic slide gate	--	--	--	Incl	--	--	--
225	Biomass Line-4 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
226	Biomass Line-4 - Lock Hopper Weigh Bin - Discharge Screw Conveyor	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
227	Biomass Line-4 - Lock Hopper Weigh Bin - Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
228									
229	Biomass Line-4 - Metering Bin - Inlet Valve	• Inlet pneumatic slide gate	Incl	Incl	Incl	Incl	--	$75,000	--
230	Biomass Line-4 - Metering Bin	• Pressure vessel • Pressurized with nitrogen	Incl	$120,000	Incl	Incl	--	$197,100	--
231	Biomass Line-4 - Metering Bin - Outlet Valve	• Outlet pneumatic slide gate	Incl	--	Incl	--	--	--	--
232	Biomass Line-4 - Metering Bin - Live Bottom Discharger	• Reclaimer with multiple screws, which discharge to a single screw conveyor	Incl	--	Incl	--	--	--	--
233	Biomass Line-4 - Metering Bin - Live Bottom Discharger Motor	• Single motor and drive mechanism used to drive multiple screws	Incl	--	Incl	--	--	--	--
234	Biomass Line-4 - Metering Bin - Bottom Reclaimer	• Reclaimer with single rotating screw, which pivets around bottom of bin to move biomass to a center discharge chute.	--	--	--	--	--	$245,400	--
235	Biomass Line-4 - Metering Bin - Bottom Reclaimer Screw Motor		--	--	--	--	--	Incl	--
236	Biomass Line-4 - Metering Bin - Bottom Reclaimer - Pivet Motor		--	--	--	--	--	Incl	--

NREL COST COMPARISONS

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
237	Biomass Line-4 - Metering Bin - Discharge Screw Conveyor	• Screw conveyor • Pressurized	--	Incl	Incl	Incl	--	--	--
238	Biomass Line-4 - Metering Bin - Discharge Screw Conveyor Motor		--	Incl	--	Incl	--	--	--
239	Biomass Line-4 - Metering Bin - Transfer Screw Conveyor		--	$17,000	Incl	Incl	--	$761,700	--
240	Biomass Line-4 - Metering Bin - Transfer Screw Conveyor Motor		--	Incl	--	Incl	--	Incl	--
241	Biomass Line-4 - Metering Bin - Transfer Screw Conveyor Discharge Expansion Joint		--	--	--	--	--	$57,500	--
242	Biomass Line-4 - Metering Bin - Transfer Screw Outlet Chute		--	--	--	--	--	$15,000	--
243	Biomass Line-4 - Metering Bin - Transfer Screw Outlet Valve	• Pneumatic slide gate	--	--	--	--	--	$75,000	--
244									
245	Biomass Line-4 - Gasifier Feed Screw	• Screw conveyor • Pressurized • Water cooled	Incl	$34,000	Incl	Incl	--	$243,400	--
246	Biomass Line-4 - Gasifier Feed Screw Motor		Incl	Incl	Incl	Incl	--	Incl	--
247	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-5**								
248	Biomass Line-5 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen • Inlet and outlet pneumatic slide gates	--	--	--	Incl	--	--	--
249	Biomass Line-5 - Lock Hopper Weigh Bin Live Bottom Discharge Device	• Proprietary • Reclaimer with multiple screws discharging to a screw conveyor	--	--	--	Incl	--	--	--
250	Biomass Line-5 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	• Single motor and drive mechanism used to drive multiple screws	--	--	--	Incl	--	--	--
251	Biomass Line-5 - Lock Hopper Weigh Bin Discharge Screw Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
252	Biomass Line-5 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
253	Biomass Line-5 - Metering Bin	• Pressure vessel • Pressurized with nitrogen • Inlet and outlet pneumatic slide gates	--	--	--	Incl	--	--	--
254	Biomass Line-5 - Metering Bin Live Bottom Discharge Device	• Proprietary • Reclaimer with multiple screws discharging to a screw conveyor	--	--	--	Incl	--	--	--
255	Biomass Line-5 - Metering Bin Live Bottom Discharge Device Motor	• Single motor and drive mechanism used to drive multiple screws	--	--	--	Incl	--	--	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
256	Biomass Line-5 - Metering Bin Discharge Screw Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
257	Biomass Line-5 - Metering Bin Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
258	Biomass Line-5 - Transfer Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
259	Biomass Line-5 - Transfer Conveyor Motor		--	--	--	Incl	--	--	--
260	Biomass Line-5 - Gasifier Feed Screw	• Screw conveyor • Water cooled	--	--	--	Incl	--	--	--
261	Biomass Line-5 - Gasifier Feed Screw Motor		--	--	--	Incl	--	--	--
262	**BIOMASS FUEL HANDLING & STORAGE SYSTEM LINE-6**								
263	Biomass Line-6 - Lock Hopper Weigh Bin	• Pressure vessel • Pressurized with nitrogen • Inlet and outlet pneumatic slide gates	--	--	--	Incl	--	--	--
264	Biomass Line-6 - Lock Hopper Weigh Bin Live Bottom Discharge Device	• Proprietary • Reclaimer with multiple screws discharging to a screw conveyor	--	--	--	Incl	--	--	--
265	Biomass Line-6 - Lock Hopper Weigh Bin Live Bottom Discharge Device Motor	• Single motor and drive mechanism used to drive multiple screws	--	--	--	Incl	--	--	--
266	Biomass Line-6 - Lock Hopper Weigh Bin Discharge Screw Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
267	Biomass Line-6 - Lock Hopper Weigh Bin Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
268	Biomass Line-6 - Metering Bin	• Pressure vessel • Pressurized with nitrogen • Inlet and outlet pneumatic slide gates	--	--	--	Incl	--	--	--
269	Biomass Line-6 - Metering Bin Live Bottom Discharge Device	• Proprietary • Reclaimer with multiple screws discharging to a screw conveyor	--	--	--	Incl	--	--	--
270	Biomass Line-6 - Metering Bin Live Bottom Discharge Device Motor	• Single motor and drive mechanism used to drive multiple screws	--	--	--	Incl	--	--	--
271	Biomass Line-6 - Metering Bin Discharge Screw Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
272	Biomass Line-6 - Metering Bin Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
273	Biomass Line-6 - Transfer Conveyor	• Screw conveyor • Pressurized with nitrogen	--	--	--	Incl	--	--	--
274	Biomass Line-6 - Transfer Conveyor Motor		--	--	--	Incl	--	--	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
275	Biomass Line-6 - Gasifier Feed Screw	• Screw conveyor • Water cooled	--	--	--	Incl	--	--	--
276	Biomass Line-6 - Gasifier Feed Screw Motor		--	--	--	Incl	--	--	--
277	**GASIFIER BED MEDIA STORAGE & HANDLING**								
278	Gasifier Bed Media - Unloading Station	• Truck unloading station • Dolomite or silica material	$38,800	$5,000	$38,800	$38,800	$8,500	$8,500	--
279	Gasifier Bed Media - Unloading Transfer Line	• Bed Media From Unloading Station To Storage Silo • Pressurized air is the motive power source	Incl	$1,500	Incl	Incl	Incl	Incl	--
280	Gasifier Bed Media - Storage Silo	• Atmospheric vessel • Bottom discharge	Incl	$109,425	Incl	$116,300	$105,819	$105,819	--
281	Gasifier Bed Media - Storage Silo Vent Filter	• Fabric filter	Incl	--	Incl	Incl	--	--	--
282	Gasifier Bed Media - Pneumatic Transporter	• Rotary feeder • Pressurized air or nitrogen gas is the motive power source	Incl	--	--	--	$250,000	$250,000	--
283	Gasifier Bed Media - Pneumatic Transporter Motor		Incl	--	--	--	Incl	Incl	--
284	Gasifier Bed Media - Nitrogen Gas Tank	• Dedicated tank to supply nitrogen to bed media transporter • Pressurized tank	--	--	--	--	$83,111	$83,111	--
285	Gasifier Bed Media - Nitrogen Gas Line	• Dedicated line to supply nitrogen to bed media transporter	Incl	--	--	--	$2,500	$2,500	--
286	Gasifier Bed Media - Makeup Air Blower	• Pressurized air is the motive power source	--	$35,000	--	--	--	--	--
287	Gasifier Bed Media - Makeup Air Blower Motor		--	Incl	--	--	--	--	--
288	Gasifier Bed Media - Transfer Screw Conveyor	• Metering screw conveyor • Pressurized	--	--	--	Incl	--	--	--
289	Gasifier Bed Media - Transfer Screw Conveyor Motor		--	--	--	Incl	--	--	--
290	Gasifier Bed Media - Recycled Media Mixing Hopper	• Atmospheric vessel • Bottom discharge	--	--	--	Incl	--	--	--
291	Gasifier Bed Media - Dense Phase Conveyor Bin	• Pressure vessel	--	--	--	Incl	--	--	--
292	Gasifier Bed Media - Pneumatic Metering Conveyor	• Bed material and recycled char • Pressurized nitrogen is the motive power source	--	--	--	Incl	--	--	--
293	Gasifier Bed Media - Weigh Hopper	• Atmospheric vessel • Bottom discharge fluidizing air system	--	--	Incl	--	--	--	--
294	Gasifier Bed Media - Lock Hopper	• Pressure vessel • Inlet shutoff valve • Outlet shutoff valve	--	--	Incl	--	--	--	--

