Technical Memorandum

To: St. Paul Port Authority
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Subject: Work Order No. # 3, Plant Technology, Size and Arrangement for the Rock-Tenn Energy Facility Study
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1.0 Task Background and Overview

This technical memorandum reports on the evaluation conducted for Work Order No. 3 that considers the plant technology, size, and arrangement for the Rock-Tenn Energy Facility Study for the St. Paul Port Authority. The primary objective of this work order is to develop options to replace the steam generation capacity of the existing facility with one that uses biomass as the fuel source. The options included four technologies considered at two different sizes. The four technologies considered in this study include:

- Stoker Fired Boiler
- Bubbling Fluidized Bed Boiler
- Circulating Fluidized Bed Combustor
- Gasification System

2.0 Fuel Considerations

The fuel design basis for the proposed facility is based on using available and practical biomass sources. A feedstock study conducted by Campbell Consulting characterized the available fuel options into two categories. They are:

Off-site woody biomass – A study was completed on woody biomass available within a 100 mile radius of the site. These sources offer a reliable and significant quantity of fuel. As a fuel source, various forms of wood have been used in conventional boilers for years. This fuel, as received, typically has a moisture content in the range of 40 percent.

<u>Agricultural biomass</u> – Agricultural biomass could include crop residue left after an agricultural process, or a crop specifically harvested for this purpose. These products could include cornstover, grasses, wheat straw, etc. Vendor experience in using these fuels is very limited. One concern expressed by vendors is the alkali content of these fuels as it combusts in the system. The primary concern is that combustion of these fuels will cause slagging and fouling of the boiler heat transfer surfaces. Due to these concerns, this analysis assumes that agricultural biomass would be limited to 30% of the boiler heat input.

3.0 Plant Configuration and Sizing

The Rock-Tenn facility has thermal energy requirements with a demand profile that varies on a seasonal basis. Recent conservation measures have resulted in reductions in the energy used at the facility. The Rock-Tenn staff reported that during the winter of 2007/2008, a load of 235,000 lbs/hr of steam was determined to be the peak demand. This represents a significant reduction over previous years and was accomplished in a winter that was colder than average compared to previous years.

Two plant sizes were established to examine different approaches to a future biomass facility. It is noted that HDR's presentation on the Technologies, Feasibility and Site Logistics given to the RCAP Panel on April 21, 2008 initially discussed two sizing options. These two options delivered by HDR to the Project Team and the RCAP Panel had an error. In the presentation, HDR presented a base load steam requirement of 150,000 lbs/hr and peak steam load requirement of 275,000 lbs/hr. The base steam load requirement has been revised from 150,000 lbs/hr to 195,000 lbs/hr. The reason for the change is an error which occurred associated with the conversion of the thermal requirements and the enthalpy at the relatively high pressure and temperature steam conditions. HDR has also re-examined the initial baseline thermal requirements of 2,250,000 MMBtu/yr for the Rock-Tenn facility and has revised the thermal requirements to 2,000,000 MMBtu/yr. These differences results in the 195,000 lbs/hr base load requirement which is representative of the actual base load needs.

1. In the first scenario, the plant would be able to accommodate seasonal peak energy needs after recent energy conservation efforts have been completed, plus the potential for some additional growth due to increasing recycling plant throughput. Rock-Tenn recorded a peak demand over the winter of 2007/2008 of 235,000 lbs/hr (compared to previous winter of 305,000 lbs/hr). When designing energy plants, it is necessary to include additional margin in the equipment design to accommodate load variations

and equipment conditions. One would not expect to operate the facility at 100% design capacity. Margin also allows for some future anticipated growth potential. In this case the selected boiler size of 275,000 lb/hr (Nameplate capacity) would mean that at the expected operating load the plant would be running at 85% design capacity. Note that the current total plant capacity is approximately 600,000 lbs/hr.

2. The second size scenario recognizes that economics may be different for a biomass facility that only supplies the base-load energy needs of the facility with the remainder being made up by the plant's existing boilers. This option would provide the majority of the facility's energy needs from biomass at a lower capital cost than Option 1, however, it would require Rock-Tenn to continue to operate their boilers firing gas and oil to meet the seasonal peak energy demand requirements. Review of the available energy data for previous operating years indicates that the base-load steam demand flow is approximately 205,000 lbs/hr. It is expected to be approximately 195,000 lbs/hr after conservation efforts. This size would represent additional significant energy conservation greater than that already achieved.

