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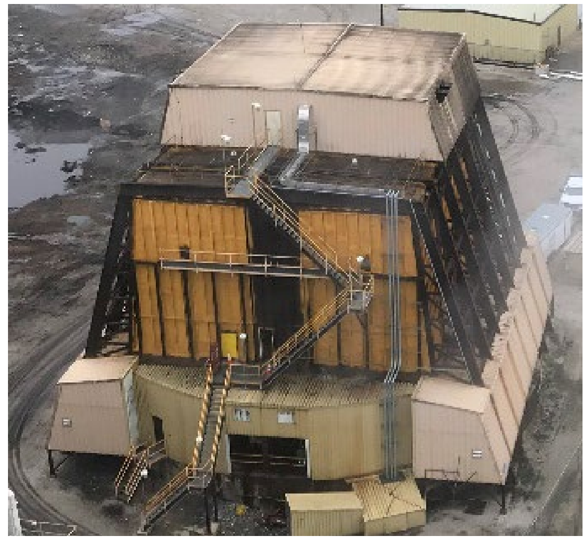

FINAL Report

City of Ames Waste-to-Energy Option Study

Report No. 507-006-01

September 2022

Prepared for
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CITY OF AMES WASTE-TO-ENERGY OPTIONS STUDY

Report No. 507-006-01

REVISION HISTORY

Issue	Issue Date	Summary
0	03/23/2022	Final Report Draft for Owner Review
1	SEP2022	Final Report

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The information contained in this report is intended for the exclusive use of the City of Ames. This document has been prepared pursuant to Contract for Waste-to-Energy Options Study for the City of Ames dated April 27th, 2021, therein between the City of Ames and RRT entered into effective as of April 27,2021.

To the extent that specific vendors/equipment names are used in this report, it is for the sole purpose of evaluating the City’s various options in the Study. These statements are not meant to preclude any unlisted vendors/equipment from future opportunities to propose to the City of Ames on the WTE system upgrades, nor are they meant to recommend the listed vendors/equipment as the selected system(s)/equipment for a given option. The information obtained from these vendors/suppliers was used only to develop indicative costing, conceptual layouts and designs, and to determine key performance parameters of the technical analysis.

This report does not purport to be all-inclusive or to contain all of the information that may be relevant in making any decision concerning an evaluation of the project. It is the intention of RRT to have provided services that performed in accordance with the standard of professional practice ordinarily exercised by the applicable profession at the time and within the locality where the services are performed and responsive to the contents of the City of Ames’ RFP for the project. RRT does not provide any warranty or guarantee, express or implied, including warranties or guarantees contained in any uniform commercial code.

REPORT UPDATE

RRT has no responsibility to update this report for any changes occurring subsequent to the Final Issuance of this Report

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1 EXECUTIVE SUMMARY

The decade of the 70's brought about several changes in everyday life in America, but one factor that created numerous challenges for the United States and its citizens was the energy crisis that occurred during this period. There was both the 1973 oil crisis and the 1979 energy crisis. Another key event from the 1970's was the founding of the Environmental Protection Agency (EPA) in 1970. The concepts of environmental stewardship and conservation of resources became key focus areas for the EPA and many progressive communities. These two key factors combined to form a waste management revolution in the U.S. and a number of resource recovery facilities and waste-to-energy plants were developed as a result. A vast majority of these facilities were developed near large population centers as a way to manage their large volumes of solid waste and to create additional base load energy (electricity and thermal).

In the early 1970's the City of Ames was considering the best way to deal with solid waste disposal and made the forward-thinking decision to avoid burying all of their waste in a landfill and instead decided to build a Waste-to-Energy (WTE) system to recover valuable materials from the waste stream, convert municipal solid waste (MSW) into energy thereby reducing reliance on landfills and saving valuable farmland for growing crops. Construction of the Resource Recovery Plant (RRP) began in 1973 and it started operations in 1975 with the Refuse Derived Fuel (RDF) co-fired with coal in the existing boiler Unit 7. Shortly thereafter the construction of Unit 8 was approved in 1978, and it was similarly designed to burn RDF co-fired with coal. The combination of the Resource Recovery Plant (RRP) and construction of Unit 8 at the Power Plant paved the way for WTE production, landfill avoidance and greater environmental stewardship for the City and the surrounding communities.

The community (residents, businesses and the member agencies) has long supported the City's environmentally focused approach to waste management and as a result the City has worked to maintain the "System" (Resource Recovery Plant, RDF storage bins and the Power Plant (PP)) in good working order for the last 46 years. Factors driving a need for updating of the System include (1) the input waste stream approaches or exceeds the current power plant's capacity, requiring increasing amounts of waste to be bypassed to landfill (2) the current high variable cost of power derived from the co-firing of natural gas versus the growing abundance of renewable power at lower power prices in Iowa, (3) the operational limitations of the combustion process associated with the current fuel mix in the decades old boilers originally designed to burn primarily coal and (4) the potential of reducing environmental impacts using newer air pollution control technology. As a result, the City of Ames commissioned this WTE Options Study to consider a number of potential options to modify or replace the System and analyze the technical and financial merits of each of these options. The City of Ames will then utilize this study and accompanying financial model to consider several options to maintain the current system or to modify/replace the current system.

The electric utility for the City of Ames is a full service municipal electric utility serving approximately 27,500 metered customers. The Electric Department owns and operates four generation resources, two RDF/natural gas co-fired boilers totaling nameplate capacity of 98 MW (65 MW+33MW) and two oil-fired combustion turbines. Under the current operation, all of the net power produced from the combustion of RDF co-fired with natural gas serves the City's electricity needs first. The balance of the City's electricity needs is then purchased from the MISO Zone 3/Northern District (Ames node). The significant wind energy in the region has driven wholesale energy costs down and this further magnifies the challenge of the requirement to co-fire the RDF with significant amounts of natural gas as required under the Title V Air Permit. On January 5th, 2021, the City issued an RFP to evaluate five identified options for the disposal of MSW in a waste-to-energy (WTE) facility to meet its disposal demands for the period between 2023 through at least 2040. Through discussion with the City staff and early technical analysis, two sub-options were added (3A-2 and 3B-2) and all seven options are fully evaluated within this WTE Options Study. The seven WTE options are briefly described in ***Section 1.1 - WTE Options Study Overview***.

This executive summary presents the options studied and key findings of the technical, environmental and financial analysis performed by the RRT consulting team in partnership with the City of Ames. All of the options presented would require permitting by the Iowa Department of Natural Resources (DNR) and while a high-level overview of environmental impacts is presented in ***Section 1.4***, a more detailed write-up is provided in ***Section 5 - Environmental Impacts***.

1.1 WTE Options Study Overview

In order to evaluate the City's options, there was a need to establish a base case using the current operations of the existing Resource Recovery Plant (RRP) and Power Plant (PP). The technical team documented both the performance of the current System as well as the operational and maintenance costs, which were used as inputs in the financial model. The base case served as the primary case to compare all other options against. This section describes all seven evaluated options including the base case, the four[1] primary new options, and the two sub-options. A detailed side-by-side Process Options summary table is provided in ***Appendix A***.

1.1.1 Option 1 – Resource Recovery and Power Plants As-Is (Base Case)

This is the base case reflecting the current operations at both the RRP and PP. The RRP continues to process Municipal Solid Waste (MSW) in the existing RRP built in 1975. The output of the RRP is a 4 inch minus sized RDF that is stored in a two-sided RDF storage bin and conveyed pneumatically to the PP. The RDF is then combusted with natural gas in existing steam boilers 7 or 8, which were commissioned in 1967 and 1982 respectively. The steam passes through the respective steam turbines to produce electricity for the City's electric utility. Under the air permit, Units 7 and 8 cannot consume RDF simultaneously, nor is the system designed to support that operation. The available waste stream currently approaches or exceeds the Power Plant physical consumption limit of 32,000 TPY by about 6%. The City of Ames projected population growth and coinciding growth in waste tonnage makes this current limitation a key issue to be addressed by whatever option is selected by the City.

1.1.2 Option 2A – Existing RRP with a New RDF Combustion Unit in the Existing PP

The existing RRP plant, RDF storage bin, and RDF conveyance system would remain mostly as-is with a few modifications to address current processing challenges in the overall WTE system. As an example, it is proposed that the City replace the existing air knife and add a new Eddy Current Separator (ECS) to improve separation and non-ferrous metal recovery from the RDF stream.

The Power Plant side of Option 2A utilizes a new boiler to exclusively burn the 4 inch minus RDF and eliminate the need to co-fire RDF with natural gas during normal operations. The RDF boiler would be installed where retired boilers 5 and 6 are located or at the adjacent former water treatment plant. Subject to inspection, Steam Turbine 5 (ST5) would be refurbished or have its steam path replaced. The associated ST5 generator would be rewound. Much of the existing power plant infrastructure including the electric utility interconnection would be re-used in this option and Unit 8 would serve as a backup to the new RDF boiler. Unit 8 would only be used a small percentage of the time as a backup to the new Unit 9, but Unit 8 would still require co-firing with natural gas. Unit 7 & 8 would be available as gas-fired (only) units for reserve capacity.

1.1.3 Option 2B – Modified RRP (20" RDF) with Two New RDF Combustion Units

This option includes modifying the existing RRP to create a rough-shred, large RDF (20" minus) for combustion. The re-designed RRP would also provide up-front (pre-combustion) metal recovery. This large size RDF requires a similar MSW boiler technology to Option 3B.

This option would utilize two new combustors, Units 9 and 10, for the large size RDF, similar to mass burn technology. The new combustors would be located in a new boiler plant building at the existing coal yard location. The study assumes the two combustion units will operate in parallel for the life of the facility and

[1] Options 3A and 3B have two sub-options (-1 & -2), depending on the location of the new facility. Sub-option 2 assumes a greenfield site not contiguous with the current operations for the intention of selling steam.

if one unit is offline (for whatever reason) the other combustor would continue to process the RDF. Due to its large size the RDF would be transported from the RRP to the boilers using a conveyor over the street in lieu of the current pneumatic lines. As a result, the existing RDF storage bin and associated pneumatic system would not be needed and thus would be abandoned or demolished. Approximately 12,000 square feet of floor space in a new storage building adjacent to the new boiler plant would be included for storing the large RDF and then loaded into the boilers using conveyors. Steam would be piped to the refurbished ST5 located at the existing steam plant. Units 7 and Unit 8 would be capacity-only resources to the Mid-continent Independent System Operator (MISO) and would no longer consume RDF.

1.1.4 Options 3A-1 & 3A-2: New RRP and New RDF Combustion Unit(s)

Option 3A-1 (Coal Yard)

A new RRP, creating 4 inch minus RDF, and a new combustion boiler (Unit 9) would be provided. The new RRP would provide state-of-the-art (S-O-A) processing equipment and would have improved throughput capability resulting in more RDF from the same incoming quantity of MSW as well as better up-front material recovery. One key aspect of higher throughput is the need for more storage space to provide the same number of days in the event the lead (larger) unit is off-line. A detailed RDF/MSW storage analysis for all of the evaluated options is discussed in ***Appendix B***.

For Option 3A-1 the S-O-A RRP and one new boiler would be in a new building at the existing coal yard location. Option 3A-1 also augments the conveyance system with a new supplemental RDF storage system.

The new boiler for Option 3A-1 requires some new balance of plant support equipment since it is not contiguous to the existing power plant. The existing Unit 8 would serve as the backup boiler to consume RDF and would utilize the existing RDF conveyance system and storage bin. Steam would be piped over to the refurbished steam turbine ST5 in the existing power plant with condensate returned back to the new boiler. Unit 8 serves as a backup boiler, still co-firing RDF with natural gas. Both Units 7 and 8 are available as capacity resources for MISO when burning only natural gas.

Option 3A-2 (Greenfield)

Option 3A-2 locates the new S-O-A RRP, creating 4 inch minus RDF, and a new waste combustion facility with two new RDF boilers at a potential industrial site to provide steam to an industrial customer. Option 3A-2 requires all new power plant support infrastructure. The study assumes two new twin RDF boilers would share the load throughout the life of the facility. If one unit is offline (for whatever reason), the other unit would continue consuming RDF. The new RDF boilers would be sized to burn only RDF, using natural gas only during start-up, shutdown and for flame stabilization. A single back pressure steam turbine would generate a small amount of power (~1.5 MW) for plant use prior to exporting the steam to a nearby customer. Units 7 and 8 remain as capacity resources when burning only natural gas.

1.1.5 Options 3B-1 & 3B-2: Two New MSW Mass Burn Combustion Units

These two options provide two new dedicated MSW mass burn boilers with post combustion metal recovery located at either the existing coal yard (Option 3B-1) or an industrial site (Option 3B-2). Per the RFP, the post-combustion recovery scenario was used as input into the financial model and development of a site layout. The pre-combustion recovery of metal is discussed briefly in the technical analysis of Option 3B, and an estimated cost is provided if the City would like to pursue up-front metal recovery in lieu of post-combustion metal recovery. Units 7 and 8 remain as capacity resources for MISO when burning only natural gas.

Option 3B-1 (Coal Yard)

For Option 3B-1, two new MSW mass burn combustion boilers would be located in a new building at the existing coal yard location. Steam would be piped over to the refurbished steam turbine (ST5) in the existing power plant with condensate returned to the new boilers. Some new balance of plant supplemental infrastructure is needed to support the new boilers since they would not be contiguous to the existing power plant.

Option 3B-2 (Greenfield)

In Option 3B-2 the MSW power plant would be located at a potential industrial site outside the City to provide steam to an industrial customer. The new plant would require new power plant support infrastructure and auxiliaries. The Option would utilize two new, twin boilers to share the load throughout the life of the project. If one unit is offline the other boiler would continue to combust waste. For Option 3B-2 a single back pressure steam turbine would provide some power and all the exhaust steam would be sold to a nearby industrial customer.

1.1.6 Study Methodology

The City of Ames WTE Option Study consisted of two primary areas of technical focus and evaluation. The first phase was to technically evaluate the seven options for feasibility, performance, availability/redundancy, environmental impacts, technology options (both RRP and PP), and the capital, operating and maintenance costs. The second part of the study used the developed costs from the first phase to analyze the various options through the development of a comprehensive financial model. This model is a tool that the City will be able to use going forward and will allow adjustments to key inputs and assumptions in their overall evaluation of next steps for their waste management and power production systems.

From the two-phase process, the RRT technical team provided preliminary conceptual design layouts, process flow diagrams, mass and heat balances, analysis of various system components/options, compilation of financial data, environmental impacts and advantages and disadvantages of the studied options. RRT utilized its extensive waste and power experience to analyze, review, and compare the six new options with the City's current operations. Professional opinions, evaluations, and key considerations are discussed throughout this report, but RRT did not provide any formal recommendations in the study as this activity will be performed by City staff.

1.2 WTE Technology Considerations

Waste-to-Energy (WTE) facilities divert waste from landfills to generate energy from the combustion of municipal solid waste. Initially, waste treatment (incineration) did not have energy recovery as a primary objective. State of the art facilities now recover energy with greater efficiency and have sophisticated mechanisms that result in significantly less flue gas emissions. WTE has played a significant role in reducing the global waste problem and by maximizing energy recovery and environmental performance today, much more can be achieved. Below is a brief discussion of the various WTE technologies.

Suspension Firing: Suspension firing is a common method of burning solid fuels such as pulverized coal and wood chips. RDF combustion in the U.S. was developed back in the 1970's and 1980's, when several large boiler suppliers adapted suspension fired combustor designs from other solid fuel systems to combust RDF. Several large facilities were built in the U.S., a few of which still operate today including the City of Ames. The RDF is injected into the combustor above a horizontal grate, allowing the majority of the RDF to combust before it falls to the grate surface. The RDF size requirement for suspension-fired systems is typically 6" minus, which can usually be achieved in a single shredding step. These systems were typically much larger in RDF capacity than the City of Ames, with unit capacities on the order of 1,000 TPD, as compared to current unit capacities of 80 to 150 TPD being evaluated in this study. The current City of Ames boilers employ a similar system design with suspension firing of the RDF, but the RDF is co-fired with natural gas, which improves the performance and minimizes fluctuations in the combustion caused by changes in the RDF characteristics.

Fluidized Bed: Fluidized bed combustors were adapted from biomass applications to combust RDF of a nominal size of less than 4" and 90% less than 3". A few suppliers around the world have commercialized this technology. Bubbling fluidized bed combustion systems have been successfully applied to RDF applications for many years but require a fine RDF size of 4" minus, similar to the RDF currently produced by the City of Ames. The combustion system size being evaluated for Ames is at the smaller end of the industry product line availability, leading to a higher cost per ton of waste handled compared to larger systems. The vendors also have less commercial experience with RDF created from MSW than with biomass feedstocks. There are a number of fluidized combustion plants for RDF operating and under construction in Europe, although it is much less common than mass burn. The variability in quality of processed RDF for small RDF fluidized beds systems can result in more downtime since small systems are more susceptible to impurities such as glass and aluminum which melt in the fluidized bed and disrupt the function of the bed, requiring shutdowns to clear the fouling.

Mass Burn: The vast majority of WTE systems being installed worldwide are MSW mass-burn type combustion systems. Mass burn is the direct combustion of waste as received. There is some minimal up-front processing to remove bulk items that won't fit in the process hoppers, but 99% of the waste goes into the combustion chamber to be consumed. Reasons for the popularity of WTE mass burn systems include, the cost of pre-sorting and shredding, recyclable market price fluctuations, reliance on off-takers of recyclables, contamination/quality issues with recyclables, and the desire to have a lower volume of residual material that requires landfilling and thus saves valuable airspace. The WTE mass burn technology is well developed and has found widespread use throughout the world with over 75 units operating in the US and over 500 in Europe. A number of manufacturers provide MSW combustion systems on a "chute-to-stack" turnkey basis. The size of the WTE mass burn combustion systems evaluated in this report are also at the smaller end of the equipment design spectrum and have a resulting higher cost per ton of waste handled compared to larger systems.

The overall costs to process the MSW into small RDF and combust the RDF in these facilities in a new plant (Option 3A) are higher than mass burn systems. However, by virtue of Ames' ability to utilize existing electrical infrastructure, balance-of-plant infrastructure, existing storage, etc. the premium to continue processing MSW as RDF is substantially offset. It is notable that no new RDF facilities have been constructed in the United States to combust MSW and recover energy since the early 1980's. RDF facilities continue to be installed for processing of MSW in Europe, and for biomass-only applications worldwide to combust well processed RDF (nominal size of less than 4" and 90% less than 3").

Comparing the three types of waste combustion systems summarized above, the mass-burn systems for combusting unprocessed MSW are the most commonly used and commercially available with many reliable system providers and thousands of successful operating plants around the world. Both the suspension-fired and bubbling bed combustion systems bring less vendor options with only a few companies providing RDF from waste systems. Commercial challenges with these systems are often tied to the RDF specifications on both size and composition and difficulties meeting it on an ongoing basis.

All options evaluated (except for the base case) will utilize the same State-of-the-Art air pollution control technology (scrubber, baghouse, SCNR and PAC injection described in Appendix I). By virtue of the RDF pre-processing to remove fines and recyclables, and RDF smaller size, RDF boilers will have higher boiler efficiencies (less excess air), lower raw emissions, and therefore slightly lower pollution control system maintenance costs (e.g., consumables such as activated carbon).

The RRT team performed technical analyses on a number of key system considerations to evaluate and compare the seven total options. This includes, process flow diagrams, mass and heat balances, cost (capital, operations and maintenance, and financing), analysis of pre-and post-combustion processing systems, and various combustor technologies and power plant systems to create electricity or steam from the MSW and RDF material. The system-by-system detail and technical analysis for all evaluated options is included in ***Section 3***.

1.3 Financial Analysis

To analyze the waste-to-energy options requested by the City, a financial model in MS Excel was created for each of the seven evaluated options (Option 3A and 3B have two sub-options each). In addition to each option's capital costs, the operation and maintenance costs, the Capital Improvement Plan (CIP) which includes planned major maintenance, and bond financing were developed over a 20-year operating period to determine the lifecycle costs to process the MSW using the different WTE options specified by the City in the RFP and further refined in consultation with RRT. For Option 1 (the "Base Case") the WTE System's net power production is calculated based on the RRP and PP existing equipment functioning as designed. Similar models were then created for each of the other options using coordinated inputs and assumptions for gross MSW available, population growth, net energy delivered to Ames, average boiler sizing, and equipment efficiencies. These inputs are listed on the "assumptions tab" in the model, which allows the user to edit the assumptions and key model inputs such as natural gas prices, escalation rates and utility prices to allow for "what-if" sensitivity analysis. City staff were trained in the basic use of the model and the underlying assumptions to allow the City to easily re-evaluate options in the future if key parameters change.

It is important to understand that the operating and maintenance costs of the RRP and PP facilities to produce the electricity generated by the two co-fired generating units are only a portion of the City's cost to supply and deliver the required amount of electricity to its customers. City costs such as electric distribution system operation and maintenance, corporate overhead, billing, etc. are not included in this study as these costs are independent of the WTE options. Likewise, the revenue from the retail sale of electricity to customers (a mixture of residential, institutional and commercial customers) is not specifically modelled as it does not change from option to option. Since the City Electric Department operates as a non-profit, the electric revenue used for the purpose of this study is calculated from the base case such that all 'Revenue less Expenditures' are greater than or equal to zero for all years modelled to match the City's approach to budgeting and keeping costs to a minimum to their customers. The revenue in all cases includes an average annual base value from the sale of electricity of $37.9M at an average annual escalation of 1.76%. This revenue stream is kept constant across all options to provide an accurate financial comparison of the options. As further explanation, the WTE process will not impact the customers' usage of electricity. To compare each option to the base case the power production shortfall is modeled to be purchased from the MISO Zone 3/Northern District (Ames node) electricity prices. In this way, each case provides the same amount of electricity for the City as that produced in Option 1 (base case/as-is). For the financial model the 2021 average on-peak and off-peak Ames node prices are applied and escalated 0.50% per year. A summary of the RRP and PP average annual net 'Revenues less Expenditures' after capital and debt service are shown in **Figure 1** for all options. The expenses reflect a $5.00/dth gas price for the base case in year 2022 and a $1.00/dth premium for all other cases for Citygate gas purchases. Natural gas is assumed to escalate 1% per year as directed by City personnel.