NREL COST COMPARISONS

HARRIS GROUP PROJECT NO.: 30300.00
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CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 11/02/2012

ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
295	Gasifier Bed Media - Lock Hopper Discharge Conveyor	• Metering screw conveyor • Pressurized • Outlet shutoff valve	--	--	Incl	--	--	--	--
296	Gasifier Bed Media - Lock Hopper Discharge Conveyor Motor		--	--	Incl	--	--	--	--
297	GASIFIER SORBENT MEDIA STORAGE & HANDLING								
298	Gasifier Sorbent Media - Recieving Station	• Truck unloading station • Typically limestone for removal of chlorine and sulfur	--	--	--	$58,750	--	--	--
299	Gasifier Sorbent Media - Pneumatic Unloading Conveyor	• Pressurized air is the motive power source	--	--	--	Incl	--	--	--
300	Gasifier Sorbent Media - Storage Silo	• Atmospheric vessel • Bottom discharge	--	--	--	$176,250	--	--	--
	Gasifier Sorbent Media - Storage Silo Vent Filter	• Fabric filter	--	--	--	Incl	--	--	--
302	Gasifier Sorbent Media - Transfer Conveyor	• Metering screw conveyor • Pressurized	--	--	--	Incl	--	--	--
303	Gasifier Sorbent Media - Transfer Conveyor Motor		--	--	--	Incl	--	--	--
304	Gasifier Sorbent Media - Dense Phase Conveyor Bin	• Pressure vessel	--	--	--	Incl	--	--	--
305	Gasifier Sorbent Media - Pneumatic Metering Conveyor	• Pressurized nitrogen is the motive power source	--	--	--	Incl	--	--	--
306	GASIFIER								
307	Gasifier (BFB)	• Bubbling fluid bed auto thermal gasifier • Pressure vessel • Refractory lined • Fired with biomass, oxygen & steam • Fluidized bed composed of bed media, & biomass	--	--	$14,528,047	$14,248,916	$546,361	$546,361	--
308	Gasification (CFB)	• Circulating fluidized bed allothermal gasifier • Low pressure vessel • Refractory lined • Fluidized bed composed of biomass, externally heated bed material & medium pressure steam	$14,330,003	$822,204	--	--	--	--	--
309	Gasifier - Startup Burner	• Horizontal pressure vessel fire box • Natural gas or light fuel oil burner • Refractory lined	--	$50,000	Incl	Incl	$150,000	$150,000	--
310	Gasifier - Startup Burner - Light Fuel Oil Booster Pump	• Oil pump	--	--	Incl	--	--	--	--
311	Gasifier - Startup Burner - Light Fuel Oil Booster Pump Motor		--	--	Incl	--	--	--	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
312	Gasifier - Startup Burner - Air Compressor	• Screw compressor • Air cooled • Oil free operation	--	--	Incl	Incl	--	--	--
313	Gasifier - Startup Burner - Air Compressor Motor	• Variable frequency drive	--	--	Incl	Incl	--	--	--
314	Gasifier - Startup Burner - Air Receiver	• Pressure vessel	--	--	Incl	--	--	--	--
315	**GASIFIER CYCLONES**								
316	Gasification Reactor - Cyclone No.1	• Pressure vessel • Refractory lined • Cone shaped bottom	Incl	$511,015	Incl	Incl	$160,924	$160,924	--
317	Gasification Reactor - Cyclone No.1 - Rotary Discharger	• Rotary pocket feeder discharge device • Pressurized	Incl	--	Incl	Incl	--	--	--
318	Gasification Reactor - Cyclone No.1 - Rotary Discharger Motor		Incl	--	Incl	Incl	--	--	--
319	Gasification Reactor - Heated Bed Material Surge Vessel	• Cone shaped bottom	Incl	--	--	--	--	--	--
320	Gasification Reactor - Cyclone No.2	• Cone shaped bottom	Incl	$504,655	--	--	--	--	--
321	Gasification Reactor - Cyclone No.2 - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
322	Gasification Reactor - Cyclone No.2 - Rotary Discharger Motor		Incl	--	--	--	--	--	--
323	Gasification Reactor - Ash Surge Vessel		Incl	--	--	--	--	--	--
324	Gasifier Reactor Cyclones Solids Collection Bin		--	$491,545	--	--	--	--	--
325	**GASIFIER BOTTOM ASH REMOVAL SYSTEM**								
326	Gasifier Ash Removal - Screw Conveyor	• Screw conveyor • Pressurized • Water cooled	--	--	Incl	Incl	$159,497	$159,497	--
327	Gasifier Ash Removal - Screw Conveyor Motor		--	--	Incl	Incl	Incl	Incl	--
328	Gasifier Ash Removal - Dischrage Hopper	• Pressure vessel	--	--	--	--	$165,732	$165,732	--
329	Gasifier Ash Removal - Lock Hopper No.1 Inlet Valve		--	--	--	--	$15,000	$15,000	--
330	Gasifier Ash Removal - Lock Hopper No.1	• Pressure vessel • Pressurized with nitrogen	--	--	Incl	Incl	$165,185	$165,185	--
331	Gasifier Ash Removal - Lock Hopper No.1 Discharge Screw Conveyor	• Screw conveyor • Pressurized	--	--	--	Incl	$310,935	$310,935	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
332	Gasifier Ash Removal - Lock Hopper No.1 Discharge Screw Conveyor Motor		--	--	--	Incl	--	--	--
333	Gasifier Ash Removal - Lock Hopper No.1 Inlet Valve		--	--	--	--	$15,000	$15,000	--
334	Gasifier Ash Removal - Lock Hopper No.2	• Pressure vessel • Pressurized with nitrogen	--	--	--	Incl	--	--	--
335	Gasifier Ash Removal - Screen	• Atmospheric	--	--	--	Incl	--	--	--
336	Gasifier Ash Removal - Scree Rejects Conveyor	• Atmospheric	--	--	--	Incl	--	--	--
337	Gasifier Ash Removal - Scree Rejects Conveyor Motor		--	--	--	Incl	--	--	--
338	Gasifier Ash Removal - Conveyor Hopper	• Atmospheric vessel • Nitrogen gas pneumatic discharge	--	--	Incl	--	--	--	--
339	Gasifier Ash Removal - Pneumatic Conveyor	• Pressurized nitrogen gas motive power source	--	--	Incl	--	--	--	--
340	Gasifier Ash Removal - Ash Storage Silo	• Atmospheric vessel	--	$109,425	Incl	--	--	--	--
341	Gasifier Ash Removal - Ash Transfer Conveyor	• Screw conveyor	--	--	$40,000	--	--	--	--
342	Gasifier Ash Removal - Ash Transfer Conveyor Motor		--	--	Incl	--	--	--	--
343	**COMBUSTION REACTOR**								
344	Combustion Reactor - Vessel	• Circulating fluidized bed combustion reactor • Fluidized bed composed of externally heated bed material & clean gasifier syngas • Atmospheric vessel • Refractory lined	Incl	$896,891	--	--	--	--	--
345	Combustion Reactor - Flue Gas Fan		Incl	--	--	--	--	--	--
346	Combustion Reactor - Flue Gas Fan Motor		Incl	--	--	--	--	--	--
347	Combustion Reactor - Startup Burner	• Horizontal pressure vessel fire box • Refractory lined • Natural gas burner	Incl	$50,000	--	--	--	--	--
348	Combustion Reactor - Air Heater	• Screw conveyor • Water cooled	Incl	$159,000	--	--	--	--	--
349	Combustion Reactor - Air Fan		Incl	$262,500	--	--	--	--	--
350	Combustion Reactor - Air Fan Motor		Incl	Incl	--	--	--	--	--