4.0 Fuel Storage and Handling Requirements

Consideration of the fuel handling systems arrangement is an important and often overlooked element of a project at this stage. An improperly designed system can significantly impact the plant’s operation and economic performance. The design must take into account site constraints, unloading logistics, storage capacity, and the ability to feed the boilers reliably. The quantity of fuel required and the expected operating constraints are very similar for the various technologies considered. As such, the fuel storage and handling requirements were developed for one arrangement and are assumed similar for all the technologies considered. The fuel storage and material handling flow diagrams are depicted in Appendix A on 01G-01 through 01G-05 and 02G-01 through 02G-04.

4.1 Onsite Storage

The existing warehouse on the east side of the site (Building #120) offers a potential storage location that would prevent fugitive dust emissions and protect the wood from moisture. An arrangement for a material handling system that integrates the warehouse as a storage building was developed and is depicted in Appendix B. The building has capacity to store two and a half days of fuel required for the biomass boiler firing at the peak demand load. If the base demand was considered, the building would have enough storage for three days. Sheet 01G-04 shows the woody biomass and agricultural biomass fuel storage footprint in this area that will primarily be stored in the existing warehouse. This fuel will be conveyed to material handling systems shown on sheet 01G-05. The gasification option requires a storage silo, shown on 02C-01, due to the necessity of drying the material to a lower moisture level to meet the vendor's requirements.

4.2 Material Handling

The material handling systems layout is designed to adapt for the boiler, fuel storage, and logistics, as well as current site constraints. HDR consulted with an equipment vendor to obtain information on the layout of the material handling systems. The material handling, flow diagrams, and site plan arrangement for this project are included in Appendices A and B. The two options for delivery of biomass fuel to the site are rail and truck receiving.

Rail Receiving

We completed an evaluation of the existing rail line to determine the further utilization of this line at the Rock-Tenn site. The existing rail line east of Building #2 was considered to meet Federal Rail Administration (FRA) inside track measurement guidelines, with a few exceptions. One clearance violation was noted at the northeast corner of Building #132. The HDR team also observed areas of FRA inside track measurement violations west of Building #2, which might impede the amount of rail traffic that could come into the site in regards to staging of the fuel cars.

If the existing rail line is to be used, the facility would have to purchase (or lease) its own rail cars for a dedicated delivery service with a suggested shorter box car length due to the smaller radius around the existing warehouse. Drawing 01G-05 shows a possible arrangement for unloading of wood with a bottom dump system. This system uses available equipment and technology but presents some operational concerns including fuel bridging, pluggage, and freezing problems. If rail unloading is deemed desirable in the future, HDR recommends further analysis and the possibility of using a side dump unloading system.

Truck Receiving

Truck access to the facility would be from Intestate 94, through Vandalia Street, near the existing entrance. Both woody and agricultural biomass systems are included. Trucks would deliver the fuel required, which would be staged, maneuvered, and unloaded in a new woody biomass receiving area located on the north side of the existing warehouse. This truck receiving option would include a truck dumper that would lift a truck in the air and unload the woody biomass by gravity into a receiving hopper. Trucks would also bring agricultural biomass into the site in baled form. Bales would be unloaded near the existing warehouse. The agricultural biomass would be transferred from the truck to the existing warehouse using a pallet unloader. Depending on the final arrangement of the site, a second pallet unloader may have to be used in order to transport the agricultural biomass into the bale shredder.

5.0 Conversion Technology Options

The power generation systems evaluated consisted of the following:

Stoker Fired Boiler

This is a conventional boiler with a spreader stoker and utilizes the existing back-pressure steam turbine generator. The stoker grate boiler offers fuel flexibility that has a long operating history. Fuel flexibility includes many conventional solid fuels and also woody biomass and agricultural biomass. The fuel specification for this system requires wood product fuels be provided at 40% to 45% moisture content. Biomass combustion has historically used stationary or traveling grates. This configuration typically uses motor driven feeders or air swept spouts to feed fuel onto a grate where it burns. The stoker fired boiler typically has an efficiency range of 70-75% and a reliability rating of around 90%.

Combustion air is supplied to the underside of the grates in volumes that are controlled to meet the combustion conditions of each burning zone. This close control of air volume and distribution promotes uniform combustion, minimizes hot spots on the grates, and promotes a stable steam flow. Additional combustion air is introduced above the grates. This promotes intense flame turbulence and minimizes the escape of any unburned gases from the combustion zone. Water wall and boiler tubes are included to transfer the heat from the combustion to the water and steam for the turbine.

Diagram 01G-02 shows the combustion air and flue gas train expected. This includes emissions control equipment required to meet the expected environmental performance. This option would include a system to reduce nitrous oxide (NOx) emissions such as Selective Non-Catalytic Reduction (SNCR) or Regenerative Selective Catalytic Reduction (RSCR) system along with acid gas treatment to remove sulfuric oxide (SOx) and a Fabric Filter for particulate control.