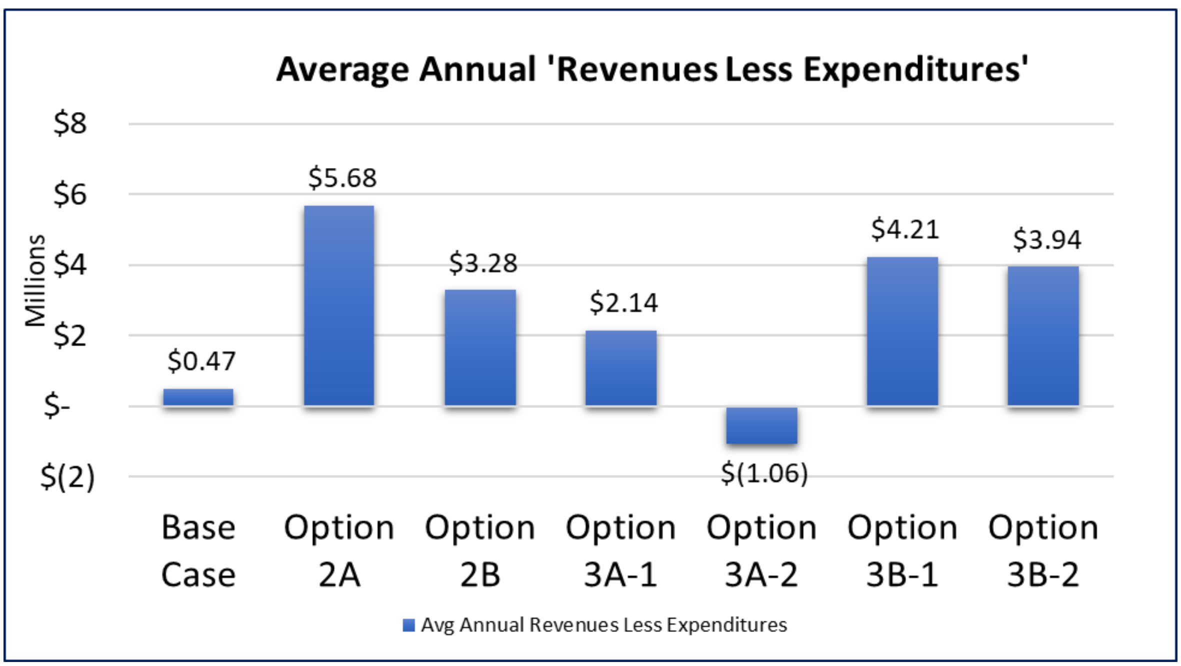

Figure 1: Average Annual 'Revenue Less Expenditures'

Other revenue streams such as metal sales and tipping fees are also included. Revenue for steam sales to a thermal user is included for Options 3A-2 and 3B-2 (only). Costs include variable costs; O&M costs for the System; landfill costs; natural gas for startup, shutdown, and flame stabilization; CIP and debt service; including maintaining and operating the capacity-only resources (Units 7 and 8) in some of the options.

In order to compare multi-year projects with different net annual cash flows and different project implementation costs, the Net Present Value (NPV) for each option is calculated to include the capital investment needed for each option and the debt service. The NPV discounts the annual net cash flow for each year during the 20-year bonding period to the first year and sums them together. If the NPV of an investment is positive, it means that the discounted present value of all future cash flows related to that project's investment will be positive as compared to the base case, and therefore attractive. The NPV is a key financial metric used to evaluate all the options over the entire 20-year bond period from 2025 to 2044. Financing is assumed to occur in early 2025 (year "one") to support construction and initial operation in late 2026. The NPV of each option is plotted in **Figure 2,** assuming $5.00/dth gas price in the base case. **Figure 1** and **Figure 2** show that Option 2A has both the highest average annual 'Revenue less Expenses' (calculated over the period from 2025 to 2044) and the highest NPV of all the options assuming a base case gas price of $5.00/dth. This result is driven primarily by the lower debt service (as compared to other new options), despite the need to burn natural gas when utilizing Unit 8 as backup. MSW mass burn Options, 3B-1 and 3B-2 have the next highest positive NPV values. Different assumptions, such as higher gas prices could change the magnitude, and therefore the NPV ranking. For example, the impact of the natural gas price on the Average 'Revenue less Expenses' ('Profit') and NPV for the Options is shown in **Table 1** and **2** respectively. Note that at a base case gas price of $7.00/dth the NPV of Option 3B-2 is slightly greater than that of Option 2A. The financial model enables the City to evaluate the impact of different gas prices and other market sensitivities and assumptions. It is clear that the price of natural gas significantly impacts the operating costs of the base case. The increase in 'Profit' and NPV at higher gas prices for Options 3A-2 and 3B-2 are attributable to the increase in the steam unit sales price (which is linked to the price of natural gas). It is important to note that the change in gas price may indirectly affect other parameters such as MISO electric prices, transportation costs, consumables, etc. These impacts are not modelled as they are outside the scope of this study.

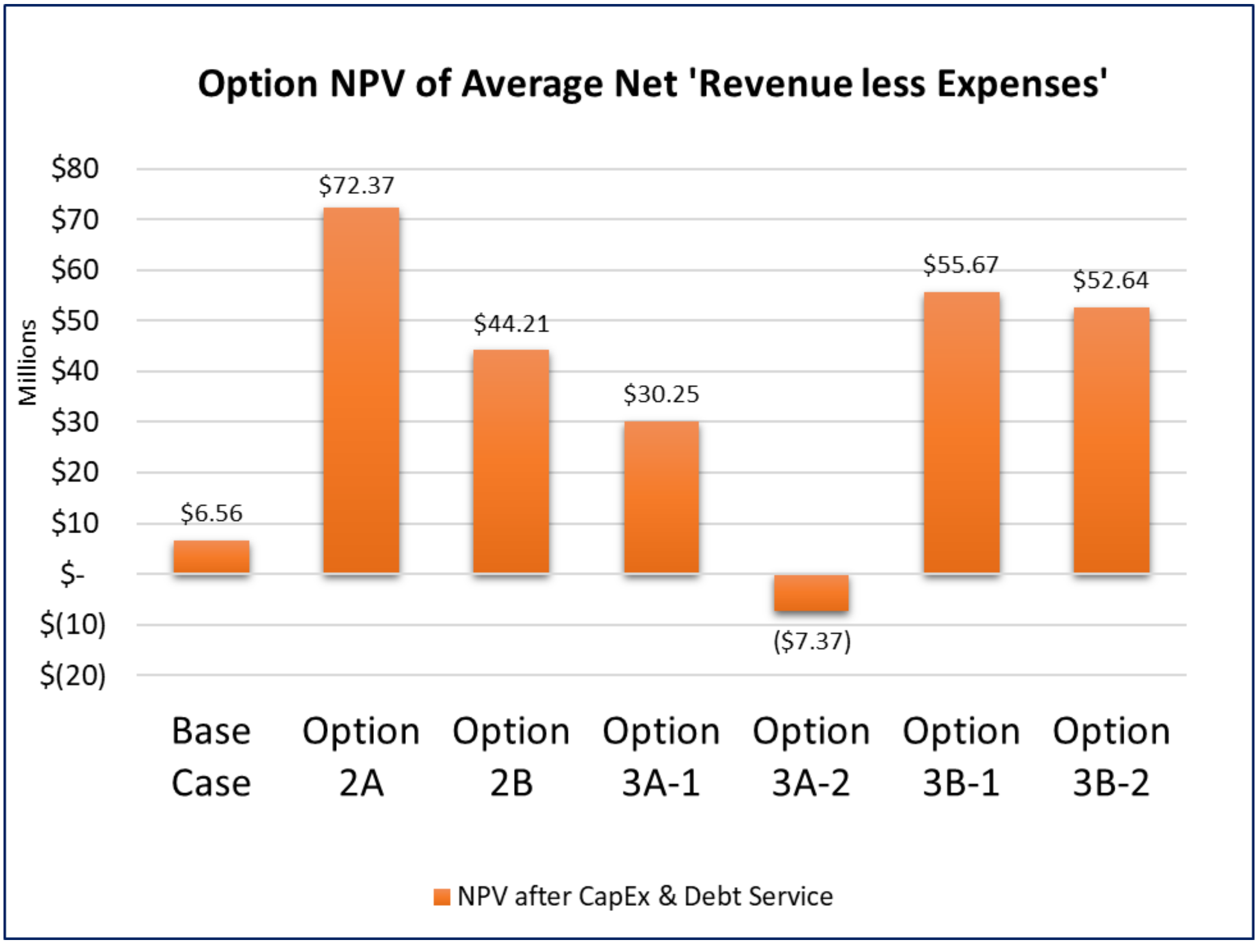

Figure 2: NPV Comparison of Net 'Revenue Less Expenditures' over Bond Period

Table 1: Average Annual 'Revenue less Expenses' Sensitivity to Gas Prices [$M]

Base Case Gas Price	Base Case	Option 2A	Option 2B	Option 3A-1	Option 3A-2	Option 3B-1	Option 3B-2
$4.00/dth	$4.6	$6.3	$3.3	$2.8	($1.6)	$4.2	$3.6
$5.00/dth	$0.5	$5.7	$3.3	$2.1	($1.1)	$4.2	$3.9
$6.00/dth	($3.7)	$5.1	$3.3	$1.5	($0.6)	$4.2	$4.3
$7.00/dth	($7.8)	$4.5	$3.3	$0.9	($0.1)	$4.2	$4.7
$8.00/dth	($12.0)	$3.9	$3.3	$0.2	$0.4	$4.2	$5.1

Table 2: Option NPV Sensitivity to Base Case Gas Price [$M]

Base Case Gas Price	**Option 2A**	**Option 2B**	**Option 3A-1**	**Option 3A-2**	**Option 3B-1**	**Option 3B-2**
$4.00 /dth	22.3	(13.1)	(19.3)	(70.7)	(1.6)	(9.5)
$5.00 /dth	65.8	37.7	23.7	(13.9)	49.1	46.1
$6.00 /dth	109.3	88.4	66.7	42.8	99.8	101.6
$7.00 /dth	152.8	139.1	109.7	99.5	150.6	157.2
$8.00 /dth	323.0	371.2	318.5	396.5	380.6	413.3

It is expected that the actual bonding of the project will not be performed until 2024 to support construction commencement in 2024-2025 timeframe. An average inflation index of 2.13% per year is used to estimate the cost in 2024 for the debt model. The model allows for inflation and other escalation factors to be customized. Further discussion of the financial model's structure and methodology as well as other key findings are included in ***Section 4 – Financial Analysis***.

1.4 Environmental Impacts

The environmental impacts of the seven total options are described in detail in ***Section 5***. There are a number of environmental topics that are evaluated, but for the purposes of comparison, there is little variation regarding the approach to minimizing environmental impacts among the non-base case options. Municipal waste combustors (MWCs) are highly regulated by the Federal government and by the state governments, particularly regarding air emissions and this has set the benchmark for air pollution control. The designs of all of the alternatives to the base case can and will facilitate compliance with the regulations using the same S-O-A air pollution controls including baghouse, scrubber, PAC injection and SNCR. All of the alternatives to the base case will result in water consumption falling to one-tenth the current level, due to the drastic reduction in steam production requiring proportionately less makeup to the cooling tower and steam system.

The total MSW is the same for all options. Because of the large difference in density of ash vs. MSW (approximately 10:1), options that combust more material create more ash by weight and will result in less required landfill space. Since all alternatives to the base case relieve the existing system combustion tonnage limitation, they will produce more ash and also less volume to landfill. **Table 4 on Page 13** shows a landfill diversion percentage by mass and volume for all the evaluated options. All of the new options have higher diversion rates than the base case.

All of the non-base case options evaluated will require a new Title V Air Permit, as MWCs of any size require this permit. The State of Iowa will require a Construction Permit for each non-base case alternative, along with state air permits for each source or point of emissions.

The City's has recently committed to reducing greenhouse gas (GHG) by 83% from 2018 levels by the year 2030. The GHG impact of each option was evaluated considering the following contributing components:

- CO2 from the combustion of the non-biogenic fraction of the waste
- CO2 from the combustion of natural gas (Unit 7 and Unit 8)
- Equivalent CO2 generated from the landfilling of by-passed waste
- CO2 from the production of replacement power

All of the six new considered options significantly reduce the GHG emissions by roughly half from the base case by avoiding the CO2 generated from the constant co-fired combustion of natural gas. The electric energy produced from the consumption of natural gas in the base case would be replaced with electricity purchased from MISO Zone 3/Northern District (Ames node) which has an estimated average emissions of 611.11 lbs/MWh according to the EPA[2]. Since this is a large component of the GHG, Ames can improve the CO2 reduction by contracting with more renewable power contracts to further reduce the GHG footprint. A thorough GHG narrative and GHG calculations are included in ***Section 5.2***.

1.5 Summary of Evaluated Options

As stated in the RFP, the City's goal of the WTE Options Study was to have a consulting team provide the detailed analysis across a number of key criteria to allow the City to then take those results and determine their path forward to selecting a preferred option for the long-term benefit of the community, the City and the environment.

The following Summary Comparison tables (**Tables 3 and 4**) show a number of key factors of each of the seven evaluated options (including the two sub-options for both 3A and 3B). These tables are intended to be used as a quick comparison tool, but do not replace the detailed evaluation found within the overall *City of Ames – WTE Options Study*.

The tables are meant to compare some of the key factors including, but not limited to the following:

- Technical performance of the selected RPP and PP systems
- Overall environmental performance
- Greenhouse Gas Performance of each option
- Financial merits and considerations of each option
- Landfill diversion estimates
- Comparative evaluation of the seven options to allow the City to narrow down or select the best option

[2] US EPA Egrid CO2 output emission rate for all fuels value for Iowa, 2020 (MISO Zone 3)

Table 3: Summary Comparison of Evaluated Options (1 of 2)

	Option No.						
	1	2A	2B	3A-1	3A-2	3B-1	3B-2
Option Description	Base Case (As Is)	New RDF Unit & Nominal RRP Improvements	New 20" RDF Units & New RRP	New RDF Unit & New RRP	New RDF Units & New RRP	New MSW Combustion Units	New MSW Combustion Units
Location	Existing Buildings	Existing Buildings	Existing Buildings	New Facility @ Coal Yard	New Facilites @ Industrial Site	New Facilities @ Coal Yard	New Facilities @ Industrial Site
Feedstock RDF/MSW	<4"RDF	<4"RDF	20" RDF	<4"RDF	<4"RDF	MSW	MSW
Backup Unit	Existing Unit 7	Existing Unit 8	New Unit 10	Existing Unit 8	New Unit 10	New Unit 10	New Unit 10
Max CONTINUOUS MSW Processing Capacity of System [tons]	49,005	66,150	66,150	66,150	66,150	66,150	66,150
Net Present Value from 2026 to 2044 w/Capital Inv and Debt Service [$Millions]	$6.6	$65.8	$37.6	$23.7	($13.9)	$49.1	$46.1
Avg. Annual (Costs)/Revenue including O&M and Capital Financing [k$] (2026-2044)	$473	$5,677	$3,279	$2,144	($1,059)	$4,211	$3,942
Avg Annual Bypassed Waste to Landfill Over System Capacity (TPY) (2025 - 2044)	10,428	0	0	0	0	0	0
Avg MSW Process Rejects (including bulk rejects) (TPY) (2025 - 2044)	15,240	16,166	6,395	6,888	6,888	594	594
Avg Annual Ash to Landfill (TPY) (2025 2044)	2,720	3,435	6,245	4,112	4,112	11,532	11,532
Avg Total Equiv. GHG (CO2) (TPY) at Design Conditions (2025-2044) (from Table 12)	253,024	135,220	126,116	143,481	136,192	122,829	130,292

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Table 4: Summary Comparison of Evaluation Options (2 of 2)

		Technical Features and Additional Considerations						
		Option No.						
		1	2A	2B	3A-1	3A-2	3B-1	3B-2
RRP Summary		Existing	Existing with small improvements	Rough Shred only	S-O-A RRP	S-O-A RRP	None	None
Primary Combustion Unit(s)		Existing Unit 8	One New 125 TPD RDF Unit 9	Dual "Large RDF" Units 9 & 10	One new RDF Unit 9	Dual RDF Units 9 & 10	Dual MSW Units 9 &10	Dual MSW Units 9 & 10
Backup Combustion Unit		Existing Unit 7	Existing Unit 8	Unit 9/10	Existing Unit 8	Unit 9/10	Unit 9/10	Unit 9/10
Steam Turbine		Existing 7/8	Refurbished ST5	Refurbished ST5	Refurbished ST5	New ST9	Refurbished ST5	New ST9
Steam Sales		NO	NO	NO	NO	YES	NO	YES
AVERAGE AMOUNT TO LANDFILL BY MASS (2025-2044)	Excess Beyond System Capacity	17.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Bulky Rejects	2.9%	3.5%	3.5%	3.5%	3.5%	1.0%	1.0%
	RRP Process Rejects	22.6%	23.6%	7.2%	8.0%	8.0%	0.0%	0.0%
	Ash	4.6%	5.8%	10.5%	6.9%	6.9%	19.3%	19.3%
Landfill Diversion Total % [mass]		52.4%	67.1%	78.8%	81.6%	81.6%	79.7%	79.7%
Landfill Diversion Total % [volume][1]		56.3%	72.1%	87.8%	87.5%	87.5%	96.2%	96.2%
Design Storage Mass (tons)	at RRP inlet	400+	400+	400+	400+	400+	~400 (MSW pit/floor)	~400 (MSW pit/floor)
	at RDF Bin	200	200	400	400	400	n/a see above	n/a see above
Bin Storage Duration with Lead or Single Unit Off-line in CY2044		~16	~8	~7	~7	~7	~5	~5
RRP Staffing (FTE)		17.5	17.5	8.5	9.1	16	2	2
PP staffing (FTE)		41	41	41	41	43	46	48
Total Staffing		58.5	58.5	49.5	50.1	59	48	50

[1] Based on 10 lb/cuft average density of MSW and 70 lb/cuft density of ash

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2 INTRODUCTION, BACKGROUND, AND STUDIED OPTIONS

2.1 Objective

This study was prepared in response to an RFP issued by the City of Ames ("City") on January 4, 2021 to study and assess the potential options for the City's future waste-to-energy ("WTE") operations including the existing Resource Recovery Plant ("RRP") and the Ames Power Plant ("PP") as well as potential new facility options. The following report details the associated technical and financial analysis to evaluate five primary options (and two sub-options) listed in ***Section 2***. The City will then utilize this study to determine the best path forward for their waste management and power production system and continue to serve as a progressive environmental leader in the solid waste industry. The study's overall goal is to provide the City with viable options to meet their waste management objectives, address current system limitations, enhance material recovery and diversion opportunities, address greenhouse gas (GHG) objectives, and serve the City's energy needs into the future.

2.2 Background

The City of Ames, Iowa is located in central Iowa, approximately 30 miles north of the state's capital, Des Moines. Ames has a population of approximately 67,000 and is the largest city in Story County. Ames is also home to Iowa State University, with over 30,000 students. The City has developed a new comprehensive plan, which is estimated to accommodate a population of 82,000 by the year 2040. Story County is estimated to reach a population of 119,500 at this same time. This WTE Options Study is intended to consider these population impacts and future growth in the area.

The Arnold O. Chantland Resource Recovery Plant (RRP) is owned and operated by the City of Ames Public Works Department. The system has been operating since 1975 and is available to process 52,000 tons of MSW annually. The MSW comes from the 12 cities within Story County, Iowa State University and parts of rural Story County. This system processes the incoming waste by removing bulky and undesirable materials and recovering ferrous and non-ferrous metals. The resulting material stream is then shredded to less than 4 inches in size and fed by a pneumatic system to a storage bin. The stored RDF is then pneumatically fed to one of two steam boilers in the Ames Power Plant (PP). The RDF is co-fired with natural gas to produce steam, which is sent to a turbine to create electricity. Rejected material from the RRP plant is taken to the Boone County Landfill. For environmental stewardship reasons the City would like to minimize the need to landfill during all operations.

The City's other waste management programs outside the RRP plant include a food diversion program, no-charge yard waste drop-off days each year (material goes to a privately operated yard waste disposal site), Rummage RAMPage, community and river cleanups, pumpkin diversion, household hazardous waste collection, and glass recovery through collection bins located throughout the County. Glass cannot be processed effectively by the RRP plant, so this diverted material is collected at drop-off centers and about 10% of the total glass in the area is received by the RRP and then sent for recycling. This broad range of material recovery is a further example of the City's focus on environmental stewardship. The following study is meant to provide options to the City that are in line with its over five-decade approach to managing waste as a resource.

2.3 WTE Study Options Descriptions

Portable Document Format (PDFs) images of the preliminary conceptual facility layouts for each of the options discussed in this section are found in ***Appendix C***.

2.3.1 Option 1: Resource Recovery and Power Plants As-is (Base Case)

As part of the study's overall analysis and to establish a base case, the existing RRP and PP were evaluated and associated system operating, and maintenance costs were determined as part of Option 1 (Base Case). All other options in the Study were evaluated technically, operationally, and financially in comparison to the current operations.

The seven studied options are briefly described in this section and detailed analysis and further system descriptions are provided in ***Section 3 - Technical System Analysis***. The following items are already on the City's agenda to address and excluded from this analysis: (1) remediation and removal of Units 5 and 6 boilers and associated coal bunkers, (2) remediation of the coal yard and removal of two underground tanks, and (3) structural repairs to the existing storage bin.

2.3.2 Option 2A: Existing RRP With New RDF Combustion Unit in the Existing PP

Option 2A, utilizes the RRP plant in its current condition with a few proposed equipment upgrades, and provides a new dedicated boiler (labeled Unit 9) for combusting RDF. Unit 9 would be located in the existing Power Plant building where retired Units 5 and 6 boilers are currently located. Unlike the current Units 7 and 8, this new RDF combustor would be designed to only utilize natural gas for start-up, shutdown, and flame stabilization. During regular operation the new unit would burn 100% RDF. Unit 8 (boiler and turbine) would be utilized as back-up to the new RDF combustor in this option and would still require co-firing with natural gas. A new air permit will be required for Unit 9. Steam from Unit 9 would be piped over to the existing turbine hall to generate power. Power would be generated either from (a) a single new, significantly smaller, steam turbine generator (approximately 6 MW) or (b) steam turbine ST5 (7.5 MW) would be refurbished with a new steam path and generator rewind to utilize the steam from Unit 9. For this analysis the refurbishment of ST5 is assumed.

2.3.3 Option 2B: Modified RRP (20" RDF) with Two New RDF Combustion Units

Option 2B utilizes a modified RRP plant (in the existing building) to deliver a 20" nominal RDF. This RDF would be combusted in two new boilers located at the adjacent coal yard. The larger RDF would be transferred from the RRP to the new storage building using a conveyor in a tubular gallery (See **Figure 15**) over 2nd Street. The material would then be fed from the storage building with conveyors to metered feed hoppers into the boilers. Steam from Unit 9 would be piped to the existing power plant. The steam turbine and associated generator options would resemble that of Option 2A, either refurbishing steam turbine 5 (including a generator rewind), or a new steam turbine and generator. The refurbishment of ST5 is assumed. For Option 2B, the existing Units 7 and 8 would continue to be available as capacity resources burning natural gas only.

2.3.4 Options 3A-1 & 3A-2: New RRP and New RDF Combustion Unit(s)

Option 3A includes an entirely new state-of-the-art (S-O-A) RRP to produce 4 inch minus RDF (same size as currently produced) and new RDF combustor(s). The new RRP would provide enhanced processing equipment, improved throughput capability, and deliver higher metals recovery resulting in more RDF produced from the waste stream and therefore more waste diverted from the landfill. The new RDF boilers, in both Option 3A-1 and 3A-2, would only use natural gas during start-up, shutdown and flame stabilization. For both options, the existing Units 7 and 8 continue to be available as capacity resources for MISO when burning natural gas only.

Option 3A-1 (Coal Yard)

For Option 3A-1 the S-O-A RRP and a new RDF combustion boiler would be located at the existing coal yard. Option 3A-1 also augments the RDF conveyance and storage system, by adding new pneumatic conveyors and additional RDF storage and utilizing much of the existing power plant infrastructure. For Option 3A-1, only one new boiler would be installed, and Unit 8 would be kept as a backup to co-fire RDF with natural gas. The steam turbine and generator options would be the same as in Option 2A.