NREL COST COMPARISONS

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
351	COMBUSTION REACTOR CYCLONES								
352	Combustion Reactor - No.1 Cyclone	• Pressure vessel • Refractory lined • Cone shaped bottom	Incl	$785,028	--	--	--	--	--
353	Combustion Reactor - No.1 Cyclone - Rotary Discharger	• Rotary pocket feeder discharge device	Incl	--	--	--	--	--	--
354	Combustion Reactor - No.1 Cyclone - Rotary Discharger Motor		Incl	--	--	--	--	--	--
355	Combustion Reactor - No.1 Cyclone Solids Collection Bin		--	$488,556	--	--	--	--	--
356	Combustion Reactor - No.2 Cyclone		--	$780,928	--	--	--	--	--
357	Combustion Reactor - Transfer Screw Conveyor	• Screw conveyor • Water cooled	Incl	--	--	--	--	--	--
358	Combustion Reactor - Transfer Screw Conveyor Motor		Incl	--	--	--	--	--	--
359	COMBUSTION REACTOR ASH DISPOSAL								
360	Combustion Reactor - Ash Storage Bin	• Atmospheric vessel	Incl	--	--	--	--	--	--
361	Combustion Reactor - Ash Storage Bin Discharge Screw Conveyor	• Screw conveyor • Process water added to supress dust • Ash discharged as a moist solid suitable for soil ammendment	Incl	--	--	--	--	--	--
362	Combustion Reactor - Ash Storage Bin DischargeScrew Conveyor Motor		Incl	--	--	--	--	--	--
363	Combustion Reactor - Ash/Bed Material Disposal - Screw Conveyor	• Screw conveyor • Water cooled	Incl	$20,000	--	--	--	--	--
364	Combustion Reactor - Ash/Bed Material Disposal - Screw Conveyor Motor		Incl	Incl	--	--	--	--	--
365	Combustion Reactor - Ash/Bed Media Screw Conveyor Outlet Pocket Feeder		--	$7,000	--	--	--	--	--
366	Combustion Reactor - Ash/Bed Media Screw Conveyor Outlet Pocket Feeder Motor		--	Incl	--	--	--	--	--
367	SYNGAS TAR REFORMER BED MEDIA STORAGE & HANDLING								
368	Syngas Tar Reformer Bed Media Truck Unloading Station		--	$5,000	--	--	--	--	--
369	Syngas Tar Reformer Bed Media Feed Bin		--	$109,425	--	--	--	--	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
370	Syngas Tar Reformer Bed Media Makeup Blower		--	$35,000	--	--	--	--	--
371	Syngas Tar Reformer Bed Media Makeup Blower Motor		--	Incl	--	--	--	--	--
372	**SYNGAS TAR REFORMER**								
373	Syngas Tar Reformer	• Pressure vessel • Refractory lined • Internal catalyst support trays • Packed with catalyst blocks	--	$1,522,654	Incl	Incl	--	$2,138,600	--
374	Syngas Tar Reformer - Conditioning Reactor	• Circulating fluidized bed tar reformer • Fluidized bed composed of externally heated bed material & clean gasifier syngas • Atmospheric vessel • Refractory lined	Incl	--	--	--	--	--	--
375	Syngas Tar Reformer - Pulse Tank	• Pressure vessel • Steam receiver tank for periodic back flow pulsing of catalyst blocks to clean catalyst	--	--	Incl	--	--	--	--
376	Syngas Tar Reformer - Burner	• Horizontal pressure vessel fire box • Natural gas or light fuel oil burner • Refractory lined	--	--	Incl	--	--	--	--
377	**SYNGAS TAR REFORMER CYCLONES**								
378	Syngas Tar Reformer- No.1 Cyclone		--	$992,814	--	--	--	--	--
379	Syngas Tar Reformer - No.2 Cyclone		--	$992,813	--	--	--	--	--
380	Syngas Tar Reformer - Cyclones Solids Collection Bin		--	$491,545	--	--	--	--	--
381	**REFORMER BED MEDIA HEATING REACTOR**								
382	Reformer Bed Media Heating Reactor		--	$593,441	--	--	--	--	--
383	Reformer Bed Media Heating Reactor Air Heater		--	$159,000	--	--	--	--	--
384	Reformer Bed Media Heating Reactor Air Blower		--	$262,500	--	--	--	--	--
385	Reformer Bed Media Heating Reactor Air Blower Motor		--	Incl	--	--	--	--	--
386	Reformer Bed Media Heating Reactor Burner		--	$75,000	--	--	--	--	--
387	**REFORMER BED MEDIA HEATING REACTOR CYCLONES**								

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
388	Reformer Bed Media Heating Reactor No.1 Cyclone		--	$193,670	--	--	--	Incl	--
389	Reformer Bed Media Heating Reactor No.2 Cyclone		--	$193,670	--	--	--	--	--
390	Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin		--	$488,556	--	--	--	--	--
391	**REFORMER BED MEDIA HEATING REACTOR - ASH DISPOSAL**								
392	Reformer Bed Media Heating Reactor - Ash Cooling Screw Conveyor		--	$20,000	--	--	--	--	--
393	Reformer Bed Media Heating Reactor - Ash Cooling Screw Conveyor Motor		--	Incl	--	--	--	--	--
394	Reformer Bed Media Heating Reactor - Ash Cooling Screw Conveyor Outlet Pocket Feeder		--	$7,000	--	--	--	--	--
395	Reformer Bed Media Heating Reactor - Ash Cooling Screw Conveyor Outlet Pocket Feeder Motor		--	Incl	--	--	--	--	--
396	Reformer Bed Media Heating Reactor - Ash Storage Bin		--	$109,425	--	--	--	--	--
397	**PROCESS AIR SYSTEM**								
398	Process Air - Compressor	• Screw compressor • Air cooled • Oil free operation	$50,000	--	$50,000	$50,000	--	$50,000	--
399	Process Air - Compressor Motor	• Variable frequeny drive	Incl	--	Incl	Incl	--	Incl	--
400	Process Air - Dryer		Incl	--	Incl	Incl	--	Incl	--
401	Process Air - Receiver Tank	• Pressure vessel	Incl	--	Incl	Incl	--	Incl	--
402	**AIR SEPARATION SYSTEM**								
403	Air Separation Plant - Oxygen / Nitrogen Separator	• Screw compressor • Oil free operation	$784,539	--	$7,198,807	$7,186,112	--	$7,186,112	--
404	Air Separation Plant - Oxygen Gas Receiver Tank	• Pressure vessel	--	--	Incl	Incl	--	Incl	--
405	Air Separation Plant - Nitrogen Gas Receiver Tank	• Pressure vessel	Incl	--	Incl	Incl	--	Incl	--
406	**OXYGEN SYSTEM**								
407	Oxygen System - Booster Compressor	• Screw compressor • Air cooled • Oil free operation	--	--	$50,000	$50,000	--	$50,000	--

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
408	Oxygen System - Booster Compressor Motor	• Variable frequeny drive	--	--	Incl	Incl	--	Incl	--
409	Oxygen System - Oxygen Gas Supply Tank	• Pressure vessel • Oxygen supply for gasifier & tar remover combustion	--	--	Incl	Incl	--	Incl	--
410	Oxygen System - Oxygen Heater	• Indirect heat supplied by medium pressure steam	--	--	Incl	--	--	--	--
411	**NITROGEN SYSTEM**								
412	Nitrogen System - Instrument Nitrogen Gas Supply Tank	• Pressure vessel • Nitrogen supply for instrumentation operation	Incl	--	Incl	$75,000	--	$75,000	--
413	Nitrogen System - Booster Compressor	• Screw compressor • Air cooled • Oil free operation	Incl	--	Incl	Incl	--	Incl	--
414	Nitrogen System - Booster Compressor Motor	• Variable frequeny drive	Incl	--	Incl	Incl	--	Incl	--
415	Nitrogen System - Process Nitrogen Gas Supply Tank No.1	• Pressure vessel • High pressure nitrogen • Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements	Incl	--	Incl	Incl	--	Incl	--
416	Nitrogen System - Process Nitrogen Gas Supply Tank No.2	• Pressure vessel • Low pressure nitrogen • Nitrogen supply for biomass feed system, gasifier,tar reformer pressurization & purge requirements	--	--	Incl	--	--	--	--
417	Nitrogen System - Emergency Booster Compressor	• Screw compressor • Air cooled • Oil free operation	--	--	Incl	--	--	--	--
418	Nitrogen System - Emergeny Booster Compressor Motor	• Variable frequeny drive	--	--	Incl	--	--	--	--
419	Nitrogen System - Emergency Nitrogen Gas Storage Tank	• Pressure vessel • High pressure nitrogen • Nitrogen supply for emergency shutdowns to prevent fires and explosions	--	--	Incl	--	--	--	--
420	**FLARE STACK**								
421	Syngas Flare Stack		Incl	$6,000	$25,000	Incl	--	$25,000	--
422	**COMBUSTION REACTOR EXHAUST STACK**								
423	Exhaust Stack		Incl	--	--	--	--	--	--
424	**ASH SCREW COOLING WATER SYSTEM**								