Bubbling Fluidized Bed Boiler

The bubbling fluidized bed boiler utilizes the existing back-pressure steam turbine generator. The bubbling fluidized bed boiler offers fuel flexibility in a technology that has a great deal of operating history. The fuel specification for this system requires wood product fuels be provided at 40% to 45% moisture content. The fluidized bed process contains a mixture of particles suspended in an upwardly flowing gas stream that exhibits fluid-like properties. The bubbling fluidized bed boiler typically has an efficiency range of 70-75% and a reliability rating of around 90%.

The fluidized bed offers lower emissions exiting the boiler which leads to reduced reagent usage in the downstream pollution control equipment. Water wall and boiler tubes are included which transfers the heat from the combustion to the water and steam for the turbine. Diagram 01G-02 shows the combustion air and flue gas train expected. This includes emission control equipment required to meet the expected environmental performance. The equipment includes a mechanical dust collector and a fabric filter to remove particulates. It is assumed, for this option, that additional NOx reduction would not be required; however, depending on permitting conditions, it may be necessary to add Selective Non-Catalytic Reduction (SNCR) to remove NO_x emissions. Addition of limestone in the bubbling bed and possibly injection of some lime before the fabric filter is often sufficient to achieve the required acid gas removal.

Circulating Fluidized Bed Combustor

This option is similar to the bubbling fluidized bed boiler, except that the furnace where combustion takes place is not constructed of water walls and no heat transfer takes place in the combustion area. Instead the hot flue gases exit the combustor and pass through a waste heat boiler, sometimes called a heat recovery steam generator (HRSG). These systems are somewhat more modular in their construction and may be installed at a lower capital cost. The equipment required downstream of the boiler would be virtually identical to the bubbling fluidized bed option and would include a fabric filter for particulate control. The circulating fluidized bed combustor efficiency is similar to a bubbling fluidized bed boiler. The reliability rating is equal or greater to the bubbling fluidized bed boiler.

Gasification System

Gasification systems generate a producer gas (synthetic gas) that could be supplied to and combusted in the existing boilers. This gasification option offers fuel flexibility with a variety of biomass options, but does not have a long operating history or track records available from any vendor contacted for this study. Three vendor systems were considered. The systems are similar but have some differences. The following generally summarized the system.

The biomass gasification system considered in this study is a fluidized bed, air blown, pressurized system, which makes a clean and cooled producer gas. The producer gas is cooled by means of a waste heat-style boiler, is cleaned of chars, tars, and ash by a fabric filter, and supplied to the existing boilers, thus potentially reducing the capital costs of the project. Ash and char are present in the gas passing through the producer gas cooler (heat recovery steam generator), which may cause concern for potential plugging. The system is in positive pressure, which requires ASME pressure vessels as well as a potential for unwanted fugitive emissions should any leaks occur. The gasification system efficiency has been calculated to be at 74% and the reliability is unknown due to the limited established commercial applications of this size.

The fuel specification for this system is fairly strict and wood products must be provided at 15% to 20% moisture content. This is much lower than the expected as-received moisture content of the wood, so supplemental drying would be required. Drying could be accomplished by means of direct contact dryers using flue gas from the boiler exhaust as the energy source. It would be necessary to run an insulated duct from the existing boilers back to the gasification system, approximately 500-600 feet away. The exhaust from the direct contact dryers would need to pass through another fabric filter to reduce particulate emissions before exhausting to the atmosphere. The auxiliary power requirements are higher due to the high energy gasifier blower and compressors.

6.0 Performance

Performance calculations were developed using Steam Pro/Steam Master software and the output of this modeling is included in Appendix D. The Steam Pro/Steam Master software calculates fuel flow on a 365 day/yr operating cycle (conversions were made to account for a plant fuel delivery cycle at 304 days/yr with considering downtime such as weekends and nine holidays). The results are summarized in the table below.

Technology Comparison				
	Stoker Fired Boiler	Bubbling Fluidized Bed Boiler	Circulating Fluidized Bed Combustor	Gasification System
Nameplate Steam Flow (lbs/hr)	275,000	275,000	275,000	275,000
Operating Steam Flow (lbs/hr) at 85% of maximum	235,000	235,000	235,000	235,000
Fuel Flow (tons/day) – based on 304 delivery days/yr	1,039	1,029	1,029	965
Gross Electrical Generation (kW)	12,194	12,194	12,194	12,194
Auxiliary Loads (kW)	1,850	1,754	1,754	3,630 plus existing plant
Net Generation (kW)	10,344	10,440	10,440	8,564