Option 3A-2 (Greenfield)

Option 3A-2 locates the S-O-A RRP, and a new RDF combustion building at a potential industrial site to provide steam to an industrial customer. For Option 3A-2, two new RDF combustion boilers would be provided as the installation would be on a new, non-contiguous industrial site. All steam would flow through a back pressure steam turbine and the exhaust steam would be sent to the thermal host. The back pressure steam turbine would drive a small electric generator of about 1.6 MW. A condenser would be supplied to enable the continued processing of waste should the industrial steam user's ability to accept the steam be interrupted. The City could consider an extraction steam turbine to enable the production of electricity and/or steam, but an extraction turbine would limit the amount of steam that could be exported, since some steam (5-10%) must always flow through to the back-end and condenser.

2.3.5 Options 3B-1 & 3B-2: Two New MSW Mass Burn Combustion Units

Option 3B utilizes two mass burn waste-to-energy (WTE) units to combust unprocessed MSW. Similar to Option 3A, this option has two sub-options. Both sub-options include receiving and storage of MSW followed by direct feed into the WTE units for combustion and a planned post-combustion metal recovery system. It is assumed both units would be designed to run in parallel during normal operation, and together, capable of the expected future MSW growth. In case of a unit outage, one unit would continue to operate to process waste. Significant oversizing of the parallel boilers is not recommended to avoid both boilers operating below 70% load during normal operation. Operation below 70% can negatively impact boiler efficiency and emissions (See storage discussion in Appendix B for additional background information). For both sub-options the existing Units 7 and 8 continue to be available as capacity resources burning natural gas only.

Option 3B-1 (Coal Yard)

For Option 3B-1, two new MSW mass burn boilers would be located at the existing coal yard. Power would be generated either from (a) a single new, significantly smaller, steam turbine generator (approximately 6 MW) or (b) steam turbine generator ST5 (7.5 MW) would be refurbished with a new steam path and generator rewind to utilize the steam from Unit 9 and 10. For this analysis, the refurbishment of STG 5 is assumed.

Option 3B-2 (Greenfield)

Option 3B-2 locates the two new MSW mass burn boilers in a new power plant at a potential industrial site to provide steam to an industrial customer. The boilers would only use natural gas during start-up, shutdown and flame stabilization. All steam would flow through a back pressure steam turbine (ST9) and the exhaust steam would be sent to the thermal host. The back pressure steam turbine would drive a small electric generator of about 1.5 MW. A condenser would be supplied to enable the continued processing of waste should the industrial steam user's ability to accept the steam be interrupted. The City could consider an extraction steam turbine to enable the production of electricity and/or steam, but that would limit the amount of steam that could be exported, since some steam (5-10%) must always flow through to the condenser.

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3 TECHNICAL SYSTEM ANALYSIS

The following subsections provide key details for all the studied options. For convenience and readability, the process flow diagrams for the RRP systems and the overall process flow diagrams for all of the options can be found in ***Appendix D and Appendix E,*** as well as being featured in the following narrative.

3.1 Option 1 – Resource Recovery and Power Plants As-is (Base Case)

3.1.1 MSW Storage

Currently the RRP facility can store approximately 400 tons of MSW on the existing tipping floor, which translates into a nominal 2 days of storage based on the RRP throughput capability. The RRP does not have any storage capabilities on the back end (exit of the RRP) as the processed RDF is immediately fed into the pneumatic system and transferred to the RDF bins.

3.1.2 RRP Plant Processing System Summary

The RRP currently accepts up to approximately 200 tons/day of MSW at its tipping floor and the current system processes about 12 to 14 TPH. As the MSW enters the facility it is first sorted to remove larger objects (mattresses, carpet, furniture, and other bulky materials) and then fed to an inclined infeed conveyor using a front-end loader. A primary shredder liberates the material and reduces the size to less than 8 inches.

A process flow diagram depicting the current RRP system is shown in **Figure 3 on page 21**. A drum magnet along with magnetic head pulleys installed throughout the process line removes ferrous metals which are sold as scrap. The remaining material is screened through a two-screen process and small fines and rejects are removed. The overs from the primary screen are shredded a second time and combined with the overs from the secondary disc screen resulting in a RDF typically less than 4 inches in size, referred to as “4-inch minus”. The RDF exits the secondary shredder and is processed through an air knife system, which separates the light fraction from the heavy fraction. The heavy fraction is processed through an eddy current separator, which removes non-ferrous metals for sale as scrap, and is then transferred via a series of conveyors and combined with the rest of the rejects. The light fraction is discharged into a pneumatic feed system. The pneumatic feeder conveys the RDF, via a single 14-inch underground pipe to storage bins located in the existing Power Plant coal yard, approximately 600 feet away. The conveyance system has a maximum throughput of 10 – 12 TPH and an average of 8 TPH.

During the technical evaluation, RRT worked with the City to determine potential RRP upgrades that would deliver better and more consistent operations. These upgrades are listed as part of Option 2A to increase both the throughput and RDF quality going into a new RDF combustor. Option 1 (Base Case) does not include these system upgrades to allow for a clear technical and financial comparison from the current operations to the other six options. If the City decides to continue with their current operations, they may still want to consider implementing the system enhancements recommended by RRT.

As further consideration of maintaining the existing RRP system versus replacing it in its entirety, the following narrative is provided and applicable for all RDF options that re-use the existing or provide a new RRP. Continuing the City’s ongoing maintenance and repairs as well as replacing parts that are beyond repair will continue extending the life of the existing RRP. These costs are included in the model and were developed from historical data at the RRP. As with all options there are risks and factors that need to be considered by the City. For the existing RRP, we assumed with reasonable certainty that the existing RRP is sufficiently funded for long-term continued service. For the options with complete replacement of the RRP, different risks emerge including the assumptions for the operating costs and system efficiency whereas the existing RRP is proven. Again, the financial analysis is sufficiently “funded” to cover the operational risks and uncertainties of new equipment. Whichever option is ultimately selected, the detailed engineering would need to include a comprehensive reliability analysis so the equipment and component selections achieve the intent of a long-service life. At that point, the financial model should be refined to reflect the more detailed information. This narrative and comments would also apply to the re-use of Unit 8 as a back-up and also other components of the overall existing WTE system to remain.

RRP Equipment and Systems

A description of the RRP equipment/systems is provided in this section as these will be referenced in other options within the study.

Shredders/Size Reducers: Equipment that processes and reduces the size of the MSW material, liberates the material by opening bags or containers and reduces the volume of unsorted waste.

Disc Screens: Equipment that separates the material by size and consists of rotating discs for separating wastes through the clearance between the discs, depending upon the size and the weight of the waste while the remaining material moves on the rotating discs.

Air Knife/ Air Classifier: Air separation systems used to separate material based on material density and on their aerodynamic properties. Separates light fraction from the heavier pre-processed MSW.

Eddy Current Separator (ECS): Equipment used to separate non-ferrous metals from the pre-processed MSW stream using high frequency magnetic field.

Magnetic Separator: Suspended magnets, magnetic pulleys, drum magnets and electro-magnets are types of equipment used to separate ferrous metals from the pre-processed MSW stream.

Pneumatic Conveyance System: Pneumatic conveying is a type of system that uses compressed air to transfer the RDF material from one process area to another. The system works by moving the material through an enclosed conveying line using a combination of pressure differential and the flow of air from a blower or fan.

Trommel Screen: A trommel screen is a mechanical screening device which separates MSW into different sizes. It consists of a perforated cylinder with different screen size openings, elevated at an angle and rotating.

Other Balance of Plant (BOP) RRP Systems: Conveyors, air compressor system for equipment and maintenance tools, fire sprinkler system, dust collection system, scales for inbound and outbound truck traffic, sorting platforms, chutes and bunkers.

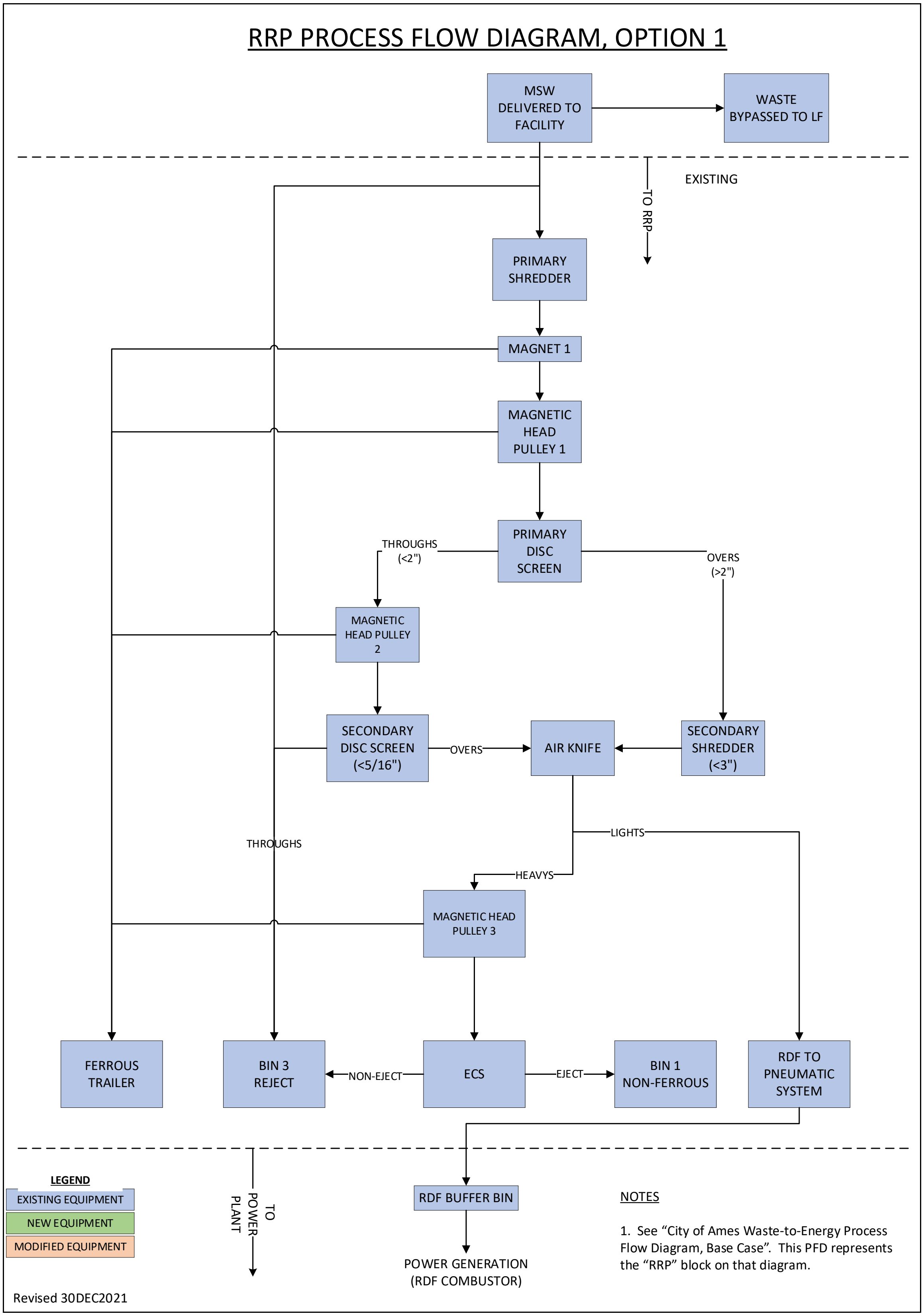

Figure 3: Option 1 Overall RRP Process Flow Diagram

3.1.3 RDF Transport and Storage

The RDF is stored in an approximately 5,600 ft^2 rectangular storage bin containing two sides separated by a dividing wall. Each side is capable of storing a theoretical amount of 100 tons, for a total of 200 tons, which can support 2 days of storage when the power plant is not operating or nearly 16 days of storage when lead Unit 8 is offline. Refer to ***Appendix B*** for a detailed RDF/MSW Storage Analysis for all options.

The bin provides storage for the RDF to balance the operation of the RRP as needed, Sunday through Friday, as opposed to the power plant which must be fully staffed 24 hours per day, 7 days per week.

The bins are alternately filled and emptied in order to burn older RDF first. Having two bins also provides the option to perform maintenance on one bin, while processing into and out of the other bin. The RDF bin is normally unmanned and feeds the material automatically through a series of conveyance systems made up of augers, drag conveyors, and rotary feeders to eventually drop the RDF into a pneumatic conveyance system going from the RDF storage bins via two (2) 8" diameter underground pipes. The original RDF storage bin was designed by Atlas as a single round shaped bin. The original bin was replaced with two side-by-side bins from Clarke Industries, which are a trapezoid shaped type of design with independent augers for each bin. These bins were designed for a storage height of 25 feet of RDF, but this resulted in high levels of compaction at the base and makes the RDF very hard to extract. Therefore, the RDF storage height is currently limited to 15 ft, which equates to 100 tons per side. The compaction is also increased by higher moisture content at times.

From the RDF bin, the RDF is transported pneumatically to the power plant boilers using two 8" pipes with a max feed rate of 6 TPH and an average operating rate of 3.6 TPH (32,000/8,760). A total of four lines go to the power plant, however only two are being used for RDF conveyance. One remaining line is used for cables, while the other is currently not in use.

3.1.4 Power Plant Combustion System Summary

The Power Plant (PP) is located at 200 East 5th Street. It consists of two (2) operating steam boilers, Units 7 and 8. Units 5 and 6 are retired but are still in place, along with their respective steam turbines and generators, which gives the power plant a total of four (4) steam turbine generators (ST).

Boiler Unit 7 is a Combustion Engineering tangentially fired boiler that was constructed in 1967. It was designed to generate 360,000 lb/hr of superheated steam using pulverized coal with startup and shutdown on fuel oil. The boiler includes an electrostatic precipitator to remove fly ash. The steam drives Steam Turbine No 7 (ST7), a non-reheat, GE turbine generator with a nameplate rating of 33 MW. The steam produced by Unit 7 is 900 psig and 850F.

In conjunction with the construction of the RRP in 1975, Unit 7 was retrofitted to co-fire RDF with coal.

In 1982, the PP added Unit 8, a Babcock and Wilcox wall-fired boiler designed to co-fire RDF with coal and produce 620,000 lbs/hr of high pressure, high temperature steam. The boiler included two (2) parallel hot side electrostatic precipitators and steam turbine 8 (ST8), a 65 MW GE non-reheat steam turbine generator. The steam exits Unit 8 at 1,250 psig and 955F.

In the current combustion process, the RDF is directed into either Unit 8 (primary) or Unit 7 (backup) for co-firing with natural gas. Under the Title V operating permit, both units are not allowed to be co-fired with RDF simultaneously.

In 1986, Unit 5 and Unit 6 boilers and steam turbine generators were decommissioned. The Utility intends to remove boilers 5 and 6 in 2022. Steam turbine generator 6, which is rated at 12.65 MW, is slated to remain until its re-use is ruled out. ST5 and ST6 are of similar vintage, and ST5 will be retained as it is much closer in size to that needed for all of the non-base case options considered. ST5's refurbishment and its generator rewind would also be less expensive than refurbishing ST6. Note there is a shared overhead crane with ST5, ST6 and ST7.

In 2016, both boilers were converted from coal/RDF (with fuel oil for startup/shutdown) to natural gas/RDF fuel mix. Under the power plant's Title V permit, the boilers are permitted to consume no more than 30%

RDF by weight. Therefore, approximately 10% of the electricity comes from the energy released from RDF consumed in the boiler. The remaining 90% of the electricity is from the co-fired combustion of natural gas. Only one boiler at a time can consume RDF per the Title V permit. Unit 7 can consume up to ~85 tons of RDF per day and Unit 8 can consume up to ~120 tons/day. This RDF limit requires 70% or more of natural gas to be burned while co-firing RDF.

Fly ash and bottom ash from the boilers are sluiced to an ash pond northeast of the PP where it is eventually mounded and dried. The ash generated is solely a result of combusting RDF (i.e., there is no ash generated from the combustion of natural gas). The ash storage site is located approximately 0.5 mile northeast of the PP. It is operated as a “zero discharge” basin (no outflow) and is periodically emptied of accumulated ash and hauled to a landfill.

A Continuous Emissions Monitoring System (CEMS) monitors SO_2, NOx, CO_2 and flow within the stack. Opacity is also monitored with a Continuous Opacity Monitoring System (COMS) as required under the air permit.

3.1.5 RDF Co-Combustion System

In 1975, the power plant added the ability to co-fire RDF provided by the RRP with coal. In 1982, a new boiler, Unit 8, was designed as a co-fired (coal/RDF) unit. In order to continue to qualify as an Electric Generation Facility under Title V of the EPA, the RDF co-firing is limited under the Power Plant’s Air Permit to 30% of the total fuel consumption by weight and limited to 10% of total boiler energy consumption per calendar quarter.

In 2016, Unit 7 and Unit 8 were converted to enable operation on natural gas only and to also co-fire RDF with natural gas in lieu of coal. Boiler start-up is done using only natural gas.

It has been observed that the combustion characteristics of the natural gas with RDF, compared to coal with RDF, has resulted in increased corrosion rates in the equipment that comes in contact with the combustion gases, namely the boiler tubes and stack breeching. The co-firing with natural gas has required on-going operation and maintenance costs to the PP operation and negatively impacted the throughput due to downtime needed for repairs, in particular with Unit 8, which is the larger of the two boilers. The City has worked to remedy this issue by undertaking a recent Inconel cladding of the boiler tubes in the super-heat section of the boiler. The PP has now installed corrosion resistant coating on the tubes located in the high corrosion areas of Unit 8. This remedy is expected to slow the tube corrosion to a more manageable rate. The City may also want to continue to evaluate the possible injection of hydrated lime into the furnaces of Units 7 and 8 to reduce the potential of corrosion from the flue gas. This technique may negatively impact the rate of boiler fouling, so a planned testing and evaluation approach should be followed to quantify any potential negative impacts.

3.1.6 Steam Turbine Generators

The steam throttle conditions for steam turbines 7 and 8 are unique to each boiler and cannot be cross connected to each other. Unit 7 steam conditions are 900 psig and 850 F while Unit 8 steam conditions are 1250 psig and 950 F. While higher steam temperatures improve steam turbine performance, the higher temperature also results in accelerated corrosion of the boiler tubes. For waste-to-energy systems the boiler design conditions are generally below 775 F to minimize corrosion. Retired steam turbine generators 5 and 6 of 7.5 MW and 12.5 MW rated capacity have not operated since the 1980’s. Due to its robust design, it is highly likely that ST5 can be refurbished, and the generator rewound for re-use. The same overhead 50-ton crane services ST5, ST6 and ST7.

3.1.7 Balance of Power Plant Equipment

The balance of power plant (BOP) equipment/systems that support the boiler(s) and steam turbine generator(s) are listed below. A description of the plant equipment/systems is provided in this section as these will be referenced in other options within the study.

Fresh air supply fans: These provide combustion air needed for the boilers.

Boiler feed pumps: These pumps raise the pressure of the condensate return water to the boiler operating pressure.

Water Treatment: Using reverse osmosis and de-ionization, city-water is treated to remove minerals and other contaminants to meet the boiler and steam turbine water quality specifications. A monitoring system and periodic testing of the water are included.

Steam Condenser(s): The condensers are heat exchanges used to condense the steam exiting the steam turbine (condenser shell side) using water from the cooling tower (condenser tube side).

Cooling Water System (Cooling Tower(s)): Cooling water is circulated through the steam condensers to the cooling towers where the heat removed from the condenser is rejected to the atmosphere. Other heat rejection may also be rejected to the system such as from lube oil coolers, HVAC systems or auxiliary systems.

Electrostatic Precipitator(s): Devices in the exhaust of the boiler used to collect and remove particulate matter from the exhaust air using an electrostatic charge and periodic rapping of the plates that collect the aggregated particles.

Continuous Emission Monitoring (CEMS): Continuous sampling of the exhaust gas and measurement of the products of combustion being monitored. For Ames the CEMS is required under permit to monitor opacity, SO_2, NO_x, CO_2 or O_2 .and flow.

Continuous Opacity Monitoring System (COMS): System that continuously monitors the exhaust gas opacity as a measurement of particulate matter being released.

Generator Step up Transformer(s) (GSU): Transformers used to step up the generation voltage to the electric voltage of the utility interconnection.

High Voltage Interconnection: A system of relays, switches, breakers, metering and detection devices assembled to safely interconnect, meter, monitor and control the interconnection to the electric utility.

Auxiliary Cooling Systems: Closed loop cooling water circulating system that removes residual heat from auxiliary power equipment (e.g. boiler feed pumps, compressors) and rejects the heat to the atmosphere using fin-fan coolers (radiators).

Auxiliary Power Transformers: Transformers to reduce the voltage from the generation voltage to the voltage needed for the power plant auxiliary equipment (4160V and/or 480V).

Power distribution system (4160/480/120): Breakers, cables, wires and trays and conduit and protection devices used to distribute power to the electric auxiliary equipment within the PP.

Poker Picker: Provision added to equipment to collect and remove long items (pokers) such as cables, sticks, rods from the waste stream to prevent damage of downstream equipment.

Distributed Control System (DCS): An electronic control and monitoring system for the plant.

Uninterrupted Power System (UPS): A battery backup system for ensuring critical controls and services (emergency lighting) is powered for the safe shutdown of the facility or until permanent power is restored.

Fire Protection: A fire alarm system monitors smoke and temperature conditions with detectors throughout the facility and automatically alarms and activates fire water pumps that distribute water through a hydrant and sprinkler piping system to suppress the fire.

3.1.8 Emission Control

Both Units 7 and 8 utilize electrostatic precipitators (ESPs) to remove fly ash particulate from the flue gas prior to the stack. The fly ash is then conveyed and mixed with the bottom ash and sluiced to the ash disposal area. Neither of the units employ scrubbers to control the SO2 and HCl emissions that are generated from the combustion of the RDF. SO2 stack emissions are monitored for both units using a continuous Emissions Monitoring System (CEMS). HCl stack emissions are not monitored from either Units 7 or 8.

It should be noted that ESPs are commonly used in fossil fuel combustion applications for particulate control. Baghouses, also known as fabric filters, are the best technology to control particulates, mercury, and dioxins in waste-to-energy applications, as well as improve the control of SO2 and HCl.

Combustion related emissions of CO and NOx are controlled by the combustion control system of the boilers. Typical stack emissions from plant data reports along with the Title V Air Permit values for Units 7 and 8 are listed in **Table 5**. Note the production of SO_2 is significantly below the permit limits.

Table 5: Typical Emissions and Permit Values for Units 7 and 8

Unit		Typical	Title V Permit	Units of Measure	Typical	Title V Permit	Units of Measure
7	CO	0.004	0.20	lb/MMBTU	1.55	95.2	lb/hr
	NOx	0.174	0.40	lb/MMBTU	58.9	n/a	lb/hr
	SO2	<0.02	2.5	lb/MMBTU	<8.5	520	lb/hr
	Opacity	<2%	40%	n.d.			
8	CO	0.0003	0.20	lb./MMBTU	0.23	155	lb./hr.
	NOx	0.122	0.46	lb./MMBTU	57.4	538.1	lb./hr.
	SO2	<0.01	5	lb./MMBTU	<8	923	lb./hr.
	Opacity	<2%	20%	n.d.			