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			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
425	Ash Screw Cooling Water - Storage Tank		--	--	Incl	--	--	--	--
426	Ash Screw Cooling Water - Heat Exchanger	• Indirect heat exchanger with clean ash screw cooling water on one side being cooled by cold mill water on the other side	--	--	Incl	Incl	--	--	--
427	Ash Screw Cooling Water - No.1 Pump	• Centrifugal pump	--	--	Incl	--	--	--	--
428	Ash Screw Cooling Water - No.1 Pump Motor		--	--	Incl	--	--	--	--
429	Ash Screw Cooling Water - No.2 Pump	• Centrifugal pump	--	--	Incl	--	--	--	--
430	Ash Screw Cooling Water - No.2 Pump Motor		--	--	Incl	--	--	--	--
431	**SEAL WATER SYSTEM**								
432	Seal Water - Storage Tank		--	--	Incl	--	--	--	--
433	Seal Water - Heat Exchanger	• Indirect heat exchanger with clean seal water on one side being cooled by cold mill water on the other side	--	--	Incl	--	--	--	--
434	Seal Water Water - No.1 Pump	• Centrifugal pump	--	--	Incl	--	--	--	--
435	Seal Water Water - No.1 Pump Motor		--	--	Incl	--	--	--	--
436	Seal Water Water - No.2 Pump	• Centrifugal pump	--	--	Incl	--	--	--	--
437	Seal Water Water - No.2 Pump Motor		--	--	Incl	--	--	--	--
438	**DUCTS & PIPING**								
439	Line • From Bed Media Pneumatic Transporter • To Gasifier	• Refractory lined	--	$136,902	--	--	Incl	Incl	--
440	Line • From Gasifier Reactor Cyclone No.1 • To Gasifier	• Refractory lined	--	--	--	--	$191,879	$191,879	--
441	Line • From Gasifier Reactor Cyclone No.1 • To Gasifier Reactor Cyclones Collection bin	• Refractory lined	--	$104,572	--	--	--	--	--
442	Line • From Gasifier • To Gasifier Ash Cooling Screw Conveyor	• Refractory lined	--	--	--	--	$130,945	$130,945	--
443	Line • From Ash Cooling Screw Conveyor • To Ash Discharge Hopper	• Refractory lined	--	--	--	--	$5,000	$5,000	--

NREL COST COMPARISONS

HARRIS GROUP PROJECT NO.: 30300.00
PROJECT NAME: GASIFIER MODELS
CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 11/02/2012

ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
444	Line • From Ash Discharge Hopper • To Ash Lock Hopper	• Refractory lined	--	--	--	--	$5,000	$5,000	--
445	Line • From Gasifier Reactor No.2 Cyclone • To Gasifier Reactor Cyclones Solids Collection Bin	• Refractory lined	--	$103,072	--	--	--	--	--
446	Line • From Gasifier Reactor Cyclones Solids Collection Bin • To Char Combustion Reactor	• Refractory lined	--	$129,986	--	--	--	--	--
447	Line • From Char Combustion Reactor No.1 Cyclone • To Char Combustion Reactor No.1 Cyclone Solids Collection Bin	• Refractory lined	--	$103,072	--	--	--	--	--
448	Line • From Char Combustion Reactor No.1 Cyclone Solids Collection Bin • To Gasifier Reactor	• Refractory lined	--	$129,986	--	--	--	--	--
449	Line • From Char Combustion Reactor No.2 Cyclone • To Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor	• Refractory lined	--	$103,351	--	--	--	--	--
450	Line • From Syngas Reformer Reactor No.1 Cyclone • To Syngas Reformer Reactor Cyclones Solids Collection Bin	• Refractory lined	--	$63,399	--	--	--	--	--
451	Line • From Reformer Loop Bed Media Truck Unloading Station • To Reformer Loop Bed Media Feed Bin	• Refractory lined	--	$100,151	--	--	--	--	--
452	Line • From Reformer Loop Bed Media Makeup Blower • To Reformer Bed Media Heating Reactor	• Refractory lined	--	$136,902	--	--	--	--	--
453	Line • From Syngas Reformer Reactor No.2 Cyclone • To Syngas Reformer Reactor Cyclones Solids Collection Bin	• Refractory lined	--	$103,072	--	--	--	--	--
454	Line • From Syngas Reformer Reactor Cyclones Solids Collection Bin • To Reformer Bed Media Heating Reactor	• Refractory lined	--	$174,599	--	--	--	--	--
455	Line • From Reformer Bed Media Heating Reactor No.1 Cyclone • To Reformer Bed Media Heating Reactor No.1 Cyclone Solids Collection Bin	• Refractory lined	--	$103,072	--	--	--	--	--
456	Line • From Reformer Bed Media Heating Reactor Cyclone No.1 Solids Collection Bin • To	• Refractory lined	--	$174,599	--	--	--	--	--

NREL COST COMPARISONS

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
457	Line • From Reformer Bed Media Heating Reactor No.2 Cyclone • To Reformer Loop Depleted Bed Media Cooling Screw Conveyor	• Refractory lined	--	$129,986	--	--	--	--	--
458	Line • From Char Combustion Loop Depleted Bed Media & Ash Cooling Screw Conveyor • To Gasifier Loop Depleted Bed Media & Ash Storage Bin	• Refractory lined	--	$43,423	--	--	--	--	--
459	Line • From Reformer Loop Depleted Bed Media Cooling Screw Conveyor • To Reformer Loop Depleted Bed Media Storage Bin	• Refractory lined	--	$43,423	--	--	--	--	--
460	Line • From Gasifier Ash Removal - Lock Hopper No.1 • To Battery Limit		--	$43,423	--	--	$8,000	$8,000	--
461	Duct • From Gasifier Reactor • To Gasifier Reactor Cyclone No.1	• Refractory lined	--	$651,112	--	--	$161,893	$161,893	--
462	Duct • From Gasifier Reactor Cyclone No.1 • To Gasifier Reactor Cyclone No.2	• Refractory lined	--	$566,281	--	--	--	--	--
463	Duct • From Gasifier Reactor Cyclone No.1 • To Battery limit	• Refractory lined	--	--	--	--	$201,035	$201,035	--
464	Duct • From Gasifier Reactor Cyclone No.2 • To Syngas Reformer Reactor	• Refractory lined	--	$1,179,581	--	--	--	--	--
465	Duct • From Char Combustion Reactor • To Char Combustion Reactor No.1 Cyclone	• Refractory lined	--	$769,578	--	--	--	--	--
466	Duct • From Char Combustion Reactor No.1 Cyclone • To Char Combustion Reactor No.2 Cyclone	• Refractory lined	--	$721,797	--	--	--	--	--
467	Duct • From Char Combustion Reactor No.2 Cyclone • To Battery Limit (Flue Gas)	• Refractory lined	--	$648,346	--	--	--	--	--
468	Duct • From Syngas Reformer Reactor • To Syngas Reformer Reactor No.1 Cyclone	• Refractory lined	--	$1,175,795	--	--	--	--	--
469	Duct • From Syngas Tar Reformer Cyclone No.1 • To Syngas Tar Reformer Cyclone No.2	• Refractory lined	--	$1,175,795	--	--	--	--	--

NREL COST COMPARISONS

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Harris Group Inc.
Engineering for Optimum Performance®