Technology Comparison				
	Stoker Fired Boiler	Bubbling Fluidized Bed Boiler	Circulating Fluidized Bed Combustor	Gasification System
Nameplate Steam Flow (lbs/hr)	195,000	195,000	195,000	195,000
Operating Steam Flow (lbs/hr) at 100% of maximum	195,000	195,000	195,000	195,000
Fuel Flow (tons/day) – based on 304 delivery days/yr	862	854	854	802
Gross Electrical Generation (kW)	10,001	10,001	10,001	10,001
Auxiliary Loads (kW)	1,543	1,436	1,436	3,012 plus existing plant
Net Generation (kW)	8,458	8,565	8,565	6,989

Emissions Comparison				
	Stoker Fired Boiler	Bubbling Fluidized Bed Boiler	Circulating Fluidized Bed Combustor	Gasification System
NOx Control (SNCR)	Yes	Possible	Possible	No
Particulate Control (Fabric Filter)	Yes	Yes	Yes	Yes
Acid Gas Control	Yes	Limited	Limited	Possible

7.0 Conceptual Design

The basis of design was developed through discussions with Ever-Green Energy, Rock-Tenn, The Green Institute, Campbell Consulting and several equipment vendors. The design basis summaries are included in Appendix A.

Appendices A and B show the site plan, traffic flow, flow diagrams, and plant arrangement for the conventional combustion system are depicted in drawings 01C-01, 01C-02 and 01G-01 through 01G-08. The gasification system is depicted in 02G-01 and 02G-01 through 01G-04. The arrangement is based on using a conventional (stoker fired boiler, bubbling fluidized bed boiler, circulating fluidized bed combustor) and gasification technology for the combustion system along with the emissions control equipment described above. Drawings 01G-04 and 02G-03 give the overall site plan showing the layout of material handling equipment for the conventional and gasification options, cooling tower, electrical substation, and expected site features.

Access to the facility would be from Intestate 94, through Vandalia Street and Wabash Avenue, near the existing entrance. The traffic pattern for fuel delivery is depicted on 01C-02. The boiler and emissions control equipment would be located outdoors. The fuel would be stored on-site in the existing warehouse. A building would be provided for the turbine hall which would house the steam turbine, condenser, feedwater heaters, condensate pumps, deaerator, boiler feed pumps, and water treatment equipment.

The thermal cycle for the proposed conventional facility is depicted on 01G-01. The thermal cycle for the gasification facility is depicted in 02G-01. The emissions control equipment for the conventional boiler is depicted in 01G-06 through 01G-08. The emissions control equipment for the gasification option is considered proprietary information from the vendors we consulted.

7.1 Electrical System Connection

The new biomass plant will require an additional 1 to 2 MW of electricity for its auxiliary loads for the conventional combustion option and 3 to 4 MW of electricity for its auxiliary loads for the gasification option. It is assumed that the new electrical auxiliary loads can be fed from the existing 13.8kV Bus 1 and 13.8kV Bus 3 switchgear. The existing electrical room is located on the north side of Folding Carton Building (Building #121). Two new 13.8kV feeders will be required for this new biomass plant; one will normally be open for backup. The feeders will exit from the electrical room in the Folding Carton Building and will run underground to the new plant. The feeders will be in concrete encased ductbank and buried under the road and parking lot as shown on drawing E-006 located in Appendix C. The final location of all new electrical equipment shall be determined based on each design option as stated in the above sections.

The electrical equipment for the new biomass plant will consist, but is not limited to, the following major new electrical equipment for auxiliary loads:

(1) 13,800V Medium Voltage Switchgear

(1) 4,160V Medium Voltage Switchgear

(1) 480V Low Voltage Switchgear

(4) 480V Motor Control Centers (MCC)

(1) 3000kVA, 13,800V-4160V Step Down Transformer

(1) 2000kVA, 13,800V-480V Step Down Transformer

It is assumed the existing Rock-Tenn electrical system can supply an additional 3 to 4 MW of electrical loads for the new plant. Drawings E-001 through E-005 show typical one-line diagrams for the auxiliary load requirement. Exact configuration, MCC layout, and feed points are yet to be determined and will be based upon the preferred design option.

8.0 Summary and Conclusions

The site has the space and infrastructure to support the project. All the technologies presented are capable of providing the necessary thermal requirements for the Rock-Tenn facility. Conventional combustion systems (stoker fired boiler, bubbling fluidized bed boiler and circulating fluidized bed combustor) use well established technologies which have been proven to be dependable at the scale of the proposed project. For the conventional combustion technologies the bubbling fluidized bed boiler has some advantages with regards to emission requirements and the circulating fluidized bed combustor has a more constructible modular configuration.

Gasification technology, while feasible, has a less proven record for the scale of the project. Potential issues include limited commercial experience at this scale by some of the vendors, stricter fuel size/moisture criteria and reuse of the existing old boilers.

Additionally, long-term reliability and performance of the biomass gasification system has greater uncertainty at this time.