3.1.9 Ash Handling/Disposal

For both Units 7 and 8, the fly ash, which has no end markets, is conveyed and mixed with the bottom ash collected at the bottom of the combustors, and then sluiced to an ash disposal area northeast of the PP. The ash generated is solely a result of combusting RDF. Note that the RDF will contain heavy metals that were present in the MSW at trace, parts per million levels. These heavy metals are not recovered in the RRP, which only recovers ferrous and non-ferrous metals for recycling.

The ash storage site is located approximately 0.5 miles northeast of the PP. It is operated as a "zero discharge" basin (no outflow) and is periodically emptied of accumulated ash and sent to a landfill.

3.1.10 Electric Energy Sales

Electricity generated by the Plant is delivered to the City of Ames Electric Utility, which distributes and sells it to its retail customers. Since power from waste-to-energy is continuous (i.e., the PP does not cycle the RDF consumption up and down in response to the City's electric load) the PP is essentially a "must-run" generation resource for the Utility. Iowa has continued to see an increase in electricity provided by renewable energy. In 2020, 57% of Iowa's electricity was generated from wind[3] and 53% of the state's *electric usage* was provided by wind energy. As a result, wind energy is increasingly the source of power "on the margin". This drives the average wholesale price of electricity down as more wind generation comes on-line. As of 2019, approximately 3,750 MW of additional wind generation installed capacity was queued to be added in MISO Zone 3 (Iowa), and 31,121 MW in the MISO territory (see **Figure 4**). For the 2021/22 MISO UCAP (unforced capacity) auction results, the Planning Reserve Margin Requirement (PRMR) and the UCAP capacity offered in the auction for each MISO zone is shown in **Table 6**. It should be noted that the wind ***installed*** capacity is significantly discounted when converted to UCAP. A new wind resource will

[3] US Energy Information Administration, Iowa State Energy Profile, *Updated June 17, 2021*

first have the class average wind capacity credit of 16.3% applied to its rated capacity to arrive at its UCAP value.[4]

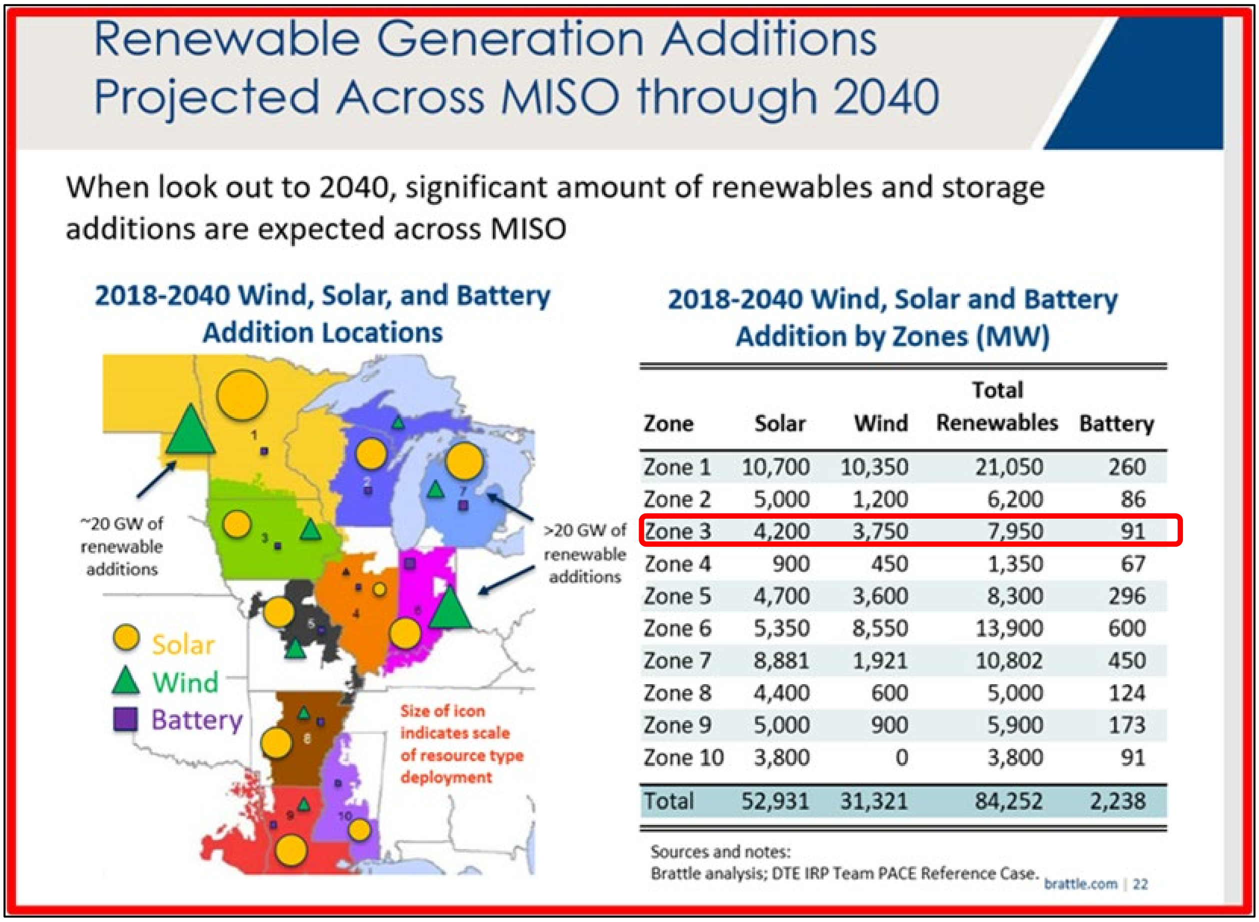

Figure 4: Renewable Generator Projected Additions Across MISO[5]

Table 6: Capacity Offered and Committed for Each MISO Zone 2021/22

	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	Z 7	Z 8	Z 9	Z 10	ERZ[6]	System
MW PRMR	18,359	13,617	10,280	9,853	8,247	18,146	21,459	7,828	21,283	4,833	n/a	133,903
MW Offered	20,289	13,980	10,827	9,506	7,811	15,832	21,666	10,642	23,017	5,354	1,639	140,565

[4] Planning Year 2021-2022 MISO Wind & Solar Capacity Credit, Draft Report PY 21-22, January 2021

[5] "*Battery Storage in MISO-How Might Batteries Change the MISO Landscape and Affect Operations*" December 11, 2019, The Brattle Group (presentation at the MISO Advisory Group Committee Meeting)

[6] ERZ=External Resource

For 2021 the average off-peak price for wholesale electricity was $17 MWh and for on-peak electricity it was $30/MWh at the Ames interconnection node. As a point of reference, a gas fired plant with an average heat rate plant of 11,500 btu/kWh and average burner tip (all-in) cost of gas of $5.00/dth, the breakeven cost of producing power to cover just the fuel expenses would be $57.5/MWh (4 x 11,500 / 1000). Historically, the average "all-in" gas price (commodity plus transportation) for the power plant during 2020/21 was $3.48/dth assuming a 95% transportation contract utilization rate. This excludes any value received from the resale of unused gas. The gross heat rates of Unit 7 and 8 when co-firing with natural gas is historically 11,552 and 11,161 BTU/kWh respectively as measured by the power plant. The price of natural gas has been on the rise as of this writing. A 12-year history of the price of natural gas at Henry Hub (Texas) is shown in **Figure 5**.

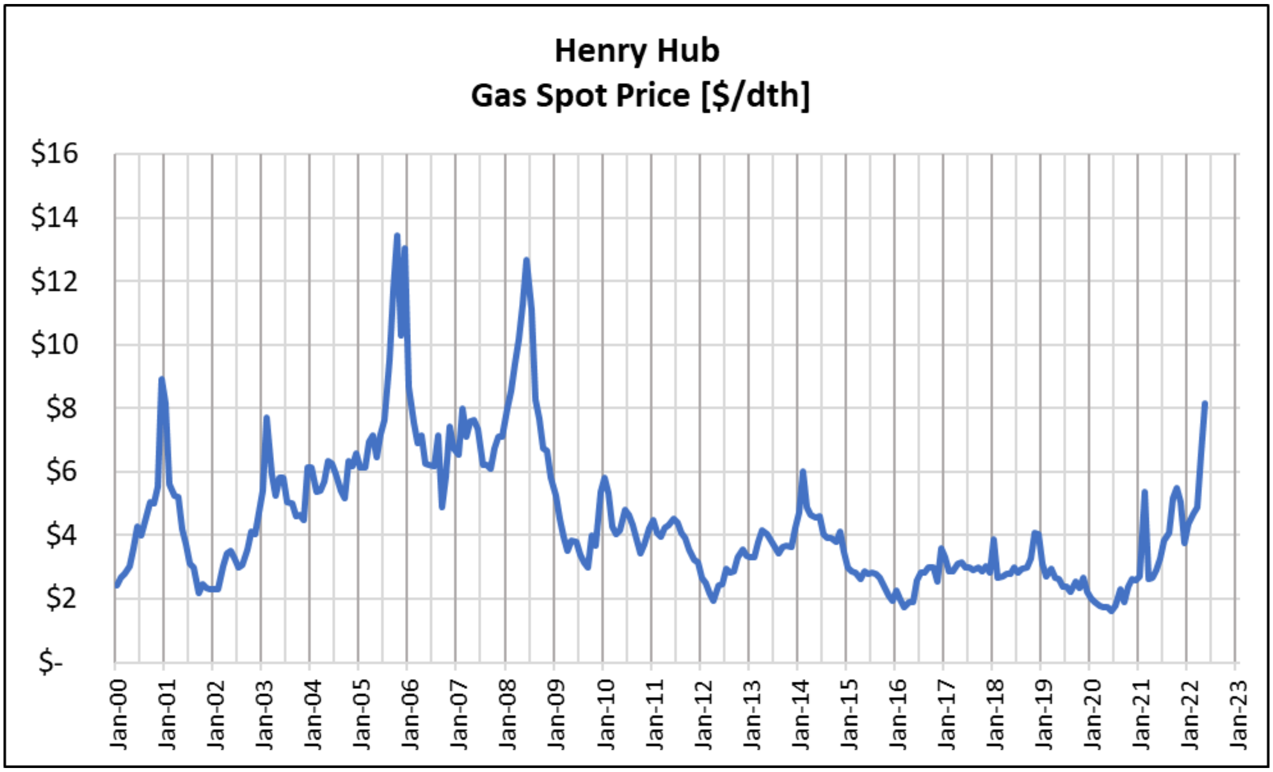

Figure 5: Historic Price of Natural Gas, Henry Hub 2000-Apr 2022 ($/dth)

3.1.11 Process Flow and Mass and Heat Balance

An overall process flow diagram depicting the existing system in Option 1 is shown below in **Figure 6**. Mass and heat balance data can be found in ***Appendix F.***

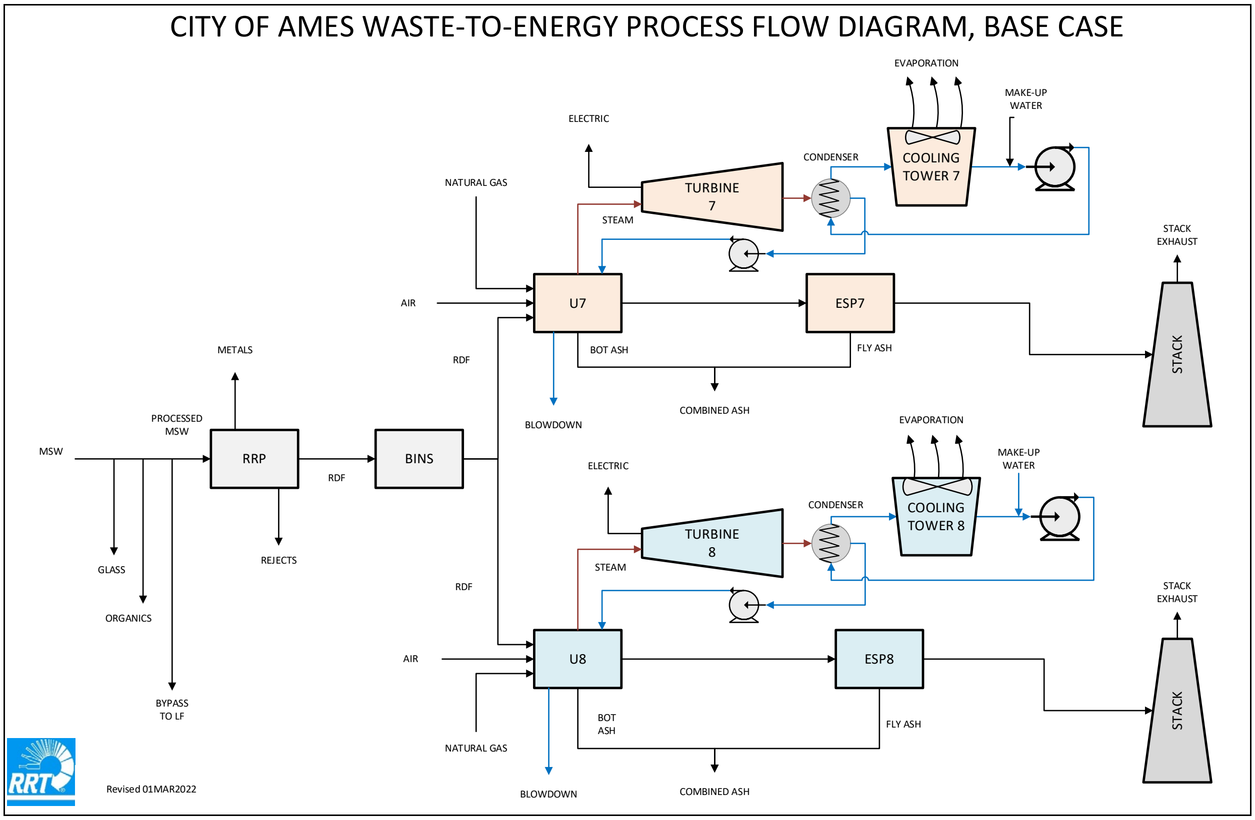

Figure 6: Option 1 (Base Case) Overall Process Flow Diagram

3.1.12 Building/Facility Description and Considerations

A facility description is not provided for Option 1, as the existing facility and system narrative is already provided in both the RRP and PP System Summary Sections and nothing is being changed in this option.

Existing City of Ames Facility Layout

The City's existing RRP, storage bins and power plant are shown in **Figure 7**. The RRP building is located along the north side of Lincoln Way east of Duff Avenue. The second-generation rectangular storage bin is located just south of the railroad on the western side of the former coal yard. The power plant is located to the North of the rail line with its main entrance on 5th Street. See **Figure 7** below for further details.

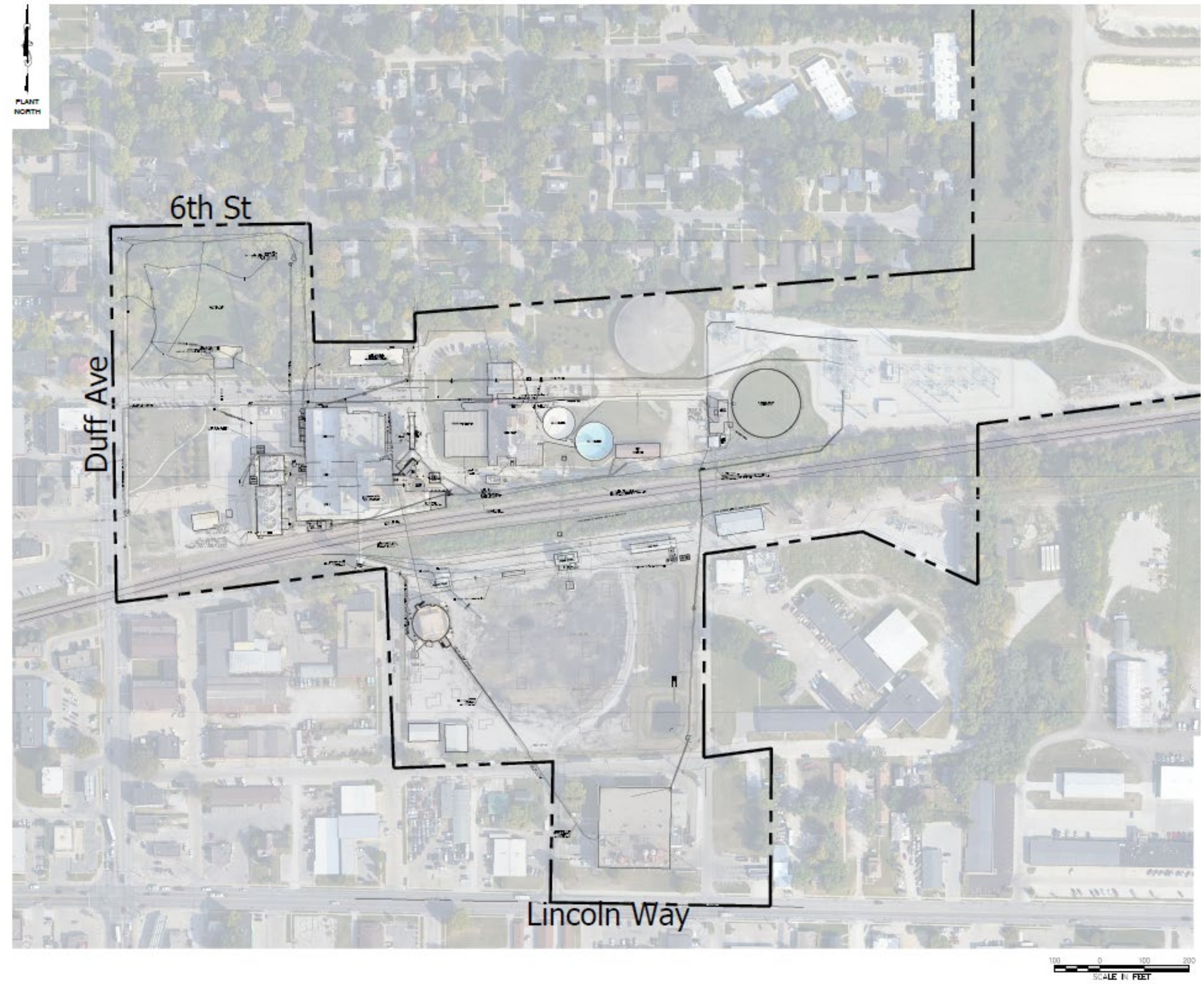

Figure 7: Existing City of Ames Facility Layout

3.2 Option 2A – Existing RRP with New RDF Combustion Unit in the Existing PP

The following items characterize the key elements of Option 2A

- Processing MSW into 4 inch minus RDF using the existing RRP
- RRP enhancements to improve processing capability to handle increased throughput
- Unit 5 and 6 boilers and associated equipment would be remediated and dismantled. Select equipment may be reusable depending on its condition (e.g., surface condenser, boiler feed-pumps) subject to inspection. This expense is currently budgeted for by the City and this report assumes it will be completed before any project engineering to enable a complete investigation of the as-left condition.
- One new, state-of-the-art RDF-only combustion boiler (Unit 9) would be installed where retired boilers 5 and 6 are currently located or in the adjacent water treatment plant area. Natural gas will be used only for startup, shutdown, and flame stability of the boiler.
- As a backup, maintain and operate Unit 8 as currently designed when Unit 9 is unavailable. Note: While Unit 7 could also be used as a backup, Unit 7 is smaller than Unit 8 and therefore would not be able to handle the full amount of incoming RDF.
- Unit 7 and 8 would be maintained by the City as capacity resources for the MISO burning natural gas only. They would be bid into the electric market based on Citygate gas prices. It is estimated that they would be selected to operate less than 5% of the time.
- The contract for well head gas and firm transportation could be cancelled and only Citygate gas purchases made as needed, since annual quantities would be small (startups and shutdowns) and timing unpredictable, including for the operation of Unit 8 as the backup boiler.
- Power would be generated from refurbished steam turbine 5 (ST5) and updated to utilize the steam from Unit 9. A new electronic control system, new steam condenser and an electric generator rewind are also assumed. An internal inspection would be conducted to confirm the feasibility and cost of the steam path refurbishment and generator rewind. A cost-benefit analysis would compare the expected performance and cost of the refurbishments vs. installing a new steam turbine and generator of comparable size. Power would be delivered to the grid via the existing electrical infrastructure.
- Steam turbines 7 and 8 will not be able to accept the new RDF boiler steam conditions and will remain as capacity only resources.
- New Balance of (Power) Plant (BOP) equipment and systems would be installed to support the installation and operation of Unit 9.

3.2.1 MSW Storage

Option 2A involves using the existing RRP equipment in its current condition along with a few recommended upgrades further described in the next section. The front-end storage capabilities at the facility are not expected to change from the base case Option 1. The same storage capacity available on the RRP tipping floor is expected to be sufficient for dealing with downtimes and maintenance issues in the facility.

3.2.2 RRP Analysis and Recommended System Upgrades

- As part of the existing RRP technical analysis, RRT and the City discussed some potential upgrades for the waste processing and transfer systems. Option 2A proposes to address the following items summarized below, and includes a cost allowance for upgrade and/or replacement. RRT proposes to upgrade the existing pneumatic conveyance system by adding capabilities for metering the RDF inbound and outbound to the existing bin as well as providing new airlock feeder systems and material handling blowers.

- Upgrades to the existing air knife system to increase separation efficiency
- Improvements to the existing data collection, instrumentation and information management system, and CCTV system.
- A new Eddy Current Separator (ECS) will be added to the overs fraction from the primary disc screen, after the secondary shredder, to increase non-ferrous recovery. The upgrade will include necessary conveyors and a poker picker to capture rods or wires that come through the screen and might be blown over by the air knife into the light fraction, the latter leading to plugs or jams in the pneumatic conveyance line.
- A new scale for outbound traffic is also proposed, given the existing inbound scale is not suitable for walking floor trailers currently used for outbound rejects.

Figure 8 shows the RRP Process Flow Diagram for Option 2A.