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			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
470	Duct • From Syngas Reformer Reactor No.2 Cyclone • To Battery Limit (Reformed Syngas)	• Refractory lined	--	$1,175,795	--	--	--	--	--
471	Duct • From Reformer Bed Media Heating Reactor • To Reformer Bed Media Heating Reactor Cyclone No.1	• Refractory lined	--	$436,706	--	--	--	--	--
472	Duct • From Reformer Bed Media Heating Reactor No.1 Cyclone • To Reformer Bed Media Heating Reactor No.2 Cyclone	• Refractory lined	--	$436,706	--	--	--	--	--
473	Duct • From Reformer Bed Media Heating Reactor No.2 Cyclone • To Battery Limit (Flue Gas)	• Refractory lined	--	$436,706	--	--	--	--	--
474	Duct • From Supplemental Gas Battery Limits • To Syngas Reformer Reactor	• Refractory lined	--	$545,714	--	--	--	--	--
475	Duct • From Duct-03 & Duct-13 • To Syngas Reformer Reactor	• Refractory lined	--	$706,251	--	--	--	--	--
476	Duct • From Char Conbustion Reactor Air Blower • To Char Combustion Reactor Startup Burner	• Refractory lined	--	$490,004	--	--	--	--	--
477	Duct • From Reformer Bed Media Heating Reactor Air Heater • To Reformer Bed Media Heating Reactor	• Refractory lined	--	$215,977	--	--	--	--	--
478	Duct • From Char Conbustion Reactor Air Blower • To Char Combustion Reactor Startup Burner & Gasifier Reactor Startup Burner	• Refractory lined	--	$378,234	--	--	--	--	--

NREL COST COMPARISONS

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ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2 CFB	2 EXCEL MODEL CFB	3 TECHNOLOGY #1 BFB OXYGEN BLOWN	4 TECHNOLOGY #3 BFB OXYGEN BLOWN	5 EXCEL MODEL BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	6 COMPOSITE SYSTEM BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	7 EXCEL MODEL SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
479	TOTAL COST								
480	Civil / Earthwork		$354,400	$683,100	$487,300	$487,300	$222,200	$489,984	$0
481	Buildings		$460,000	$4,569,300	$460,000	$460,000	$269,600	$462,534	$0
482	Equipment Foundations / Supports		$2,556,000	$12,900	$3,124,000	$3,124,000	$2,100	$3,141,208	$0
483	Piping & Ducts - Individually Identified		$0	$13,637,400	$0	$0	$703,800	$703,800	$0
484	Piping & Ducts - Miscellaneous		$2,010,000	$131,400	$2,010,000	$2,010,000	$24,000	$2,021,072	$25,200
485	Electrical		$1,792,000	$111,200	$2,116,700	$2,120,400	$14,200	$2,128,359	$21,100
486	Instrumentation		$995,600	$1,268,100	$1,175,900	$1,178,000	$135,700	$1,182,377	$84,100
487	Process Insulation / painting		$398,200	$13,100	$470,400	$471,200	$2,100	$472,991	$0
488	Equipment		$16,836,700	$14,171,200	$21,930,700	$22,000,100	$2,138,600	$21,347,700	$2,483,600
489	Total Equipment & Materials		$25,402,900	$34,597,700	$31,775,000	$31,851,000	$3,512,300	$31,950,025	$2,614,000
490	General Contractor Labor Cost		$13,698,900	$6,915,700	$14,467,500	$14,474,100	$572,400	$14,547,191	$115,600
491	Sub-Contractor Material & Labor Cost		$720,400	$700,000	$795,200	$795,200	$440,000	$799,580	$73,000
492	Total Direct Cost (Total Installed Cost)		$39,822,200	$42,213,400	$47,037,700	$47,120,300	$4,524,700	$47,296,796	$2,802,600
493	% Indirect Costs		25.00	25.00	25.00	25.00	25.00	25.00	25.00
494	Total Indirect Costs (Engineering, Taxes, Freight, etc.)		$9,955,600	$10,553,400	$11,759,400	$11,780,100	$1,131,200	$11,824,200	$700,700
495	Total Direct & Indirect Costs		$49,777,800	$52,766,800	$58,797,100	$58,900,400	$5,655,900	$59,120,996	$3,503,300
496	% Contingency		20.00	15.00	20.00	20.00	15.00	15.00	15.00
497	Contingency		$9,955,600	$7,915,000	$11,759,400	$11,780,100	$848,400	$8,868,100	$525,500
498	% Startup & Training		2.00	2.00	2.00	2.00	2.00	2.00	2.00
499	Startup & Training		$796,400	$844,300	$940,800	$942,400	$90,500	$945,900	$56,100

NREL COST COMPARISONS

HARRIS GROUP PROJECT NO.: 30300.00
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CLIENT: NATIONAL RENEWABLE ENERGY LABORATORY
LOCATION: GOLDEN, COLORADO

Harris Group Inc.
Engineering for Optimum Performance®

DATE: 11/02/2012

ROW	EQUIPMENT DESCRIPTION	EQUIPMENT DETAILS	CFB		BFB				FEED
			1 TECHNOLOGY #2	2 EXCEL MODEL	3 TECHNOLOGY #1	4 TECHNOLOGY #3	5 EXCEL MODEL	6 COMPOSITE SYSTEM	7 EXCEL MODEL
			CFB	CFB	BFB OXYGEN BLOWN	BFB OXYGEN BLOWN	BFB WITHOUT AIR SEPARATION, REFORMER OR BIOMASS FEED SYSTEMS	BFB WITH AIR SEPARATION, REFORMER AND (4) HP BIOMASS FEED SYSTEMS	SINGLE LINE HIGH PRESSURE BIOMASS FEED SYSTEM
			ORDER OF MAGNITUDE	BUDGETARY	ORDER OF MAGNITUDE	ORDER OF MAGNITUDE	BUDGETARY	BUDGETARY (EXCEPT ASU)	BUDGETARY
			COST	COST	COST	COST	COST	COST	COST
500	Total Project Investment		$60,529,800	$61,526,100	$71,497,300	$71,622,900	$6,594,800	$68,934,996	$4,084,900

APPENDIX J
GASIFICATION VENDOR COMPARISON MATRIX

Harris Group Inc. Engineering for Optimum Performance®	REV	DATE	BY	Gasification Vendor Comparison Matrix	Indicates an IBR Project, http://www1.eere.energy.gov/biomass/integrated_biorefineries.html
	G	6/14/2011	MWW		
	B	11/15/2010	MWW		
	C	2/3/2011	MWW		
	D	2/28/2011	MWW		
	E	3/17/2011	MWW		
	F	5/12/2011	MWW		

REV G | PROJECT: | DATE: 6/14/2011 | PROJECT NAME:

Technology	Suppliers	Basic process	Temp	Press. (psig)	Heat Source	Tar production	Tars methodology	HHV	Technology status:	Biomass sites:	Advantages	Disadvantages	Comments	IBR Link	Website
	Nexterra	air blown updraft gasifier, moving ash grate in bottom of vessel			auto	high - 85BTU/cuft, tar dewpoint 625F	keep gases hot, technology to convert tars to lighter gaseous hydrocarbons in development	~150 BTU/cuft	commercialized on limited basis	Tolko, Kamloops, BC and USC	have experience with 24/7 gasifiers	vendor will guarantee fossil fuel displacement of only 65% unless feedstock is dried to under 10% moisture, moving ash grate inside vessel	too small and only making power, although they have started looking at syngas		http://www.nexterra.ca/
	~~PRM Energy~~	~~updraft airblown gasifier using a bed agitator~~			auto	~~10-21g/Nm3, tar dewpoint 420F~~	~~developing in coordination with Dahlman OLGA system; considering plasma arc~~	~~syngas 147 BTU/cuft~~	~~nemerous rice hull units~~	~~Stugart, AR, Italy, Moissannes, FR~~	~~many operating units~~	~~mechanically agitated bed and primary air supply not good in wood service~~	~~1. rice hull gasifier design not optimized for wood 2. internal moving parts 3. only air blown so far~~		~~http://www.prmenergy.com/~~
	B&W Volund	updraft air blown gasifier with wet ash removal system; bed agitated at top			auto	high	tried metallic catalysts, tried water scrubbing, then settled on gas cooling with post wet ESP to catch aerosols; tars stored for industrial oil	probably 150 BTU/cuft	limited to one 3.5MW site with a lot of experience	Harboore Denmark CHP plant, new plant in Japan	93% availabilility and generating power at Harboore for several years	very limited number and size of applications to date	1. only one demonstrable plant at 3.5MW 2. internal moving parts 3. only small scale power so far 3. using Jenbacher genset		http://www.volund.dk/technologies_products/gasification/the_gasification_process
	Primenergy	updraft airblown gasifier using a bed agitator (copied PRME systems)			auto	high		syngas 147BTU/cuft	numerous rice hull units	Little Falls, MN and others	none	customer support is an issue, technology is a copy of PRME	1. potential lack of technical expertise and customer support 2. rice hull gasifier that is not optimized for wood usage 3. internal moving parts		http://www.primenergy.com/
	Heat Transfer Intl - HTI				auto				commercialized and operating several medical waste incineration facilities	none	have gasification experience more than some	no single focus area for this company, no biomass experience	not demonstratable in biomass, variation on Nexterra		http://www.heatxfer.com/
	MaxWest Environmental	use hydraulic cylinders to push feedstock into gasifier, air as oxidant, hydraulic cylinders to pull ash out; modular gasifiers in 12,000BTU/hr units							just starting up horse manure unit in Ocala area	2 Florida units		no large scale experience	not demonstrable on large scale		http://www.maxwestenergy.com/how_it_works.html
Fixed Bed - Updraft	Andritz / Carbona														
	Thermoselect	O2-blown, bottom ram-fed, upflow			Nat gas burners/allothermal								Used by Interstate Waste Technologies on a number of commercial sites??		http://www.iwtonline.com/about-us/faqs.html
	Interstate Waste Technologies	O2-blown, bottom ram-fed, upflow			Nat gas burners/allothermal					6 or 7 sites in Japan on industrial waste and MSW			same as Thermoselect??		
	Krann Energy Systems	Fixed bed up draft													http://krann.ca/index.htm
	Innovative Energy Inc	pressurized updraft											web site says nothing of technology		http://innovativeenergyinc.com/
	Lurgi (Air Liquide)	aka dry-ash moving bed. It's really just an updraft fixed bed coal gasifier			auto								not srue if this is the current technology that they market. I think the entrained flow is the current technology…		http://www.netl.doe.gov/technologies/coalpower/gasification/gasifipedia/4-gasifiers/4-1-1-1_lurgi.html
	Linde	Licensor's Engineering Contractors for a major portion of the Sasol®, Fixed Bed Dry Bottom (FBDB™) Gasification Technology for an initial term of 10 years.			auto								worked on Choren project		http://www.the-linde-group.com/en/corporate_responsibility/engineering_division/biomass/biofuels/gasification_of_biomass.html
	Entech	looks like maybe a reciprocating grate or similar furnace design			auto										http://www.entech-res.com/wtgas/
	EnviroArc	Dual vessel, first vessesl is fixed bed slagging with plasma tourch on second vessel for tar reforming			auto										
	Phoenix BioEnergy LLC. License to ICM	Auger gasifier								Licensed to ICM who has pilot plant in Newton, KS			ICM has license for transportation fuels		http://phoenixbioenergyusa.com/index.php
Mechanically Agitated Bed	ICM	has license w/ Phoenix for transportaiton fuels pathway													http://www.icminc.com/services/gasifiers/
	Range Fuels (IBR Project)	Series of externally heated augers followed by an externally heated suspension pyrolysis loop											out of business?	http://www1.eere.energy.gov/biomass/pdfs/ibr_commercial_rangefuels.pdf	

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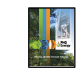
Gasification Vendor Comparison Matrix

Indicates an IBR Project, http://www1.eere.energy.gov/biomass/integrated_biorefineries.html

REV G | PROJECT: | DATE: 6/14/2011 | **PROJECT NAME:**

Technology	Suppliers	Basic process	Temp	Press. (psig)	Heat Source	Tar production	Tars methodology	HHV	Technology status:	Biomass sites:	Advantages	Disadvantages	Comments	IBR Link	Website
Fixed Bed - Downdraft	Renet	closest thing to a downdraft gasifier found so far (biomass inserted at top, air inserted on sides at upper and lower levels, syngas pulled off side)			auto	lower tar levels than updraft gasifiers, but still a challenge	syngas passes through hot oxidation zone where tars are cracked; rape methyl esther (RME) is used to further scrub tars afterward		small scale pilot	Wiener Neustadt pilot plant		very little experience, still struggling with addressing tars in syngas	not demonstrable		http://www.renet.at/english/sites/wr.neustadt/technology.php
	PHG Energy	Downdraft Gasifier is a sequential, co-current flow, gravity-assisted													http://www.phgenergy.com/?page_id=2
	Community Power Corp	fixed bed down draft			auto								small modular units up to about 2 tons/day of dry feedstock, not scalable		http://www.gocpc.com/
Plasma Arc	Alter NRG (was westinghouse)	less feedstock sizing required but still need drying, gasify with Westinghouse plasma torches, inert slag comes out bottom; three stdd sizes: 75/150/500tpd; water used on lower unit for cooling; air added at torches as well as sec/ter air zones above			allo	near zero	not needed; higher temperature gasification breaks tars	150mmBTU/cuft on air, 250mmBTU/cuft on O2 (gasifier processes more wood on O2 also)	in use at steel and aluminum foundries, hazmat facilities, MSW processers	Utashinai, Japan 280tpdMSW, Defiance,OH (GM foundry) Quebec (Alcan Aluminum) pilot plant in Madison,PA; Tallahassee and GPS signed contract to process 1000tpdMSW and make 35MW in 2010	feedstock size/moisture can vary; most forgiving design for blending knots/shives or other wastes	torch power consumes 3-10% of input BTU rate; torches last 3000hrs and take 1hr to change	plasma assisted O2 gasification, might be an option by subtracting out the plasma portion?		http://www.alternrg.ca/gasification/index.html
	MPM Technologies	three electrodes produce electric arc to gasify biomass			allo	near zero	not needed; higher temperature gasification breaks all tars	medium/high?	everything shut down now	pilot site in Libby, MT, 120tpd in Italy	feedstock moisture can vary up to 55% with no difficulty	substantial parasitic power consumption	not demonstrable		
	InEnTec (S4 Energy is partnership w/ waste mngmnt)	DC plasma arc with an AC glass melter			allo					Dow Corning's silicone-based manufacturing facility in Midland, Mic			commercialization of INL? Fulcrum is using this technology		http://www.inentec.com/
	Solena Group				allo										http://www.solenagroup.com/
	Plasco Energy Group	std technology is two-stage gasification. 2nd stage is plasma.			allo				Commercial	5 tonne/day R&D in Spain, planned sites = 100 tonne/day Demo in Ottawa, 200 tpd Commercial MSW & ICI in Red Deer, Canada			2 or 3 other commercial sites in the works, Drives IC enginers. Claim > 1 MW-hr / tonne of waste. Designs based on standard 100 tpd		http://www.plascoenergygroup.com/
	Princeton	plasma torch gasification done in sequenced batches to smooth out syngas production			allo	near zero	not needed; higher temperature gasification breaks all tars	medium/high?	used mostly for hazardous wastes	SE Asia	very little info	substantial parasitic power consumption	1. units are small 2. parasitic power consumption can be high		http://www.princetonenvironmental.com/plasma.html
	Europlasma				allo										
	AdaptiveARC, Inc.	"low temp" cool plasma			allo										http://www.adaptivearc.com/
Electrode/Electric Arc	MPM Technologies, Inc. Skygas	zero O2 or air used, similar to smelting			allo										http://www.mpmtech.com/gasification.html
Bubbling Fluid Bed	GTI Renugas	Pressurized fluid bed air/ocygen blown	835C (1535F)	333 max	auto			270 Btu/cuft					Carbona has license, Still need field verification; fully demonstrated at 12 tpd, it has been scaled up to 100 tpd at air-blown mode		http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=4reportspubs\4_8focus\biomassgasificationformultipleapplications.xml
	Andritz / Carbona (IBR Project w/ Haldor Topsoe)	circulating and bubling fluidized bed (Renugas license) air and/or O2 blown gasifier		range (100-150)	auto	.03BTU/cuft (after catalyst?)	nickel catalyst at Skive, Denmark	~150 BTU/cuft	Carbona/Ahlstom/Andritz have lime kiln experience since mid 1980s	Skive, Denmark with ties to Wisaforst, Finland Norrsundet, Sweden	more experience than most companies; Skive gasifier has worked well so far, but is still doing plant commissioning	some ash and carbon carryover in syngas with all CFB units, although this is supposed to increased radiative heat transfer at kiln burner	Carbona has probably most experience making true syngas in pilot plant, using Jenbacher gensets after removing dust, alkali, and water	http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_haldortopsoe.pdf	http://www.andritz.com/iss_17.pdf
	Frontline Bioenergy	bubbling fluidized bed air blown 60psi gasifier, single vessel		atm+	auto	5-21g/Nm3, tar dewpoint 450F	keep gases hot	~150 BTU/cuft	first commercial gasifier is in commissioning	Chippewa Valley Ethanol	CFB technology generally works well with biomass		Recently found European investor...dust is filtered, some alkalis condensed out, but adequate for power gen?		http://www.frontlinebioenergy.com/
	Enerkem (IBR Project)	bubbling fuidized bed air blown single vessel; company focus is on creating cellulosic ethanol by catalysis			auto	high	catalytic and tar re-injection to reactor			Sherbrooke, Quebec pilot plant; Westbury, Quebec cellulosic ethanol plant starting up fall08	gasifier picture looks a lot like a Carbona unit	building first plant	Limited information as Enerkem is not interested in selling the gasification technology, rather they manufacture, own and operate the plants	http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_enerkem.pdf	http://www.enerkem.com/en/home.html
	Radian Bioenergy (was Emery Energy)	air blown gasifier, technology unclear			auto			probably 150 BTU/cuft	demo and pilot plants only	25tpd plant, Salt Lake City?	have engineered a 100tpd modular gasifier system	very limited info, no large gasifier experience	1. not demonstrable beyond test/pilot plants		http://www.radianbioenergy.com/index.html
	Synthesis Energy	fluidized bed gasifier (air blown?)			auto	likely to be moderate			commericialized and operating several large units on coal	none?	CFB technology generally works well with biomass	coal experience only	not demonstrable in biomass		http://www.synthesisenergy.com/IGCC.html
	TRI (previous name was MTCI) (2 IBR Projects)	used 60pulse/sec syngas burners provide heat to aluminum oxide bed; fluidizing steam is introduced evenly spaced across vessel			allo	none	not needed	syngas medium BTU value	commercial site on black liqr; working on issue of other biomasses plugging vessel	Norampac Trenton, ON (1/7 of 3RB capacity)	the pulse heaters are in their 3rd generation design; fully operating pilot plant	91.5% availability in 2005, 87.2% in 2006; many types of biomass will plug the gasifier vessel	http://www1.eere.energy.gov/biomass/pdfs/ibr_demonstration_flambeau.pdf	http://www1.eere.energy.gov/biomass/pdfs/ibr_demonstration_newpage.pdf	http://www.tri-inc.net/index.html