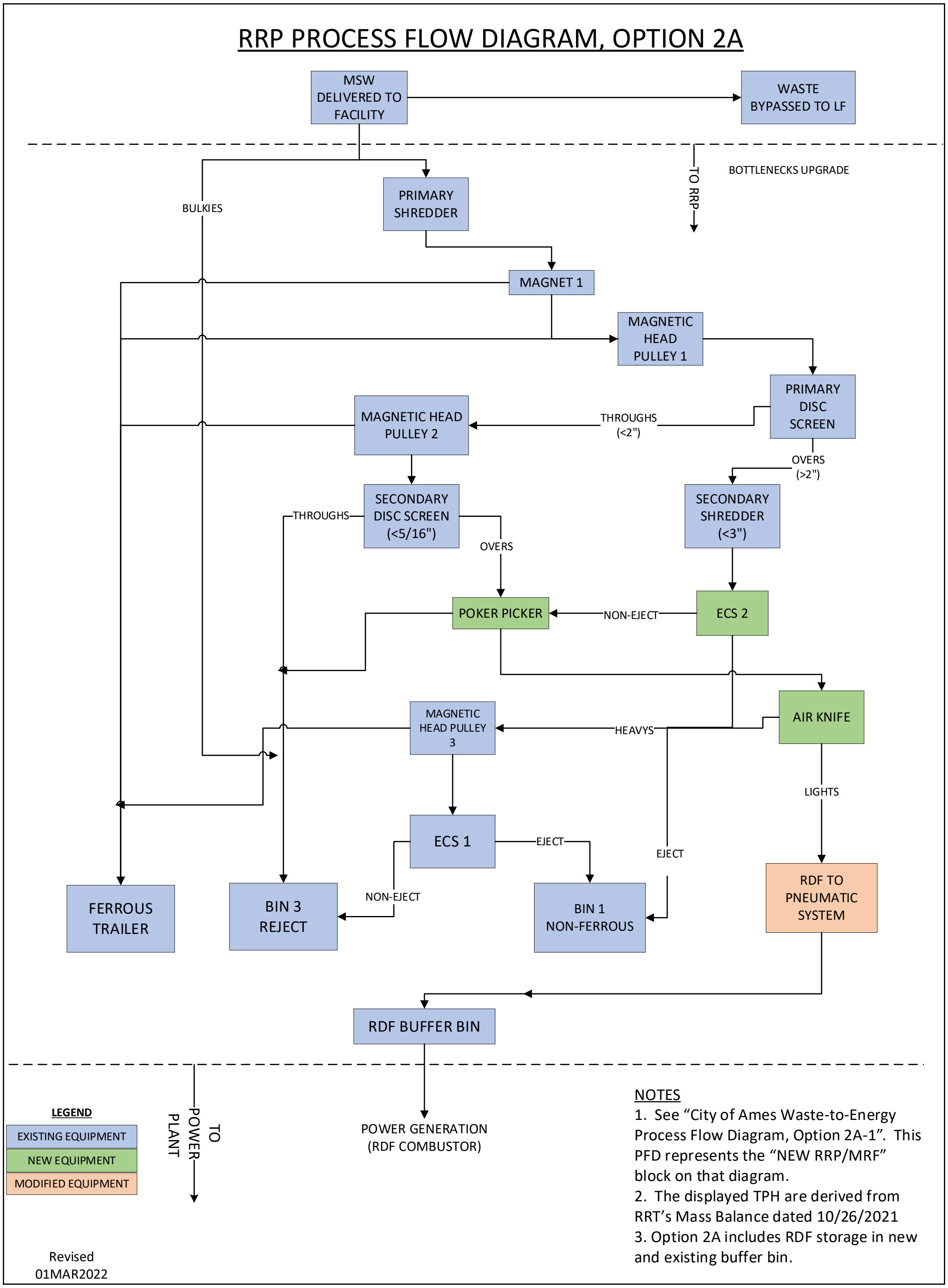

Figure 8: Option 2A Overall RRP Process Flow Diagram

3.2.3 RDF Transport and Storage

The RDF is conveyed pneumatically to the RDF storage bin for interim storage, via a single 14" pipe, which limits the throughput to a maximum of 12 – 14 TPH, with an average of 8 TPH. The bin provides storage for the RDF to balance the operation of the RRP (~80 hours per week) and the power plant (24 hours/day). The bin is divided into 2 sides, allowing one side to be emptied while the other is being filled and also enables performing maintenance on one side while the other is in operation. Each side holds approximately 100 tons of RDF. From the bin, the RDF is transported pneumatically to the power plant using two 8" pipes. As further detailed in the RDF/MSW Storage Analysis found in ***Appendix B,*** additional storage for Option 2A is not necessary. In this case, the 200 tons of existing storage, along with Unit 8 back-up capacity, yields approximately 12 days of storage at the end of the 20-year evaluation period when one unit is off-line.

Of the total four existing pneumatic lines to the boiler, only two are currently being used to convey RDF from the existing bin to the PP. One line is used as a cable conduit. As part of 2A upgrades, we recommend restoring the remaining non-operational line to improve fuel delivery reliability and redundancy to the boiler in light of the increase in RDF consumption of the new boiler.

3.2.4 RDF Combustion System Options

A variety of combustor design options could be used for the combustion of 4" RDF, including bubbling fluidized beds, suspension-fired traveling grates, and inclined reciprocating grates. Details on all of these combustor types were introduced in Section 1.2 and are provided in ***Appendix G***.

Historically, the most common combustor design for RDF utilizes suspension firing, with a horizontal traveling grate to combust larger materials that are not completely burned in suspension and fall to the grate. The RDF size requirement for suspension-fired systems is typically 6" minus, which can usually be achieved in a single shredding step. Back in the 1970's and 1980's, several large boiler suppliers adapted designs from other solid fuel systems to combust RDF, and a number of large facilities were built in the U.S., a few of which still operate today. These systems were much larger than that needed for the City of Ames, with unit capacities on the order of 1,000 TPD.

Bubbling fluidized bed combustion systems have been successfully applied to RDF applications for many years but require a finer RDF size of 4" minus, similar to the RDF currently produced by the City of Ames. A leading supplier of bubbling fluidized bed combustion systems is Metso:Outotec. A schematic of their combustor is shown below in **Figure 9**.

In the Metso:Outotec system, waste is fed to the combustor by a metering bin located above the combustor. The metered RDF flows by gravity to the inlet of an air-swept spreader that disperses the RDF across the bubbling bed of the combustor. The City's current pneumatic system for transporting and feeding RDF could feed the metering bin, or alternately, replace the metering bin and feed the RDF directly to the bubbling bed combustor. Metso:Outotec has some experience with this type of direct pneumatic feed to their bubbling bed combustion systems. A summary of all the various combustion system technologies considered in the study are included in ***Appendix G***.

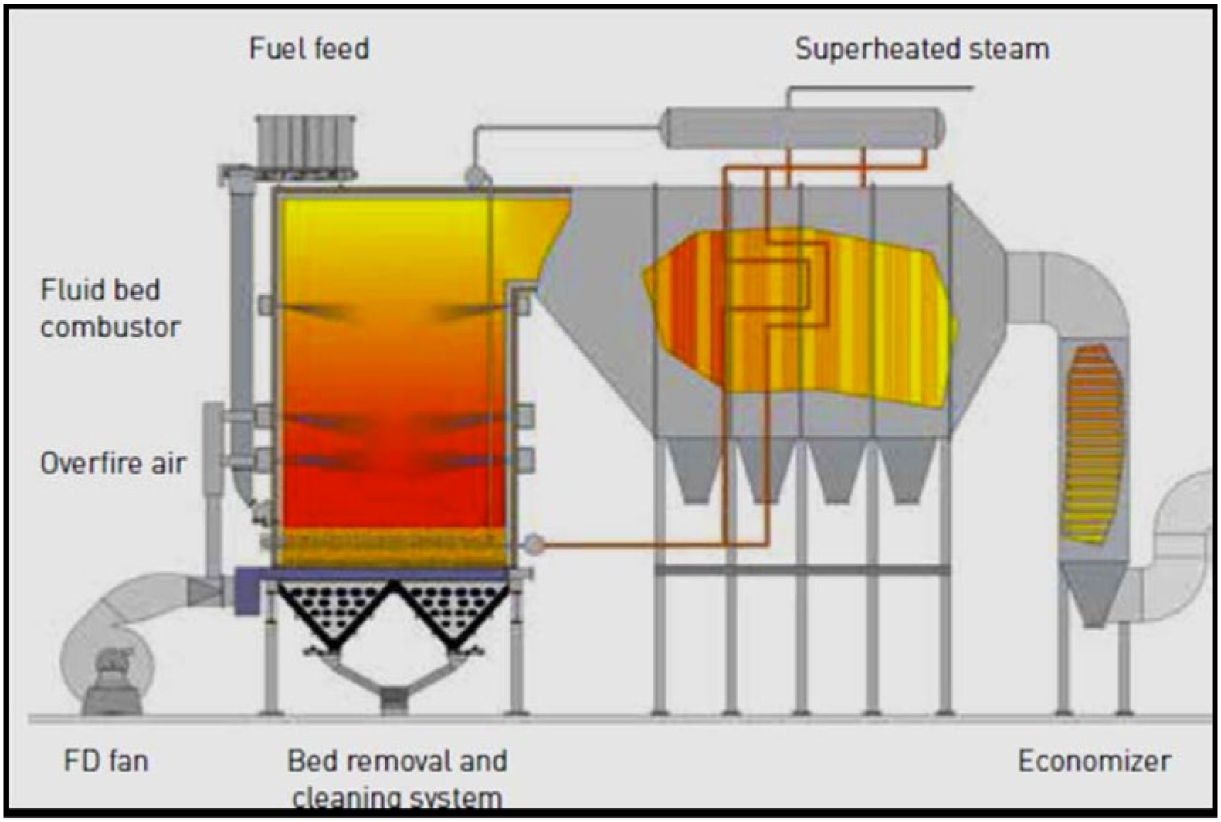

Figure 9: Metso-Outotec Bubbling Fluidized Bed Combustor for <4" RDF

RDF entering the hot, bubbling bed dries and combusts at a relatively low temperature and provides a well-mixed system that promotes efficient combustion and prevents localized high temperature areas where melting of the ash could occur. This controlled combustion condition requires less excess air when compared to suspension fired systems and leads to lower CO and NOx emissions from the combustor. Non-combustible inorganics in the RDF are removed from the bubbling bed automatically by Outotec's proprietary bed material cleaning system that recovers the bed material sand for recycling back to the combustor and rejects ash and other inerts.

Metso:Outotec has commercial experience processing RDF in their bubbling fluidized bed combustion systems, including French Island and the City of Tacoma in the U.S., three Italian facilities in Ravenna, Bergamo, Massafra, and several new facilities in the UK.

Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. While inclined reciprocating grates are designed to combust unprocessed MSW, they could also be used for the combustion of RDF. However, the mechanical design of these systems is thought to be overkill for a processed RDF feedstock, particularly one that is sized to 4", as is currently produced by the City of Ames RRP.

3.2.5 Boiler Design

The boiler design would depend on the type of RDF combustion system, but we believe the best combustor design for 4" RDF to be the bubbling fluidized bed combustion system. With a bubbling fluidized bed system, separate boiler modules can be used for the convection and economizer sections. **Figure 10** below shows the typical boiler arrangement for a bubbling fluidized bed combustion system.

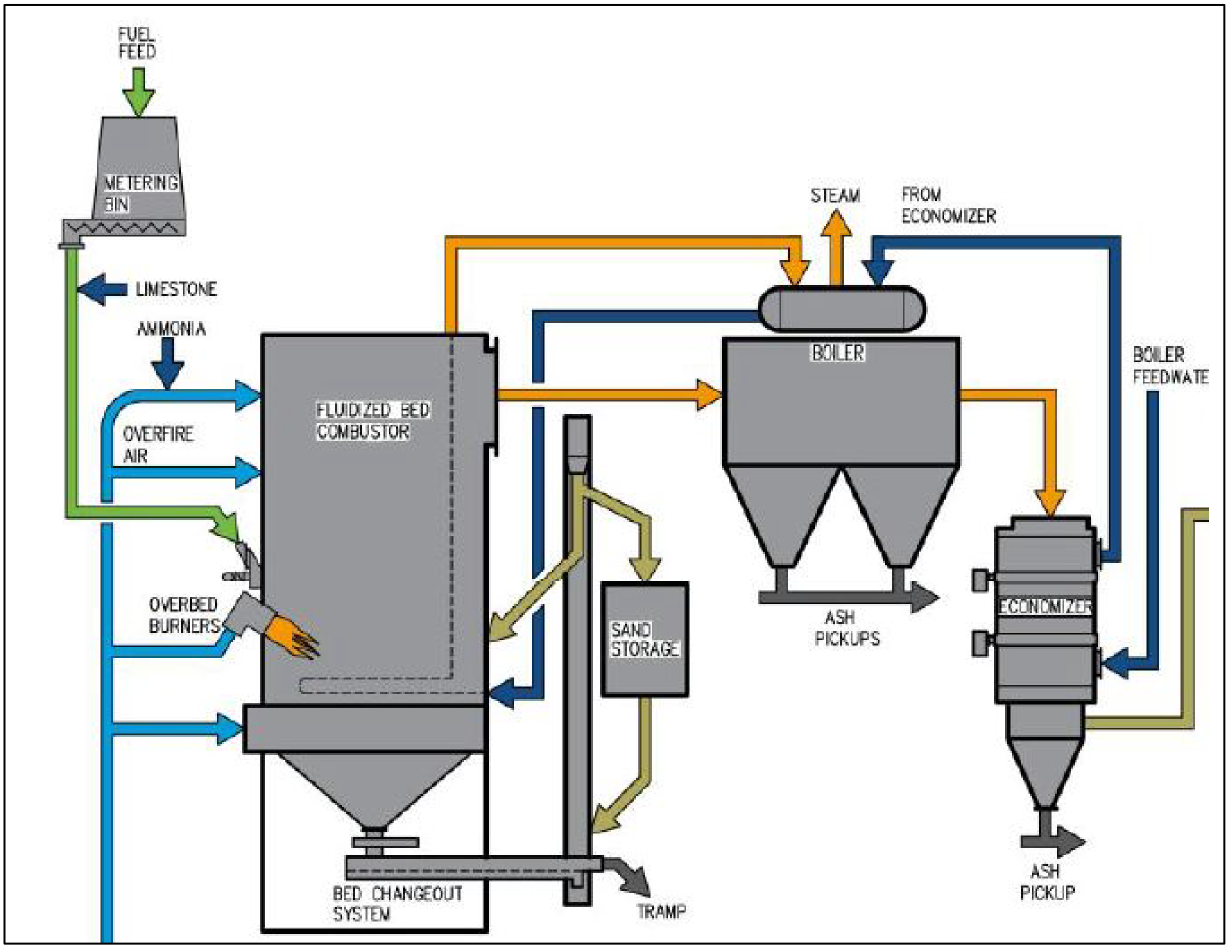

Figure 10: Typical Bubbling Fluidized Bed Combustor Boiler

The detailed design of the boiler will consider the high fouling and corrosion potential of the RDF feedstock, driven by the high chorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features, along with operation and maintenance approaches, have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Protective alloys will also be used in select areas to prevent high corrosion rates.

More details on boiler designs are provided in ***Appendix H***.

3.2.6 Power Plant System Summary

A new RDF-only boiler would be installed in the building space where Unit 5 and 6 boilers and associated coal bunkers are located. To account for growth the boiler's continuous design capacity would be at least 125 tons/day. The boiler would receive RDF from the existing 8" feed lines from the existing storage bin. The boiler would be designed to produce 600 psig, 750F steam. The existing steam turbine 5 (ST5) would be refurbished to use this steam. A new condenser would be installed at the lower level, if the existing condenser is not reusable, to condense the turbine exhaust steam. The new condenser would be equipped to handle the duty of the turbine in bypass mode, a feature not available on the current condenser. This allows the boiler to continue operating should the steam turbine be off-line for planned or unplanned events. The ST8 condenser would remain as-is since Unit 8 is for backup operation only. It has been confirmed by the vendor that the cooling tower serving Unit 7 can be upgraded to accommodate the incremental heat rejection of ST5. Other select equipment from old boiler 5 may be reusable depending on its condition (e. g. surface condenser, boiler feed-pumps) subject to inspection. The steam turbine generator would be rewound, and the existing electric interconnection infrastructure utilized. New electric distribution power and motor control centers would be provided to serve the Unit 9 equipment. Various systems (e.g., compressed air) would be integrated with the existing system for redundancy. The Ovation control system would also be expanded to include the operation of Unit 9 in the existing control room.

New equipment would include a dry scrubber and baghouse. NOx emission would be controlled using ammonia injection into a Selective Non-Catalytic Reducer (SNCR). These systems are described in further detail later in this report.

Units 7 and 8 would continue to operate as capacity resources burning natural gas only. Unit 8, since it is the larger of the two, would co-fire RDF with natural gas as a backup when Unit 9 is unavailable. Unit 7 could also be a second backup for RDF co-firing.

Fly ash collected from the baghouse and boiler will be conveyed via screw conveyors to a fly ash storage silo. A new dedicated Continuous Emissions Monitoring System (CEMS) would be provided in the stack to monitor pollutants exiting the stack and COMS for opacity.

3.2.7 Balance of Power Plant Equipment

All of the existing equipment currently used to support the operation of Units 7 and 8 would be maintained.

For the new Unit 9, the following is a list of balance of plant (BOP) equipment anticipated:

- New boiler feed pumps, condensate pumps and cooling water pumps
- Modification and/or refurbishment of the existing ST5, and associated steam turbine condenser for re-use
- New steam, condensate, cooling water and makeup water piping
- New stack, CEMS, and COMS
- New generator step-up (GSU) transformer and associated high voltage electrical support and interconnect equipment
- New step-down transformer and power distribution system
- ST5 condenser would reject heat to the existing cooling tower serving Unit 7 which can be upgraded to handle both Unit 7 and Unit 9 heat rejection at a fraction of the cost of a new cooling tower.
- New instrumentation and controls
- New foundations
- Platforms, ladders, stairs and railings to enable maintenance and operation

The following existing plant systems would be extended for Unit 9 and augmented as necessary:

- Natural gas supply (for startup and shutdown)
- RDF pneumatic feedlines from the existing 4 supply lines to Unit 9
- Compressed air

- Un-interrupted power system (UPS)
- Distributed control system
- Fire protection system

3.2.8 Emission Control

The EPA has defined the Best Available Control Technology (BACT) for waste combustion systems to be the combination of a dry scrubber and baghouse that treats the flue gas exiting the boiler. These systems are proven to meet the EPA limits on particulates, SO_2, HCl, mercury, trace metals and dioxins, and would be the recommended emission control system following a bubbling fluidized bed combustor for RDF. The scrubber / baghouse is typically augmented with the injection of powder activated carbon (PAC) into the flue gas at the entrance of the scrubber for additional control of both mercury and dioxins. CO and NOx are combustion-related emissions that are controlled by combustion control methods. Additional NOx control is typically achieved by Selective Non-Catalytic Reduction (SNCR) which injects aqueous ammonia or urea into the upper furnace of the combustor. The scrubber / baghouse, PAC injection and SNCR systems are described in more detail in ***Appendix I***.

3.2.9 Ash Handling/Disposal

Fly ash collected from the baghouse and boiler will be conveyed via screw conveyors to a fly ash storage silo. The fly ash will then be conditioned with water to control dusting before being combined with the bottom ash exiting the combustor. This combining of the fly ash and bottom ash typically occurs on a pan or belt conveyor to form the combined ash that is then conveyed to an ash storage area. The combined ash will then be loaded into trucks for transport and disposal in a landfill.

The combined ash will contain heavy metals of environmental concern, requiring regular sampling and testing to ensure it is below the EPA toxicity limits as determined by the Toxicity Characteristic Leaching Procedure (TCLP). More detailed discussion on ash sampling and testing will be provided in **Section 5 – Environmental Impacts**. Note that the RDF will contain heavy metals that were present in the MSW in trace, parts per million levels. These heavy metals are not recovered in the RRP, which only recovers ferrous and non-ferrous metals for recycling.

3.2.10 Electric Energy Sales

Electricity sales would continue as they are conducted today, however the supply of power from the PP to the City would be approximately 1/10th of the current electricity production. The reduced power is a result of eliminating the co-firing with natural gas in the new primary Unit 9 as the lead boiler. In the financial model, the difference between the electricity generated by co-firing natural gas in Option 1 and electricity generated in Option 2A would be purchased on the day ahead wholesale market at the hourly MISO price (i.e., the Location Marginal Price, LMP) for the Ames interconnect node. In 2021, the on-peak and off-peak average LMP for Ames was $30/MWh and $17/MWh respectively. This is significantly less than the power plant's variable costs to make electricity with natural gas. Assuming a 95% transportation contract utilization rate, the average "all-in" (commodity plus transportation) gas price to the power plant would be $3.48/dth based on Ames 2021 contract prices. The gross heat rates of Unit 7 and 8 when co-firing with natural gas are historically 11,552 and 11,161 BTU/kWh respectively as measured by the power plant. Therefore, the average electric production cost using Unit 8's latest heat rate is $38.84/MWh (($3.48/dth) * (11,161 BTU/kWh) / (1000)), excluding other variable costs (e.g., consumables) and fixed costs. Therefore, significant cost savings could be realized when natural gas consumption is eliminated.

The cost of natural gas for consumption in Unit 8 as a backup boiler in Option 2A is reflected in the financial model. Since Unit 8 is assumed to operate no more than 10% of the year as the backup boiler, maintaining the current gas contract arrangements for Option 2A and Option 3A is uneconomical since the fixed cost of gas transportation would have to be absorbed over very few hours of gas utilization. At a 10% utilization factor, the average gas price would climb from $3.48/dth (the Option 1 average price in the model) to over $15/dth (refer to **Figure 11**). For Option 2A and other non-base options, an assumed Citygate premium of

$1.00/dth was used on top of the $5.00/dth for purchasing the gas for Unit 8 as needed from the local utility. The premium and the $/dth price are adjustable in the model.

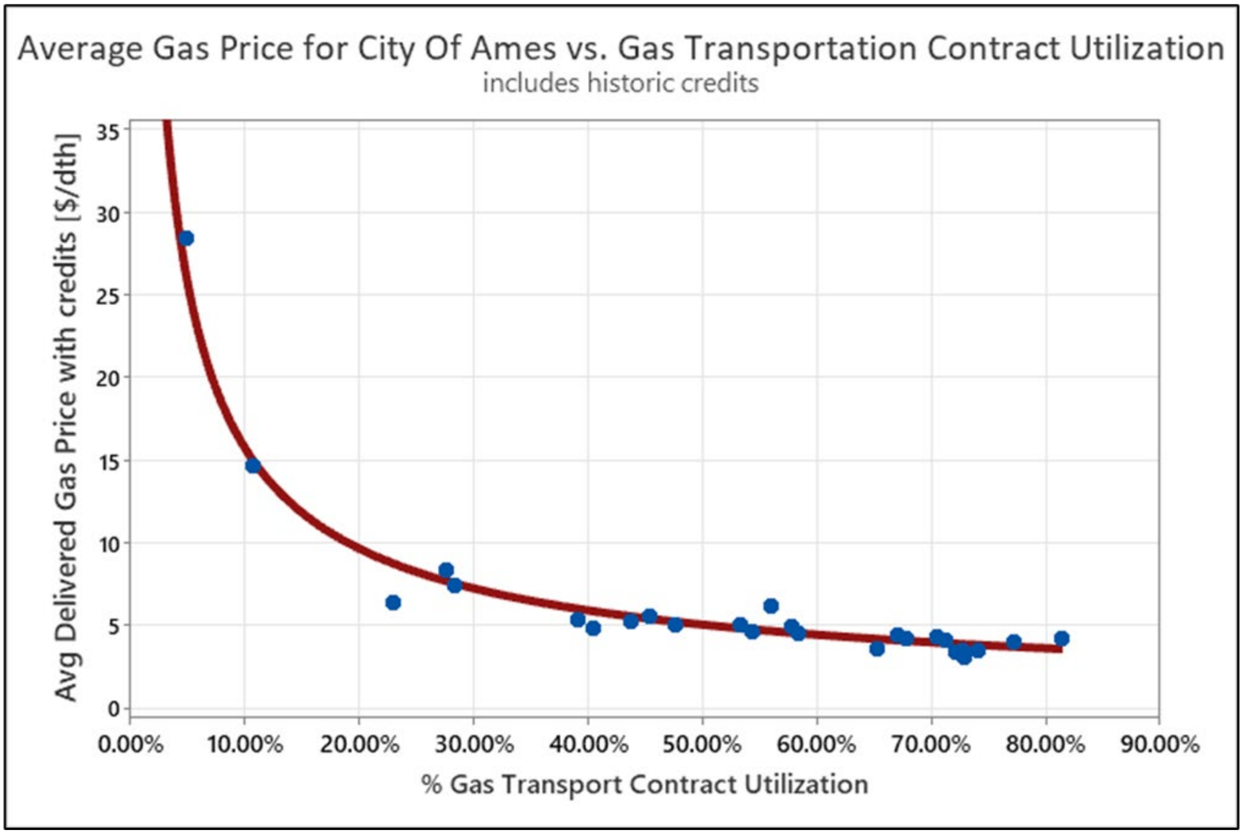

Figure 11: Avg. PP Gas Price vs. Gas Transportation Utilization (JAN2021-MAR2021)[7]

Unit 7 and 8 would be maintained by the City as capacity resources for the MISO, burning natural gas only. They would be bid into the Day Ahead (electric) Market (DAM) based on Citygate gas prices in effect at the time. It is estimated that Units 7 and 8 would be selected to operate less than 5% of the time. The associated contracts for well head gas and firm transportation should be cancelled as the capacity utilization would be very small. Natural gas would only be needed for backup Unit 8 co-firing, resulting in a very high average price for gas (See **Figure 11**). Citygate spot market gas purchases would be made as needed for startup and shutdown of all Units. Gas purchases for Units 7 and 8 as capacity resources are excluded from the Waste-to-Energy economics as there would be no more co-firing with RDF in these boilers.

3.2.11 Process Flow and Mass and Heat Balance

The Overall process flow diagram for Option 2A is shown in **Figure 12**. The data for the mass and heat balances are shown in ***Appendix F.***

[7] Includes average well-head gas commodity price of $2.83/dth (JAN2019 – MAR2021)

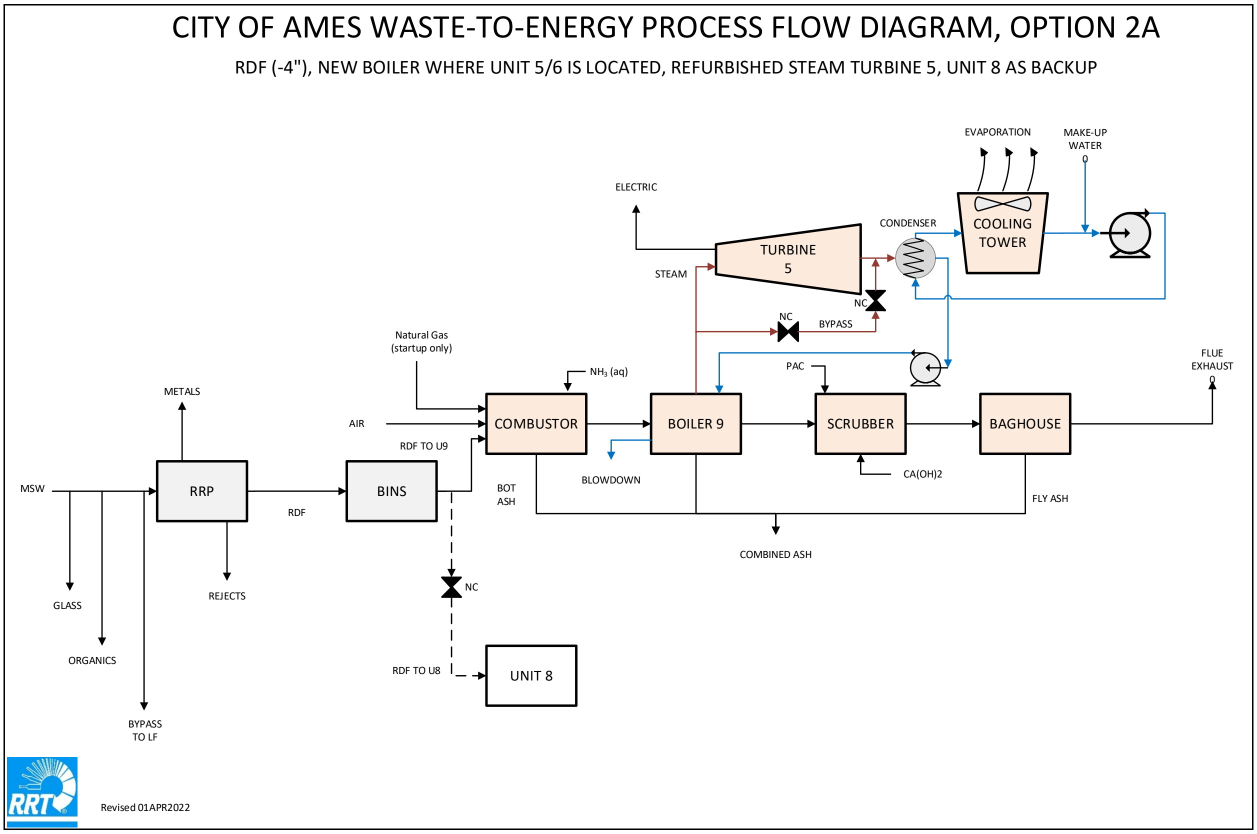

Figure 12: Option 2A Overall Process Flow Diagram

3.2.12 Building/Facility Description and Considerations

For this option, the existing RRP building would remain as is.

The existing PP building where Units 5 and 6 boilers and turbines are located would be vacated, and the space reused for the new boiler. Sufficient access would have to be made to allow for the removal of units 5 and 6 (which the City currently plans to do in 2022) and installation of unit 9 and its related new equipment. This would include removal of windows, doors and potential roof sections. A structural review would be needed to confirm the building shell is adequate for intended use. Some structural re-enforcing to comply with the latest codes is assumed.

3.2.13 Preliminary Conceptual Facility Layouts

A preliminary conceptual layout for the installation of a new dedicated RDF-only combustion boiler, scrubber and baghouse where retired Units 5 and 6 are currently installed is shown in **Figure 13**. The new equipment will also occupy the space of the coal bunkers. The City is planning to remediate and remove the coal bunkers along with Combustion Units 5 and 6 according to the current CIP Plan. ST5 will be refurbished or replaced, pending an equipment internal inspection, to confirm its condition, and the ST5 generator will be rewound. It was confirmed with the vendor that the existing cooling tower for Unit 7 can be upgraded to also reject the heat from the new or refurbished steam turbine (ST5).

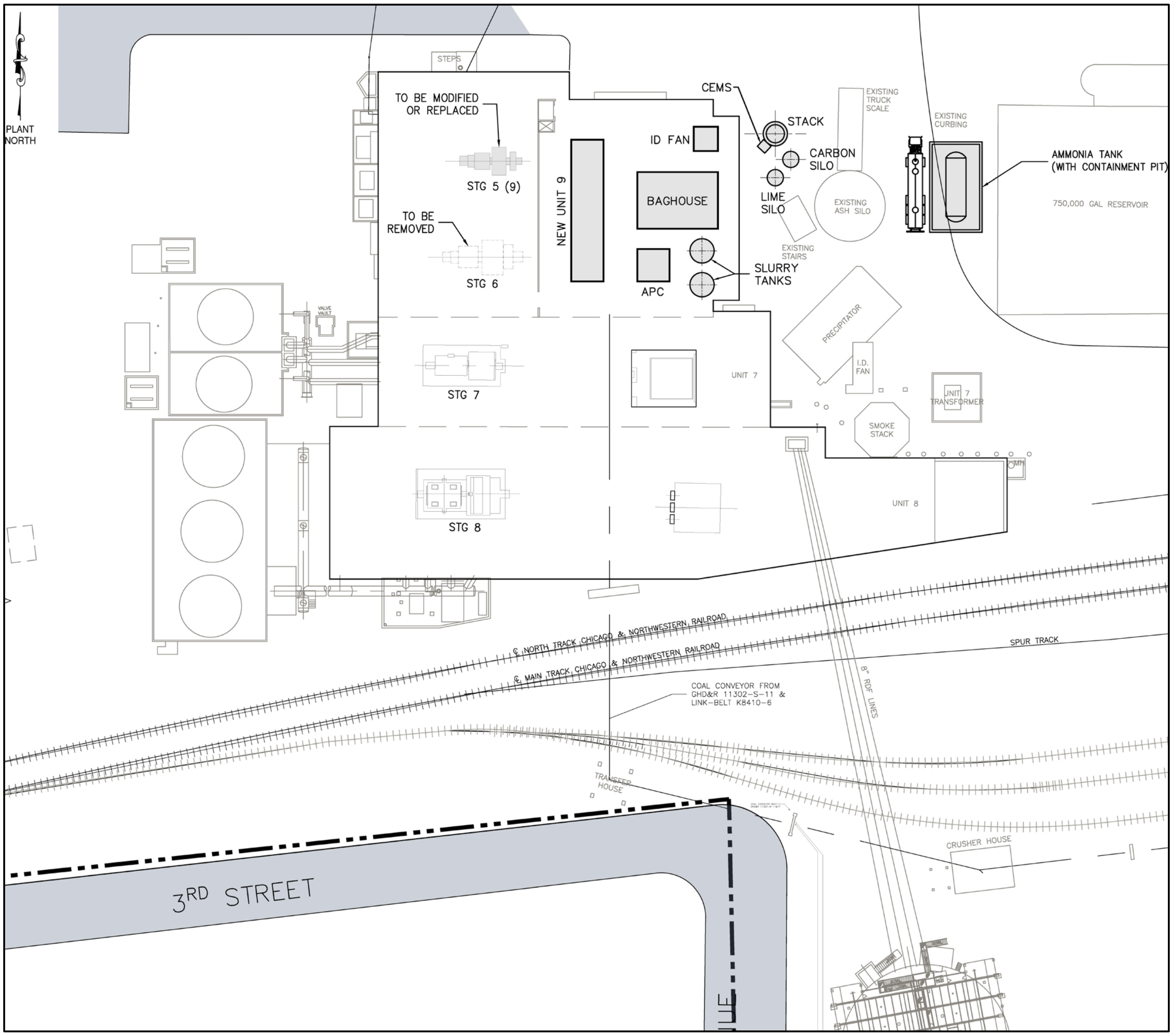

Figure 13: Option 2A Preliminary Conceptual Layout

3.3 Option 2B – Modified RRP (20” RDF) with Two New RDF Combustion Units

The following items characterize the key elements of Option 2B

- Processing MSW into a larger RDF, no greater than 20 inches in size, and reusing the existing RRP building and installing new MSW processing equipment.
- Two new, state-of-the-art RDF-only combustion boilers (Units 9 and 10) installed at the coal yard due to insufficient space in the existing power plant. Units 7 and 8 are not able to be utilized due to the larger sized RDF and thus why two new units are required for this option.
- Natural gas will be used only for startup, shutdown, and flame stability of the boilers but will not be required for normal operating mode.
- Conveyers to move the large RDF to the power plant tipping floor. RDF conveyance using the existing pneumatic system will not work for this size of material.
- New RDF storage system at the new RDF storage building located at the coal yard.
- Power would be generated from refurbished steam turbine 5 (ST5) and updated to utilize the steam from Units 9 and 10. A new electronic control system, new steam condenser and an electric generator rewind are also assumed. An internal inspection would be conducted to confirm the feasibility and cost of the steam path refurbishment and generator rewind. A cost-benefit analysis would compare the expected performance and cost of the refurbishments vs. installing a new steam turbine and generator of comparable size. Power would be delivered to the grid via the existing electrical infrastructure.
- Steam turbines 7 and 8 will not be able to accept the new RDF boiler steam conditions and will remain as capacity only resources.
- Unit 7 and 8 would be bid into the electric market based on Citygate gas prices. Gas purchases for Units 7 and 8 would be excluded from the Waste-to-Energy economics as there would be no more co-firing with RDF in these boilers.
- New Balance of Plant (BOP) equipment and systems for the power plant would be installed to support the installation and operation of the Unit 9 and 10 boilers and associated emissions control equipment in a new plant building.
- Steam from the new RDF boilers would be piped over to the existing power plant as throttle steam to generate power in ST5. Condensate would be pumped back to the boilers at the coal yard. Power would be delivered to the grid via the existing electrical infrastructure.

3.3.1 MSW Storage

The modified MSW processing equipment for Option 2B will be installed in the existing RRP building. The front-end storage capabilities at the RRP are not expected to change from the base case Option 1 and Option 2A. The 2-day storage capacity available on the existing RRP tipping floor is expected to be sufficient for dealing with downtimes and maintenance issues in the facility.

3.3.2 Modified Resource Recovery Plant (RRP)

The new RRP will be designed to process an average of 25 TPH. The system will be able to recover 80% or more of RDF in the form of 8” to 20” minus material, while recovering ferrous and non-ferrous metals and separating the rejects. New equipment as depicted in **Figure 14** below will be installed in the existing RRP building.

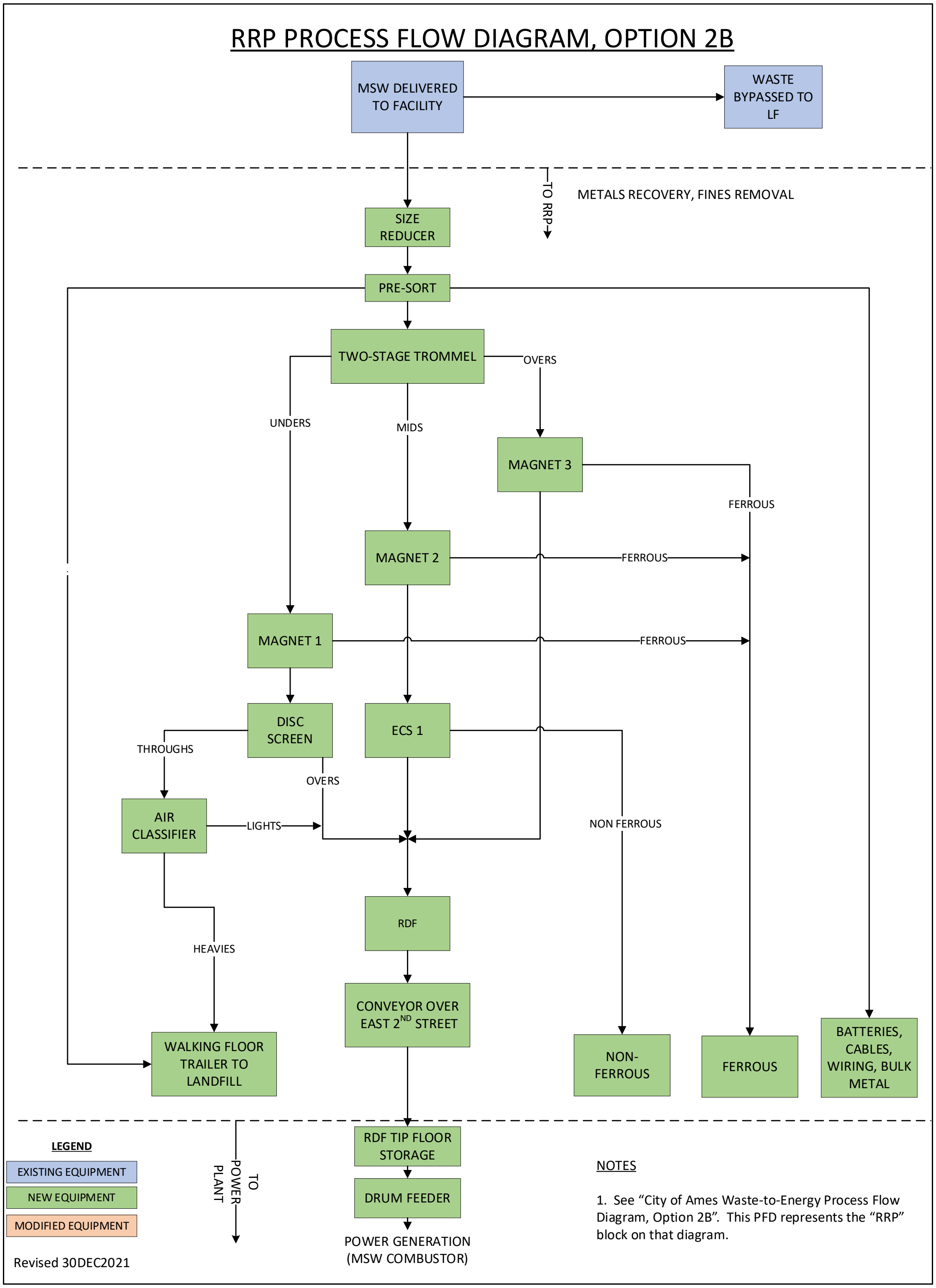

Figure 14: Option 2B RRP Process Flow Diagram

Reusing the existing building would result in large capital savings, however this approach would also negatively impact the ability to continue to run the existing facility while the construction work is going on.

For this study, it was assumed that the existing building would be re-used and therefore the City will have to plan for interim operations and divert the MSW during the modifications to the RRP for this option.

The incoming MSW is sorted on the RRP tipping floor to remove large un-processible and bulky items, such as mattresses, furniture, propane tanks, etc. Materials unloaded on the floor will be visually inspected and moved with a front-end loader toward the infeed conveyor area for processing or to the bypass area for landfilling if the material contains non-processible materials.

The MSW suitable for processing is loaded by the loader into the elevated hopper of an infeed conveyor. This process requires the operator to fill the infeed hopper to an even level along its length to keep the system running at a uniform rate. The infeed conveyor is equipped with a variable frequency drive (VFD) to regulate the conveyor speed and maintain constant and even flow of material onto the size reducer. The role of the new size reducer is to liberate the material, reduce it to a particle size of 20” minus and protect the downstream equipment from large bulky objects.

This 20” minus material will be conveyed to a pre-sort station where sorters will manually remove bulk metals such as cables, wiring, pots and pans, batteries, and pipes and drop them through a set of chutes. Another set of drop chutes will be designated for removal of non-processible materials that were missed during the feeding process, such as carpets, textiles, wood, etc. These items must be removed to prevent system jams and potential damage to downstream process equipment. These non-processible bulky objects picked off manually from the pre-sort conveyor will be deposited into bunkers beneath the sort platform to be later landfilled or salvaged (as applicable).

The MSW after having been sorted to remove the various undesirables will continue to the rotary trommel for mechanical separation into three different fractions by size. The trommel is a rotary screen containing heavy duty screens with two screening sections and different opening sizes. Although not necessary, the trommel can include sharp metal spikes mounted within the first part to open bags and liberate materials for more efficient separation.

The first section of the trommel will remove the “fines” fraction consisting of organics, broken glass, small paper items, food waste, stones, paper clips, bolts, inert material and other items that can pass through the holes. This material will drop onto a conveyor under the trommel, and a magnet will remove ferrous metals from this stream prior to being transferred to a disc screen. The disc screen removes the 1” minus material from this fraction, which continues into an air classifier, separating the light material from the heavy fraction. The heavy fraction material along with the other rejects from the plant will be shipped to landfill via transfer trailers. The light fraction from the air classifier will be combined with the overs (1” plus) from the disc screen.

The final size of the trommel screens will be designed and selected during the engineering phase. As an example, for the purpose of the mass balance, the screen sizes were assumed as described in this section. The second section of the trommel will have 7” holes to create a plus 2.5” /minus 7” fraction also called “middlings.” A suspended magnet located over the head pulley of conveyor transferring middlings will remove ferrous metal containers from the feed stream. The middlings will continue onto an eddy current separator (ECS) that will remove aluminum beverage cans (UBC) and other non-ferrous material from this feedstock and discharge them into a non-ferrous bin. Ferrous metals collected from the three magnets in the plant will be combined and transferred to a ferrous bin or bunker.

The plus 7” fraction, also called “overs”, coming out of the trommel, is dropped on a conveyor with a suspended electro-magnet to remove any ferrous materials from the feed. The remaining material is combined with the overs from the disc screen, the lights from the air classifier and the middlings coming out from the ECS, resulting in the recovered RDF stream, which is ready for combustion.

The RRP equipment can be supplied by a variety of manufacturers, with careful consideration of design features for this type of application and systems integration. Part of the existing equipment in the RRP, such as magnets or ECS could be reused in this option, however for the purpose of the financial model all equipment was assumed to be new. Moreover, depending on the timeline for this option implementation, a majority of the existing equipment at the RRP will become obsolete, therefore installing new equipment will be recommended.

3.3.3 RDF Transport and Storage

The RDF from the RRP will be transported to the RDF storage area using a belt conveyor system. The conveyor will be running overhead across East 2nd Street from the existing RRP building to the new RDF storage building contiguous to the new power plant building located at the coal yard. The conveyor system will be enclosed in a tube gallery, similar to **Figure 15**, to avoid spillages and other environmental issues and will include a walkway platform for access and maintenance.

Figure 15: Conveyor Transport System with Tubular Gallery

Sufficient space will be provided in a new storage building on the coal yard for storing approximately 400 tons of the large RDF, which is approximately 3 days of storage with no combustion. A front-end loader will be used to move and stack the material on the floor as well as feed an infeed conveyor system with a drum feeder which will meter the RDF to the boilers.

Given the RDF will be stored on a new storage floor contiguous to the new power plant the existing RDF storage bin can be decommissioned or repurposed. The cost of demolition or any repairs and upgrades associated with the existing bin were not included in the financial model.

3.3.4 Large RDF Combustion System

20" minus RDF is too large and heterogenous of a material to be combusted in suspension-fired or bubbling bed combustors that can be used for the finer RDF in Options 2A and 3A. To combust the large 20" minus RDF, a mass-burn grate system designed for unprocessed MSW would have to be used.

Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. These systems are offered by a number of proven suppliers. Inclined reciprocating grates are designed to combust unprocessed MSW and would be well suited for the combustion of the large 20” minus RDF.

One of the world’s most established suppliers of mass-burn combustion systems is Martin GmbH of Germany, who have supplied nearly 1000 units in over 500 plants around the world since 1960. The Martin system employs an inclined, reverse-acting, reciprocating grate where the grate bars move counter to the downward movement of the waste by gravity, providing enhanced stoking of the burning bed of waste. **Figure 16** provides a schematic of the Martin system showing the major components.