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Circulating Fluid Bed	~~TPS Termiska Processer~~	~~CFB air blown dual vessel~~	~~859-900C (1562-1652F)~~	~~21~~	auto	~~medium~~	~~second gasifier runs at higher temp for tar cracking; wet scrubbing afterward~~	~~syngas 153 BTU/cuft (107-188)~~	~~first syngas to TG in 2002~~	~~ARBRE project at North Yorkshire, UK (now shut down due to liquidation)~~	~~ARBRE is second only to Varnamo site to perform biomass IGCC~~	~~limited time on gas turbine due to liquidation of plant~~	~~1. not demonstrable - only one wood project that never finished startup 2. more equipment - higher capital 3. out of business~~		~~http://www.tps.se/~~
	Metso (formerly Kvaerner, Gotaverken)	circulating fluidized bed air blown gasifier			auto	moderate	keep gases hot	~150 BTU/cuft	operating on lime kiln since 1987	Varo Sodra Cell pulp mill feeding lime kiln, also affiliated with Wisa Forest Finland gasifier on lime kiln and others	21yrs experience, the gasifier sticky pluggages and tar buildups have been resolved, simple setup	lots of carryover of ash, carbon/char, and bed material if no de-duster is added to system	only repower and CHP so far		http://www.metso.com/pulpandpaper/recovery_boiler_prod.nsf/WebWID/WTB-090521-22575-A40B0?OpenDocument&mid=7CC3252B3979EB4BC22575BD0057742C
	Energy Products of Idaho	circulating fluidized bed air blown gasifier, single vessel	540-980C (1004-1796F)	atm?	auto	moderate	keep gases hot	~150 BTU/cuft (100-200)	operating a number of fluidized bed gasifiers/boilers for years on various feedstocks		lots of experience in CFB boiler and gasifier projects		fully scalable, would need to modify if other then CHP		http://www.energyproducts.com/EPITechnology.htm
	Foster Wheeler	circulating fluidized bed air blown gasifier, some (all?) at high pressure	950-1000C (1742-1832F)	262	auto	moderate	keep gases hot	~150 BTU/cuft (142-169)	supplied several lime kilns with CFB gasifiers back in 1980s	Electrabel, Belgium Varnamo, Sweden Lahti, Finland	affiliated with lime kilns using CFB gasifiers back in 1980s; running 97% availability at Lahti	this company has to date been non-responsive	fully scalable, no reponse, lack of interest?, moved HQ to switzerland, maybe track down costs through existing Swedish project		http://www.fwc.com/GlobalPowerGroup/EnvironmentalProducts/BiomassGCS.cfm
	Andritz/Carbona	apparently Carbona also offers a CFB, although the BFB seems to be the main design			auto										
	EERC	CFB			auto										http://www.undeerc.org/equipment/gasification.aspx
	Rentech/SilvaGas Corp (FERCO, Battelle) (IBR Project - ClearFuels)	CFB, dual vessel, steam to first vessel, air to second vessel	830C (1526F	atm?	allo	0.001lb/cuft (12-15BTU/cuft)	proprietary DN34 catalyst breaks ~90% of condensibles	syngas 450-500BTU/cuft (410-464)	500wettpd ran 24/7 for yrs	demo:McNeil Power Station Burlington, VT (shut down now) - permit for BG&E in Tallahassee applied for	%moisture doesn't affect gas BTU value, only the volume produced	no operating units at this time	fully scalable, not demonstrable	http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_clearfuelstechnology.pdf	http://www.silvagas.com/index.htm
	Biomass Gas and Electric	variation on silvagas			allo								has Silva gas license and working on three projects		http://www.biggreenenergy.com/
	Repotec	CFB, dual vessel, steam to first vessel, air to second vessel			allo	"low"	scrubbed out; this stream is then made into steam to be injected into first vessel for driving gasification process	syngas 322BTU/cuft		Gussing, Austria 8MW/26mmBTU/hr (studying 341mmBTU/hr syngas site for Goteborg to put natgas to header)	higher BTU value syngas, better for liquid fuels generation later	smaller scale systems experience only	prob too small		http://www.repotec.at/
	Milena (ECN)	double reactor with gasif occuring in riser tube; hot sand from char combustion drives gasif			allo		planning to use Dahlman OLGA system		developmental	none?	none	no operating units at this time	not demonstrable, too small right now, variation on slivagas and repotec		http://www.biosng.com/experimental-line-up/gasification-technology/
	FICFB	CFB			allo								This is the Repotec technology		http://www.ficfb.at/
	Taylor Biomass Energy	CFB, dual vessel, steam to first vessel, air to second vessel, syngas sent to gas conditioning vessel			allo	low; gas can be cooled to 300F before any condensation	tar converted to syngas in conditioning reactor	syngas 400BTU/cuft				no demonstration site at this time	not demonstrable, only marketing smaller 500 tpd units		http://www.taylorbiomassenergy.com/TBE%20Technology.htm
	Lurgi (by itself)	originally had a low press CFB			allo								NO INFO FOUND ON THIS AT THIS TIME		
Hybid	Choren	2 stage , pyro-gas / might consider an entrained flow design			allo	non-detect		syngas "high"				more complicated process, lots of capital, limited demonstratability	1. very complex, high pressure system 2. lots of equipment to maintain 3. higher capital cost		http://www.choren.com/en/biomass_to_energy/advantages_of_carbo-v/
	Red Lion Bioenergy (IBR Project)	Dual vessel pyrolysis followed by reforming			allo								DOE project, renewable energy institute, Ohio	http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_reii.pdf	http://www.redlionbio-energy.com/
	GE/Texaco	pulverize fuel, inject in slurry form, entrained flow, use O2, produce high pressure steam and medium BTU syngas (single-stage, downward-feed, entrained-flow)			auto			medium/high	commercialized in coal gasification, but not biomass	none?	higher BTU value syngas,	no biomass experience, biomass would be pulverized to dust to work in entrained flow configuration, higher capital	1. entrained flow is not good approach for biomass gasification - too much pulverizing required to get necessary reaction time 2. higher capital		http://www.gepower.com/prod_serv/products/gasification/en/overview.htm
	Lurgi (Air Liquide) MPG	dry fuel put into refractory-wall gasifier using steam and O2 at high 25+bar; produce hp steam and medium BTU syngas			auto		tar levels?	medium/high	commercialized in coal gasification, but only one biomass unit		higher BTU value syngas,	a Lurgi rep expressed lack of interest	1. entrained flow is not good approach for biomass gasification - too much pulverizing required to get necessary reaction time 2. higher capital		http://www.lurgi.com/website/index.php?id=19&L=1
	Shell	dry fuel put into membrane-wall gasifier using O2 at high pressure; produce hp steam and medium BTU syngas			auto		tar levels?	medium/high	commercialized in coal gasification, firing 30% biomass at one site	many coal sites; Buggenum, Netherlands is processing 30%wt biomass also	higher BTU value syngas; membrane-wall gasifier - high reliability in coal service	little biomass experience, biomass would be pulverized to dust to work in entrained flow configuration, higher capital	1. entrained flow is not good approach for biomass gasification - too much pulverizing required to get necessary reaction time 2. higher capital		http://www.shell.com/home/content/globalsolutions-en/industries/gas_and_lng/tech_papers/coal_gasification_300805.html#0