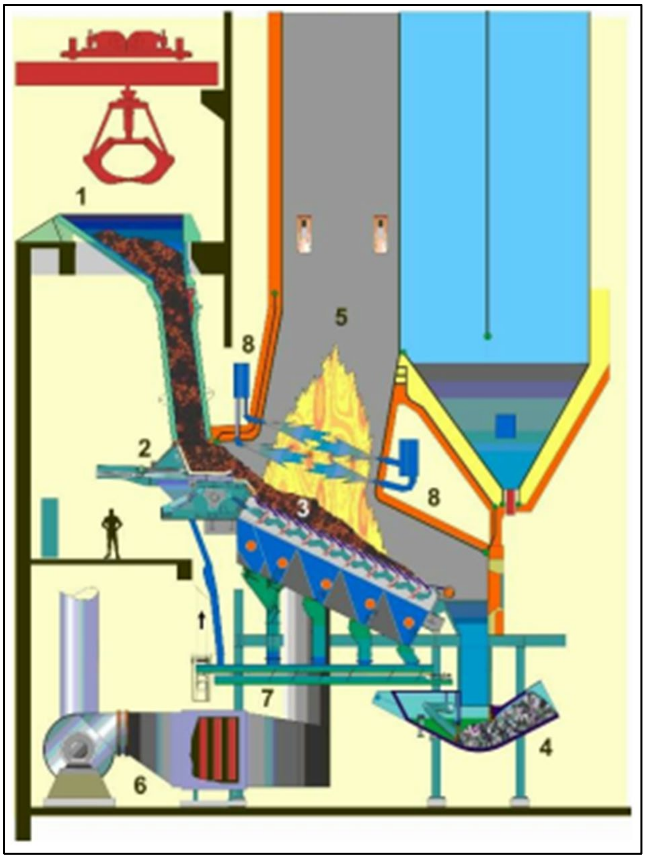

	Figure Legend
1	Feed Hopper
2	Hydraulic Ram Feeder
3	Inclined Combustion Grate
4	Bottom Ash Discharger
5	Furnace
6	Primary Combustion Air Supply
7	Ash Siftings Collection
8	Secondary Combustion Air

Figure 16: Martin Mass-Burn Combustion System

As the waste moves down the grate, it first dries from radiation of the flames and primary air flowing up through the grate. Combustible material in the waste then volatilizes and combusts in the main combustion zone. Secondary air is injected through nozzles in both the front and rear walls above the grate to ensure complete combustion of the burning gases. The combustion of the waste is substantially completed in the top two thirds of the grate. In the bottom third, additional air flow through the grate ensures good burnout and cooling of the ash residue. At the end of the grate, the ash residue falls into a water filled ash discharger that quenches the ash and discharges it to a metal pan conveyor.

There are a number of other major suppliers of mass-burn combustion systems, including Hitachi Zosen INOVA, Detroit Stoker, B&W Volund and Keppel Seghers. As with Martin, these suppliers offer mass-burn combustion systems using inclined, reciprocating grates, but with forward moving grate bars. Although the equipment is somewhat different between the suppliers, the processes are essentially the same for the combustion of MSW or RDF.

Another lesser-known European supplier of mass-burn combustion systems is Ruths S.p.A. of Genova, Italy. They offer both inclined and horizontal reciprocating grates for the combustion of MSW, which could also be used for the combustion of large 20" minus RDF. **Figure 17** below shows a general arrangement drawing of their inclined grate system. They are a proven supplier specializing in smaller capacity units with reference plants throughout Europe and parts of Asia. The option of a horizontal grate system would reduce construction costs and further lower the elevation of the feed chute for a conveyor feed system when compared to the inclined, reciprocating grate systems.

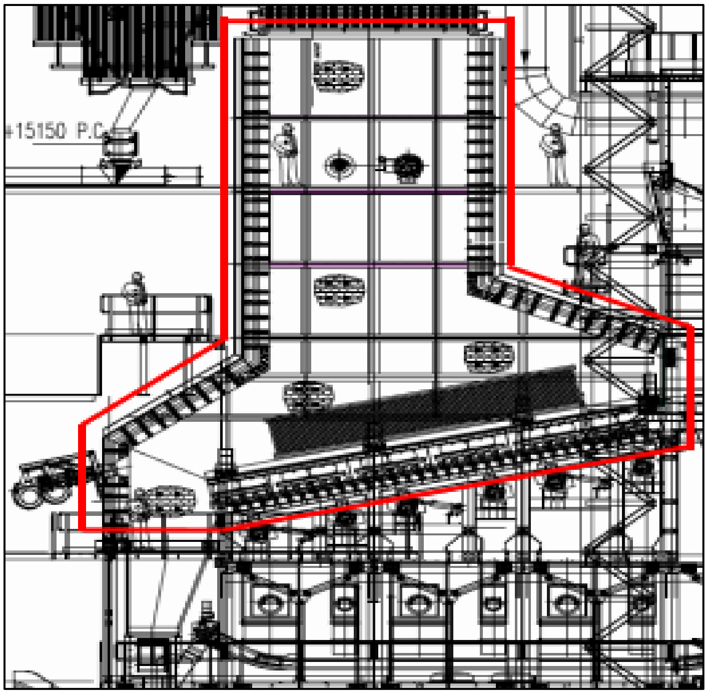

Figure 17: Ruths Inclined Reciprocation Grate Combustor

3.3.5 Boiler Design

Mass-burn, inclined reciprocating grate combustors typically use a boiler design with multiple vertical radiant waterwall passes, followed by a horizontal convection section for steam superheat and additional steam generation. The flue gas would then go to an economizer section before exiting the boiler. This boiler design is typically field-fabricated for larger mass-burn units. More details on these boiler designs are provided in ***Appendix H***.

Some suppliers, such as Ruths, which specializes in smaller mass-burn units, offer a modular design approach to maximize shop fabrication and reduce field construction costs and time. **Figure 18** below shows a schematic of their boiler design where the evaporator bundles (blue), superheater bundles (red), and economizer bundles (green) would all be shop-fabricated and delivered to the field for placement. This design and construction approach would reduce capital costs for the smaller unit sizes being evaluated for the City of Ames.

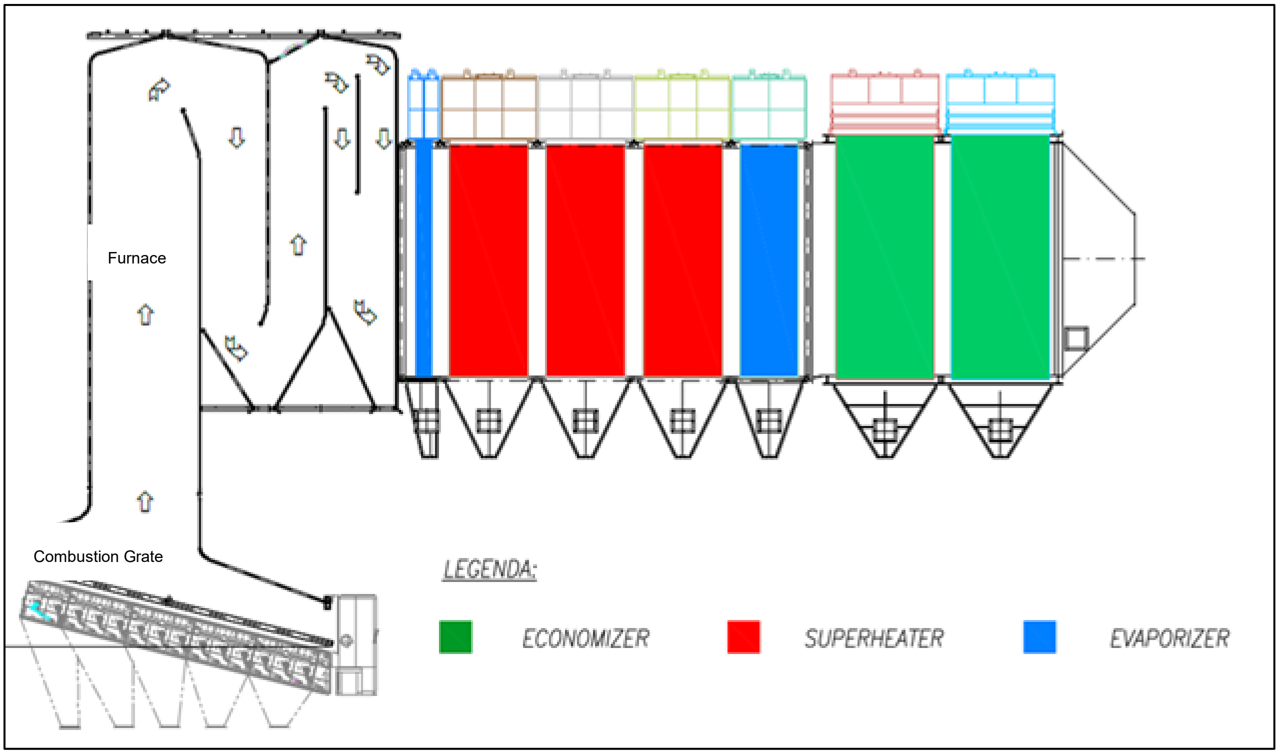

Figure 18: Ruths Modular Boiler Design

As with Option 2A, the detailed design of the boiler will consider the high fouling due to ash and corrosion driven by the high chlorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Protective alloys will also be used in select areas to prevent high corrosion rates.

3.3.6 Balance of Plant Equipment

The new boiler plant will require new auxiliary systems including:

- New building, associated services (civil works, foundations plumbing, HVAC, locker room, control room. parking),
- Utilities (water, sewer, natural gas, electric)
- Fire protection
- Distributed control system, instrumentation, controls
- Compressed air system
- Auxiliary cooling system for boiler feed pumps, air compressors, grates, if required)
- New stacks, CEMS, and COMS

- 4160 V power distribution
- 480 V power distribution
- Ash collection and handling system
- Uninterrupted Power System (batteries and backup generator connection at existing plant)
- Platforms, ladders and railings
- Plant lighting and security systems, including fencing
- Boiler feed system
- Calcium Hydroxide ($Ca(OH)_2$) storage and injection system

In addition, all of the upgrades to the existing power plant described in 2A would be provided to support the conversion of steam to electricity. These would include:

- Cooling water system (piping, circulating pumps and cooling tower No.7 expansion)
- Condensate forwarding pumps
- ST insulation
- Certain 4160 V and 480 V electric supplies
- Generator Step-Up (GSU) transformer, breaker, and relays

3.3.7 Emission Control

As with Option 2A for RDF, the Best Available Control Technology (BACT) for mass-burn combustion systems would be the combination of a dry scrubber and baghouse that treats the flue gas exiting the boiler. This system is proven to meet the EPA limits on particulates, SO_2, HCl, mercury, trace metals and dioxins. The scrubber / baghouse is typically augmented with the injection of powder activated carbon (PAC) into the flue gas at the entrance of the scrubber for additional control of both mercury and dioxins. CO and NOx are combustion-related emissions that are controlled by combustion control methods. Additional NOx control is typically achieved by Selective Non-Catalytic Reduction (SNCR) which injects aqueous ammonia or urea into the upper furnace of the combustor. The scrubber / baghouse, PAC injection and SNCR systems are described in more detail in ***Appendix I***.

3.3.8 Ash Handling/Disposal

Fly ash collected from the baghouse and boiler will be conveyed via screw conveyors to a fly ash storage silo. The fly ash will then be conditioned with water to control dusting before being combined with the bottom ash that is removed from the combustor by the ash discharger. This combining of the fly ash and bottom ash typically occurs on a pan or belt conveyor to form the combined ash that is then conveyed to an ash storage area. The combined ash will then be loaded into trucks for transport and disposal in a landfill.

The combined ash will require regular sampling and testing to ensure it is below the EPA toxicity limits as determined by the Toxicity Characteristic Leaching Procedure (TCLP). More detailed discussion on ash sampling and testing will be provided in **Section 5 – Environmental Impacts**. Note that the RDF will contain heavy metals that were present in the MSW in trace parts per million levels. These heavy metals are not recovered in the RRP, which only recovers ferrous and non-ferrous metals for recycling.

3.3.9 Electric Energy Sales

The electric energy sales, for Option 2B, would be the same as Option 2A, but is repeated here for thoroughness.

Electricity generated by refurbished ST5 will be first used to power the existing plant parasitic loads and the new RRP. The remainder of the power will be delivered to the City grid via the existing high voltage electric infrastructure.

Electricity sales would continue as they are conducted today, however the supply of power from the PP to the City would be approximately 1/10th of the current electricity production. The reduced production of power is a result of elimination of the co-firing with natural gas. For the financial model, the difference between the electricity generated by co-firing natural gas in Option 1 and electricity generated in Option 2A would be purchased on the day-ahead MISO Zone 3 LMP price at the Ames interconnect node.

Units 7 and 8 would be maintained by the City as capacity resources, burning natural gas only. The generation would be bid into the Day Ahead (electric) Market (DAM) based on market Citygate gas prices in effect at the time. It is estimated that Units 7 and 8 would be selected to operate less than 5% of the time because of their efficiency and cost of natural gas fuel. The associated contracts for well head gas and firm transportation are expected to be cancelled since the capacity utilization would be very small (as gas would only be needed for startups and shutdowns in Units 9 and 10 and for very limited operation in Units 7 and 8). This low utilization would result in a very high average price for gas (see **Figure 11**). Citygate spot market gas purchases would be made as needed, for startup and shutdown of Units 9 and 10.

3.3.10 Process Flow and Mass and Heat Balance

Figure 19 shows the overall process diagram for Option 2B. The supporting mass and heat balance data is shown in ***Appendix F***.

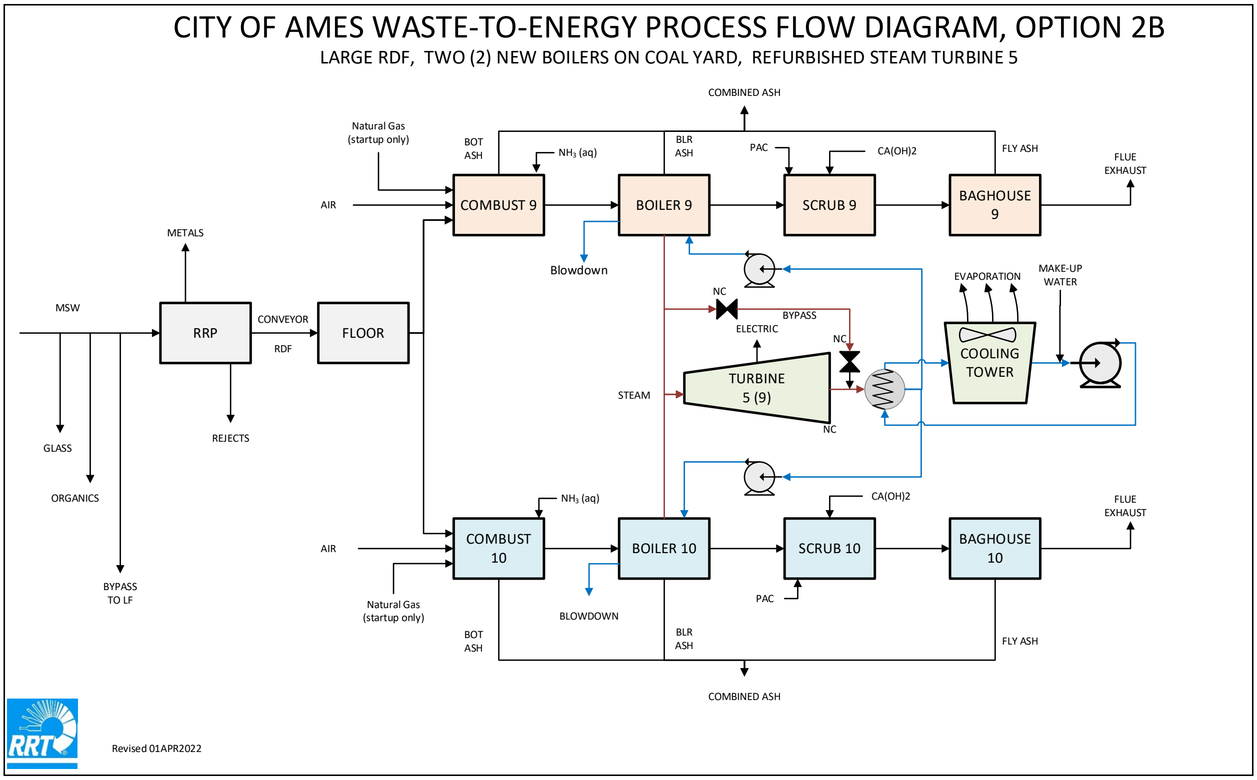

Figure 19: Option 2B Overall Process Diagram

3.3.11 Building/Facility Description and Considerations

For Option 2B the existing RRP would be modified to a single shred system and continue to provide metal removal. Processed (large) RDF will be conveyed via conveyor (see **Figure 20**) to a new RDF storage building located on the coal yard. The overall footprint of the RRP would not be expected to be modified for Option 2B. The conveying system would cross East 2nd Street at an elevation of approximately 14 ft. The new power plant would have a tipping floor capable of holding 4 days of storage.

A new power plant building would be adjacent to the RDF storage area and would contain loading conveyors, combustor/boilers, scrubbers and baghouses for each unit. Steam would be piped over to the steam turbine room in the existing plant on the north side of the railroad tracks. The new building would include walkways, parking, and utility interconnects (water, sewer, electric service etc.). A control room would include equipment enabling remote monitoring of the existing plant.

3.3.12 Preliminary Conceptual Facility Layout

Due to the larger size RDF, the existing boilers could not be used as backup, necessitating two new boilers. Two new appropriately-sized RDF-only boilers, together with their required emissions controls system (scrubber and baghouse) are assumed to be located in the coal yard site just north of the existing RRP. Note that the large RDF particles are too heavy to be pneumatically conveyed. A conveyor tube system would be used to move the RDF, from the existing RRP over 2nd Street to the new storage building. In the storage building front loaders would push the RDF into hoppers feeding inclined conveyors up to the boiler feed hopper. The steam turbine generator and electrical interconnecting infrastructure at the existing power plant can be utilized by piping the steam created by Units 9 and 10 to refurbished ST5 and pumping the condensate back to the new boilers. Units 7 and 8 remain as capacity units and would no longer consume

RDF. See **Figure 20**, below. This layout makes use of the existing RRP. A new RRP could also be placed adjacent to the PP for additional capital cost.

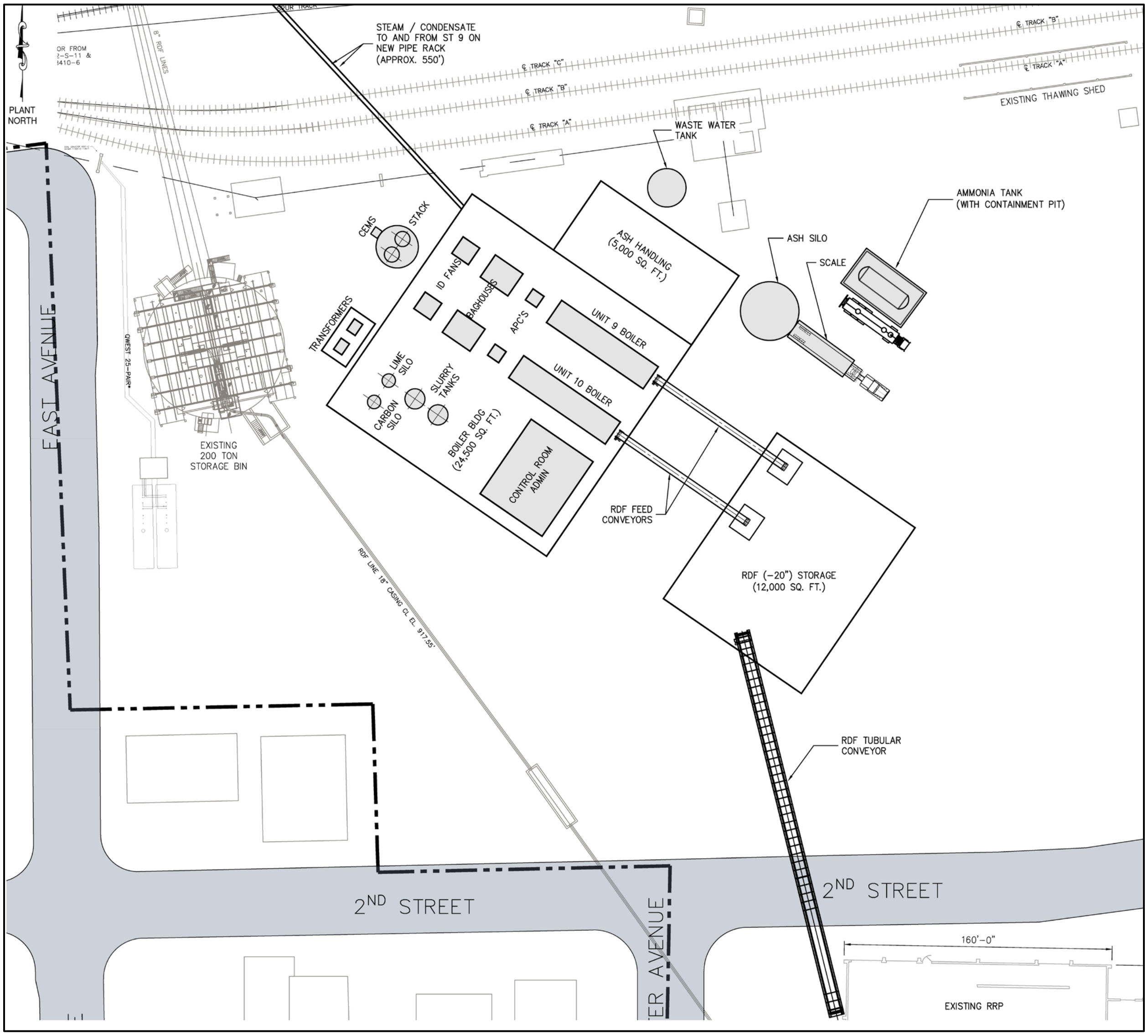

Figure 20: Option 2B Preliminary Conceptual Layout

3.4 Options 3A-1 & 3A-2 - New RRP and New RDF Combustion Unit(s)

Option 3A-1 – New RRP and New RDF Combustion Unit (Coal Yard)

The following items characterize the key elements of Option 3A-1 for a new S-O-A RRP and RDF boiler constructed at the coal yard location.

A new S-O-A RRP plant would be designed to provide improved sorting, extraction and processing to produce 4 inch minus RDF (same as is currently produced). Using newer, improved methods and technology based on the waste composition study last conducted by the City in 2016, the RRP processing rate would increase from a historic maximum of 65% to an approximately 81% recovery rate for RDF produced from the incoming waste stream. Major features would include the following:

- More front-end storage of MSW at the inlet to the new RRP receiving floor (for when RRP is out of service).

- One new, state-of-the-art RDF-only combustion boiler (Unit 9) would be installed in the coal yard. Natural gas will be used only for startup, shutdowns, and flame stability of Unit 9.

- As a backup, maintain and operate Unit 8 as currently designed (co-fired with natural gas) when Unit 9 is unavailable. While Unit 7 could also be used as a backup, Unit 7 is smaller than Unit 8 and therefore would not be able to handle as much RDF.

- A new RDF pneumatic conveyor transport system from the new S-O-A RRP to a new 200 tons storage bin at the coal yard. A new pneumatic conveyance would also be installed from the S-O-A RRP to the existing 200 ton storage bin. Once the new S-O-A RRP and conveyance systems are operational, the existing storage bins would be refurbished to enable a parallel system from the S-O-A RPP to Unit 9, providing a total of approximately 400 tons of total storage.

- Power would be generated from refurbished steam turbine 5 (ST5) and updated to utilize the steam from Unit 9. A new electronic control system, new steam condenser and an electric generator rewind are also assumed. An internal inspection would be conducted to confirm the feasibility and cost of the steam path refurbishment and generator rewind. A cost-benefit analysis would compare the expected performance and cost of the refurbishments vs. installing a new steam turbine and generator of comparable size. Power would be delivered to the grid via the existing electrical infrastructure.