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Technology	**Suppliers**	**Basic process**	**Temp**	**Press. (psig)**	**Heat Source**	**Tar production**	**Tars methodology**	**HHV**	**Technology status:**	**Biomass sites:**	**Advantages**	**Disadvantages**	**Comments**	**IBR Link**	**Website**
Entrained Flow	Conoco Phillips	pulverize fuel, inject in slurry form, use O2, produce high pressure steam and medium BTU syngas			auto		tar levels?	medium/high	commercialized in coal gasification, but not biomass (??)	none?	higher BTU value syngas,	no biomass experience, biomass would be pulverized to dust to work in entrained flow configuration, higher capital	1. entrained flow is not good approach for biomass gasification - too much pulverizing required to get necessary reaction time 2. higher capital		http://www.conocophillips.com/Tech/downstream/E-Gas/index.htm
	Siemens	dry-feed, pressurized, entrained-flow reactor, with the internal gasifier chamber enclosed by a cooling screen/wall													http://www.netl.doe.gov/technologies/coalpower/gasification/gasifipedia/4-gasifiers/4-1-2-4_siemens.html
	Pearson	entrained flow			allo/indirect										http://gasifiers.bioenergylists.org/taxonomy/term/406
	Brightstar	entrained flow			allo/indirect							focused on municipal solid waste (MSW)	not demonstrable, company exists on paper only?, clear fuels		http://www.seas.columbia.edu/earth/wtert/sofos/nawtec/nawtec10/nawtec10-1012.pdf
	Future Energy	entrained flow			allo								variation on Choren?		http://www.future-energy.de/energy-unlimited/
	MHI	entrained flow													http://www.netl.doe.gov/technologies/coalpower/gasification/gasifipedia/4-gasifiers/4-1-2-5_mhi.html
	Uhde	Prenflo process; looks much like the Shell process; runs at 40+bar			auto		tar levels?	medium/high	commercialized in coal gasification, but not biomass (??)	none?	higher BTU value syngas,	no biomass experience, biomass would be pulverized to dust to work in entrained flow configuration, higher capital	1. entrained flow is not good approach for biomass gasification - too much pulverizing required to get necessary reaction time 2. higher capital		http://www.uhde.biz/cgi-bin/byteserver.pl/archive/upload/uhde_brochures_pdf_en_11.00.pdf
Pyrolysis	Dynamotive	pyrolize biomass at coolest gasification temperature to produce black oil					most are condensed to liquids by design	bio oil ~80,000BTU/gal	two commercial scale plants currently selling bio-oil	commerical plants at West Lorne, Ontario and Guelph, Ontario	testing for use as kiln fuel and limited usage as gas TG fuel has been done	bark must be removed	operating gas turbine on bio-oil at West Lorne		http://www.dynamotive.com
	Ensyn (IBR Project, Envergent is a UOP/Ensyn partnership)	use hot turbulent sand to pyrolize biomass at 500C/930F; in their RTP process, vapor is quickly cooled to generate liquid in under 2 seconds					most are condensed to liquids by design	bio oil ~80,000BTU/gal	has operated commercially since 1989, starting in WI; currently run 7 commercial plants	largest site is 200dt/day starting up at Renfrew, ON for liquid fuel, polymers, power, chemicals	long commercial success; still growing; pushing toward more chemical products; bio-oil has been fired as industrial fuel replacement in multiple systems	plants tend to be smaller - a larger one is 31mmBTU/hr, char/carbon residue rate is high at 12%, a syngas is also produced using 13% of feedstock	1. multiple processes required to utilize all of feedstock 2. process is limited to an industrial oil replacement - doesn't lend itself to future process of transportation fuels generation options	http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_uop.pdf	http://www.ensyn.com/
	BTG	pyrolize biomass using hot sand for heat exchange, produce black oil					most are condensed to liquids by design	bio oil	Malaysia plant has run on palm residues for 2yrs	Malaysia plant	several years of commercial oil production experience	limited info, only operating commercially on palm residues (?)	1. not demonstrable except on palm residues 2. not impressed by company technical personnel		http://www.btgworld.com
	GTI (IBR Project w/ CRI/Criterion Inc.)	Integrated Hydropyrolysis and Hydroconversion (IH2) technology												http://www1.eere.energy.gov/biomass/pdfs/ibr_arra_gti.pdf	http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=1ResearchCap/1_8GasificationandGasProcessing/MajCurrentProj/Biomass-to-Diesel.xml
	Lurgi (Air Liquide)	limited info					most are condensed to liquids by design	bio oil	developmental	KIT, organisaton doing the pyrolysis, pilot plant in Karlsruhe	limited info; Lurgi handles nearly 3/4 of world's coal gasification	limited info	not demonstrable		http://www.lurgi.com/website/index.php?L=1

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Black Liquor Gasification	TRI (previous name was MTCI)	used 60pulse/sec syngas burners provide heat to aluminum oxide bed and gasify black liqr at 60% solids; fluidizing steam is introduced evenly spaced across vessel			BFB/autothermal	none	not needed	syngas medium BTU value	commercial site on black liqr; working on issue of other biomasses plugging vessel	Norampac Trenton, ON (1/7 of 3RB capacity)	the pulse heaters are in their 3rd generation design; fully operating pilot plant	91.5% availability in 2005, 87.2% in 2006; many types of biomass will plug the gasifier vessel	company is focusing on biomass now		http://www.tri-inc.net/index.html
	Chemrec	spray black liquor into gasifier, either pressurizedusing O2 or non-pressurized using air, quench syngas to make green liquor			entrained flow/autothermal	none	not needed	syngas medium BTU value	commercial at low pressure; delopment plant for O2/hi press	Weyerhaeuser New Bern 330tonBLS/day commercial plant; pilot plant in Pitea, Sweden	limited info	~91% uptime after numerous issues; refractory is now good for 2yrs			http://www.chemrec.se/Technology.aspx
Molten Metals	Clean Earth Energy	use molten sodium to gasify wood to CO and H2				near zero	not needed; higher temperature gasification breaks all tars	premium syngas due to high H2%	one commercial plant	Idaho	high BTU value gas	higher capital; very complex operation; kill process with vinegar deluge, have to chill vessel walls and prevent sodium escape which uses parasitic power	1. complexity 2. capital cost 3. safety hazards		http://cleanearthenergytech.com/company.html
	ze-gen	O2 blown liquid metal gasifier								demo plant at New Bedford, Mass	tars are not an issue similar to plazma due to the high heat		appears to be designing/offering modular units for sorted MSW/RDF gasification		http://www.ze-gen.com/#home
	Diversified Energy / Alchemix	uses 2400F molten tin/iron and steam to create H2 and CO gas; FeO is generated by stripping O off of H20, then feedstock C strips O from FeO to make CO				near zero	not needed; higher temperature gasification breaks all tars		lab testing	lab	at this high temp, nearly everything put in is gasified	energy intensive, no projects	1. not demonstrable 2. capital cost 3. safety hazards		http://www.diversified-energy.com/index.cfm?s_webAction=hydromax