- Steam turbines 7 and 8 will not be able to accept the new RDF boiler steam conditions and will remain as capacity only resources.

Option 3A-2 – New RRP and Two New RDF Combustion Units (Greenfield Site)

Option 3A-2 is assumed to be constructed on a new industrial site that is not near the existing facilities. The primary reason to construct a new remote RRP and PP facility would be the economics of selling steam to a thermal host versus exporting electricity. Major features would include:

- The new S-O-A RRP, RDF storage and PP would be located on a new industrial site, totally detached from Units 7 and 8. Therefore 3A-2 would require (a) two new equally sized RDF boilers, (b) a new building, (c) utility services (water, sewer, electric) and (d) all new auxiliary services.

- The new facility would sell steam to a neighboring industrial user continuously (24 hrs./day and 7 days/week).

- The boilers should be capable of consuming a minimum of ~85 TPD each for a combined capacity of 170 TPD. The 85 TPD boilers would provide a lower installed cost without resulting in undesirable part load operation (below 70%) during parallel operation over the project life. A storage size of 400 tons would provide approximately 13 days while one unit is operating before bypassing is required **(**see RDF/MSW Storage Analysis in ***Appendix B*****).** Alternatively, two 100% capacity boilers (145 TPD) could be installed to provide complete redundancy. The cost premium for the installation of the larger boilers would be partially offset by less storage. Sizing in between 85-145 TPD would result in years of undesirable part load operation during which the boilers would operate in parallel. The lower cost configuration is included in the financial model for the purposes of this evaluation.

- The pneumatic conveyor transport system would be all new from the S-O-A RPP to two new storage bins, and then also from the bins to the new PP**.**
- Units 7 and 8 would be maintained by the City as capacity resources when burning natural gas only.
- For Option 3A-2, a back pressure steam turbine would be utilized to generate some in-house power prior to delivering the steam to a steam host. The steam host is assumed to return 85% of the flow as condensate.

The new RRP's MSW processing equipment for options 3A-1 and 3A-2 will be installed in the new building. The design for both options will include a tipping floor which can accommodate approximately 400 tons of MSW in case of downtime. Three to four days of storage is an industry standard for MSW facilities. Storing MSW for longer periods could cause issues with potential generation of methane gas, spontaneous combustion through the reactions of various chemical compounds in waste, and bacteria and other sanitary hazards from the decomposition of waste. Moreover, the City's experience in the existing RRP plant and RRT's understanding of issues in other facilities show that spontaneous combustion can occur in piled MSW due to batteries and other ignition sources and therefore, proper fire detection and suppression systems would be in place.

3.4.1 New State-of-the-Art Resource Recovery Plant

The new S-O-A RRP will be designed to process an average of 25 TPH. The system will be able to recover approximately 81% of RDF while recovering ferrous and non-ferrous metals and separating the rejects. A Process Flow Diagram (PFD) for the State-of-the-Art RRP is depicted in **Figure 21**.

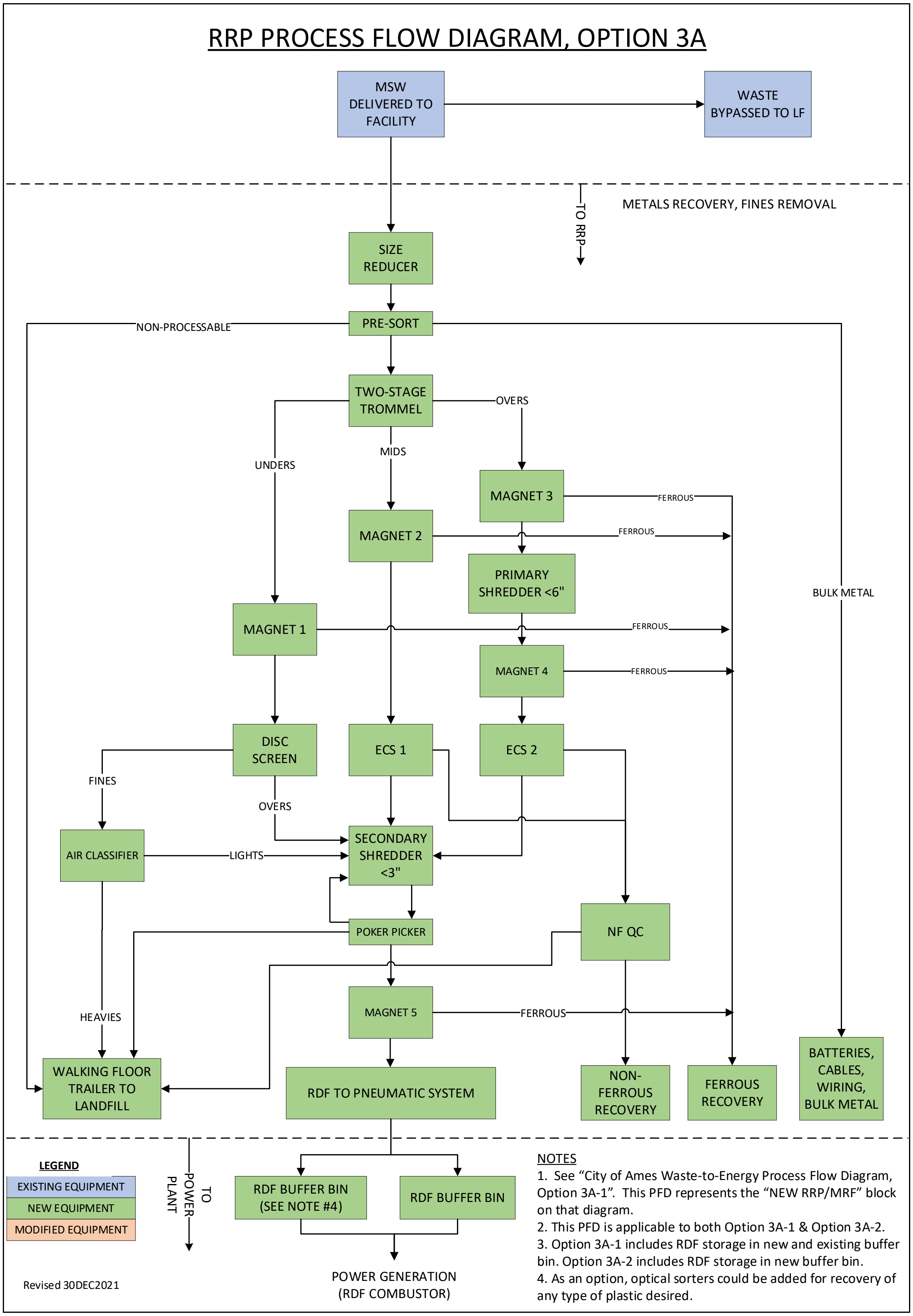

Figure 21: Process Flow Diagram for State-of-the-Art RRP

The incoming MSW is sorted on the tipping floor to remove large un-processible and bulky items, such as mattresses, propane tanks, etc. Materials unloaded on the floor will be visually inspected and moved with a front-end loader toward the infeed conveyor area for processing or to the bypass area for land filling if the material contains non-processible materials.

The MSW suitable for processing is loaded by the loader into the elevated hopper of an infeed conveyor. This process requires the operator to fill the infeed hopper to an even level along its length to keep the system running at a uniform rate. The infeed conveyor is equipped with a variable frequency drive (VFD) to regulate the conveyor speed and maintain constant and even flow of material onto the size reducer. The role of the size reducer is to liberate the material, reduce it to a particle size of 8" minus, and protect the downstream equipment from large bulky objects.

The reduced size material will be conveyed to a pre-sort station where sorters will remove bulk metals such as cables, wiring, pots and pans, batteries, small appliances and pipes and drop them through a set of chutes. Another set of drop chutes will be designated for removal of non-processible materials that were missed during the feeding process, such as carpets, textiles, wood, etc. These items must be removed to prevent system jams and potential damage to downstream process equipment. These non-processible bulky objects picked off the pre-sort conveyor will be deposited into bunkers beneath the pre-sort platform. From the bunkers materials are loaded into trailers and shipped offsite for landfilling.

The MSW after having been sorted to remove the various undesirable materials will continue to the rotary trommel for mechanical separation into three different fractions by size. The trommel is a rotary screen containing heavy duty screens with two screening sections and different opening sizes. Although not necessary, the trommel can include sharp metal spikes mounted within the first part of the trommel to open bags and liberate materials for more efficient separation.

The first section of the trommel will remove the "fines" fraction consisting of organics, broken glass, small paper items, food waste, stones, paper clips, bolts, inert material and other items that can pass through the holes. The actual screen openings size will be designed during engineering phase, however 2 ½" diameter holes were considered in the RRT mass balance. This material will drop onto a conveyor under the trommel, and a magnet will remove ferrous metals from this stream prior to being transferred to a disc screen. The disc screen removes the minus 1" material from this fraction. This material along with the other fines from the plant will be shipped to landfill via walking floor trailers. The plus 1" material going over the disc screen drops into the secondary shredder.

The actual screen openings size will be designed during engineering phase; however, for the mass balance the second section of the trommel was assumed to have 7" holes to create a plus 2 ½" to minus 7" fraction also called "middlings". A suspended magnet located over the head pulley of conveyor transferring middlings will remove ferrous metal containers from the feed stream.

The middlings will continue onto an ECS feeder which feeds an eddy current separator (ECS). The eddy current separator removes aluminum beverage cans (UBC) and other non-ferrous material from this feed and discharges it to a conveyor with a sorting area to QC the non-ferrous stream and remove any contaminants and other non-ferrous. The middlings material remaining after non-ferrous removal drops into the secondary shredder.

The plus 7" fraction, also called "overs", coming out of the trommel is dropped on a suspended electro-magnet to remove any ferrous materials from the feed. The remaining material drops into the primary shredder which reduces the size of the material to minus 6". From the primary shredder, the material is transported via a series of conveyors and will undergo further ferrous removal by a suspended head pulley magnet and non-ferrous removal by a second dedicated ECS. Ferrous metals collected from the four magnets in the plant will be combined and transferred to a ferrous bunker. Non-ferrous metals from the two eddy current separators will combine into a non-ferrous QC manual sorting line before being transferred to the non-ferrous bunker.

The remaining overs fraction will be dropped into the secondary shredder along with the remaining middlings fraction and the overs from the disc screen. The secondary shredder will reduce the particle size to minus 4” and generate the final RDF. An automatic poker picker will remove any pokers or long materials which were missed in the upstream processing. The RDF will be transferred to the RDF buffer bin using a pneumatic system via underground lines.

The S-O-A RRP overall metal recovery is approximately 7%, an increase of nearly double compared to Option 1 (the existing RRP). As an option, if the recycled plastics markets increase in value in the future, optical sorters could be added for recovery of high value plastics by specific type.

The RRP equipment can be supplied by a variety of manufacturers, with careful consideration to design features for this type of application and systems integration.

Shredders are one of the most important pieces of equipment in the new design. They are also operationally and maintenance-wise the most intensive pieces of equipment. RRT had favorable experience with manufacturers who offer reliable and robust equipment such as SSI, Lindner, Komptech, Metso USA, Vecoplan and other quality equipment providers.

Figure 22 depicts a Metso pre-shredder and **Figure 23** depicts an SSI Pri-Max shredder. A typical shredder includes rotating knives, chassis support, and the power pack. The rotating knives are usually provided with two forward and two backward cutting tips. Between each set of counter knives, a free opening in the cutting table will ensure that sand, soil, gravel, and small metal fragments fall straight through without causing wear in the cutting area. The achieved size will depend on the number of knives and the type of waste.

Figure 22: Metso USA M&J Pre-Shred 2000S

Figure 23: SSI Pri-MAX Shredder

Most shredders are equipped with electronic surveillance with alarms for shaft, conveyor, hydraulic oil (pressure, temperature, and level), oil cooler and central lubrication. In case of overload, the shafts will rotate in the opposite direction, redistribute the material, and continue the shredding. In order to protect the system against the effects of un-processible materials, the shafts will stop automatically after changing rotation 5 times, giving an alarm signal for the operator.

The primary shredder will include (2) independently operating, bi-rotational shafts to minimize bridging, jamming and wrapping. The shaft speed control is configurable through touch-screen control panel and automatic lubrication system for main shaft bearings are standard features in the industry.

The ferrous metals recovery is achieved with magnetic separators from Eriez, Steinert or equivalent and include a suspended permanent magnet, with a magnetic circuit, magnetic protection, and a self-cleaning system. Deflector plates extend past the head pulleys to help minimize ferrous material from becoming stuck to the magnet box are added features to be considered.

Non-ferrous metals could be recovered using eddy current separators from manufacturers such as Steinert, Eriez, IMRO or equivalent. A non-ferrous metal separator consists of a short conveyor driven from the feed end and a rapidly rotating system of permanent magnets (the pole system) which generates high-frequency changing magnetic fields in the head drum. These fields create strong eddy currents in the non-ferrous metal parts causing the non-ferrous metals to jump out of the remaining material flow. One of the technologies from Steinert includes a magnetic pole system arranged eccentrically in the head pulley of non-ferrous metal separators to better concentrate the effect of the magnetic alternating fields in the area at which the material is experiencing the greatest force impact, located at the discharge point from the conveyor belt. The pole system is adjustable enabling a position to be optimally configured to the material feed.

A two-stage rotary trommel screen is included in the design for the purpose of separating out the fines and middlings material from the MSW waste stream. The recommended screen hole size will be designed during the engineering phase and will be based on overall MRF design and performance requirements. The screen sizes described in this option are based on RRT`s experience. The screen sections of the trommel are made up of individual, replaceable screen panels. The trommel is supported at the inlet and outlet ends by fabricated steel base, with no other supports in-between. The rotary trommel is equipped with an inlet chute, discharge hoppers and dust hoods/cover over the trommel.

The new RRP building will include a dust collection and filtration system, consisting of pick-up hoods throughout the plant, a baghouse for air filtration with airlock and dust removal system, fans, interconnecting ductwork as well as controls, fire explosion valves and fire protection safety features.

The new RRP system will be provided with safety control systems, E-stops, fire protection system as well as modern process monitoring and controls integrated in a SCADA system.

3.4.2 RDF Transport and Storage

For Option 3A-1, the RDF processed by the S-O-A RRP will be stored in two parallel storage systems, the existing RDF bin and a new one installed in parallel, with a total nominal capacity of 400 tons. The new 200-ton storage bin will be fed in parallel from the S-O-A RRP through its own pneumatic conveyance system along with a pneumatic feed system to move RDF to either Unit 8 or 9. The existing storage system would be modified to pneumatically receive RDF from the new S-O-A RRP and new conveyance line(s) to supply RDF to Unit 9 in addition to Unit 8. The 400 tons will initially accommodate a partial power plant outage of Unit 9 for 14 days, however, should the projected MSW growth materialize, that amount of storage will only support approximately 7 days of downtime for Unit 9 (operation on Unit 8).

For Option 3A-2, two new, parallel, 200-ton capacity bins would be provided with parallel supply and feed systems to Units 9 and 10. Refer to ***Appendix B*** for a more detailed RDF/MSW Storage Analysis.

For both options 3A-1 and 3A-2, the new storage systems will include infeed, storage and discharge components similar to what is use today in Option 1. This includes an automatic infeed conveyor system, roof covered dual bunkers for RDF storage, distributing and stacking RDF equipment and enclosed automatic discharge conveyors for reclaiming and metering the material while providing a constant volumetric feed to the Power Plant. The system will require new controls, interlocks, and programming to be operated in conjunction with the combustion system. The new storage system will include its own dedicated automatic conveyor transport lines, one from the RRP to storage and one from storage to the power plant. For Option 3A-1, if both the new and existing RDF storage systems are down (unlikely) for repairs or maintenance, the existing RRP building could be used to provide additional storage by making the existing 14” line bi-directional for the purpose of pneumatically conveying the RDF to and from the existing bin from/to the existing RRP (bypass option). For the purpose of the financial model and comparing options 3A-1 and 3A-2 on the same basis, the storage system was assumed to be the same in both options and the bypass option was not included.

The upgrades to the existing bin can occur once the new bin is built and commissioned allowing for the RRP operations to continue without the need to divert MSW. The upgrades will include new stainless-steel walls and a roof. Of the total four existing pneumatic lines to the boiler, only two are currently being used to convey RDF from the existing bin to the PP. As part of 3A-1 upgrades, RRT recommends restoring one of the existing unused lines to improve fuel delivery reliability and redundancy to Unit 8.

As mentioned in Option 2A, there are several issues with RDF type of material, which need to be considered when designing a new transport and storage system. The RDF is not free flowing and needs to be reclaimed from storage by using an auger or a drag chain type of system. These systems are often referred to as live bottom storage bins. Augers can have geometry issues with maximum lengths or compacting against the bin wall and wrapping. Drag chains come with other drawbacks, such as being easier to break or stretch and sometimes their flights get twisted. The cost for these different types of reclaiming systems, however, is comparable to each other.

Given RDF is highly compressible and will easily compact by its weight, a cone bottom bin is not a recommended solution, and neither are cylindrical or sphere-shaped bins as commonly seen for storing biomass or grains. The best arrangement is a rectangular base bin with trapezoidal walls or roof covered storage bunkers with bottom discharge conveyors. In addition, the RDF retains moisture and can form clumps in freezing temperatures therefore insulating the storage systems should be strongly considered to minimize these issues.

For the purposes of the financial model, an enclosed transfer conveyor system was considered for feeding the RDF to and from the new storage system for both Option 3A-1 and 3A-2. Due to the final location and site layout for Option 3A-2 not yet being selected, RRT estimated in the financial model that the S-O-A RRP, new storage bins and PP will be in relatively close proximity to each other, and steam and condensate piped 100 ft to a steam host. However, if the bins and PP cannot be adjacent to each other we are estimating an incremental cost of $5.1M in capital cost for additional conveyance for each 1000 ft of distance between them.

3.4.3 RDF Combustion System

The RDF produced by a new RRP will be similar to the RDF currently produced by the City of Ames' existing RRP system. For this reason, the RDF Combustion Systems that would be used to process the RDF in Option 3A will be the same as Option 2A.

As with Option 2A, the bubbling fluidized bed combustion system would be the preferred technology for processing the 4" minus RDF in Option 3A. As discussed in Option 2A, a leading supplier of bubbling fluidized bed combustion systems is Metso:Outotec. The Metso:Outotec combustion system was described in ***Section 3.2.4***, with further details provided in ***Appendix G***.

Metso:Outotec has commercial experience processing RDF in their bubbling fluidized bed combustion systems, including French Island and the City of Tacoma in the U.S., three Italian facilities in Ravenna, Bergamo, and Massafra, and several new facilities in the UK.

3.4.4 Boiler Design

Similar to Option 2A, the boiler design for a bubbling fluidized bed combustion system would have separate modules for the convection and economizer sections. This boiler design is described in Option 2A and more details are also provided in ***Appendix H***.

As with the previous options, the detailed design of the boiler will consider the high fouling due to ash and corrosion driven by the high chorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Protective alloys will also be used in select areas to prevent high corrosion rates.

3.4.5 Balance of Power Plant Equipment

For option 3A-1, the Power plant BOP equipment would be similar to option 2B.

The following is a list of power plant BOP equipment anticipated for one new combustor, Unit 9:

- New boiler feed pumps, condensate pumps and cooling water pumps
- Modification and/or refurbishment of the existing ST5, and associated steam turbine condenser for re-use

- New steam, condensate, cooling water and makeup water piping
- New stack, CEMS and COMS systems
- New generator step-up (GSU) transformer and associated high voltage electrical support and interconnect equipment
- New step-down transformer and power distribution system
- For Option 3A-1, the plant would be connected to the existing cooling tower serving Unit 7 which can be upgraded to handle both Unit 7 and refurbished ST5 heat rejection at a fraction of the cost of a new cooling tower
- For Option 3A-2, a back pressure steam turbine would be utilized to generate some in-house power prior to delivering the steam to a steam host. The steam host is assumed to return 85% of the flow as condensate.
- New instrumentation and controls
- New foundations
- Platforms, ladders, stairs, and railings to enable maintenance and operation

3.4.6 Emission Control

As with Options 2A, the Best Available Control Technology (BACT) for a bubbling fluidized bed combustion system for RDF would be the combination of a dry scrubber and baghouse that treats the flue gas exiting the boiler. This system is proven to meet the EPA limits on particulates, SO_2, HCl, mercury, trace metals and dioxins. The scrubber / baghouse is typically augmented with the injection of powder activated carbon (PAC) into the flue gas at the entrance of the scrubber for additional control of both mercury and dioxins. CO and NOx are combustion-related emissions that are controlled by combustion control methods. Additional NOx control is typically achieved by Selective Non-Catalytic Reduction (SNCR) which injects aqueous ammonia or urea into the upper furnace of the combustor. The scrubber/baghouse, PAC injection and SNCR systems are described in more detail in ***Appendix I***.

3.4.7 Ash Handling/Disposal

Similar to Option 2A, fly ash collected from the baghouse and boiler will be conveyed via screw conveyors to a fly ash storage silo. The fly ash will then be conditioned with water to control dusting before being combined with the bottom ash exiting the combustor. This combining of the fly ash and bottom ash typically occurs on a pan or belt conveyor to form the combined ash that is then conveyed to an ash storage area. The combined ash will then be loaded into trucks for transport and disposal in a landfill.

The combined ash will contain heavy metals of environmental concern, requiring regular sampling and testing to ensure it is below the EPA toxicity limits as determined by the Toxicity Characteristic Leaching Procedure (TCLP). A more detailed discussion on ash sampling and testing is provided in ***Section 5 Environmental Impacts***. Note that the RDF will contain heavy metals that were present in the MSW in trace parts per million levels. These heavy metals are not recovered in the RRP, which only recovers ferrous and non-ferrous metals for recycling.

There would be no difference in the ash handling between Options 3A-1 and 3A-2 except there would be duplicate systems for each new boiler in Option 3A-2.

3.4.8 Electric (Option 3A-1) or Thermal (Option 3A- 2) Energy Sales

For Option 3A-1 electricity sales would continue as they are conducted today, however the supply of power from the PP to the City would be approximately 1/10th of the current electricity export. The reduced power is a result of eliminating the co-firing with natural gas in the new primary Unit 9. For the financial model, the difference between the electricity generated by co-firing natural gas in Option 1 and electricity generated in Option 3A would be purchased on the day ahead MISO Zone 3 wholesale market price. (i.e., the Location Marginal Price, LMP) for the Ames interconnect node. In 2020, the on-peak and off-peak average LMP for Ames was $30/MWh and $17/MWh respectively. This is significantly less than the power plant's current costs of $57.5/MWh to make electricity with natural gas at $5.00/dth. (See Option 2A math). Therefore, significant power supply costs savings are provided when natural gas consumption is eliminated.

In Option 3A-1, the financial model includes the cost of natural gas for co-firing in Unit 8 when it is operated as the backup boiler. Since Unit 8 is assumed to operate no more than 10% of the year as the backup boiler, maintaining the current gas transportation contract arrangements for Option 2A are uneconomical since the fixed cost of gas transportation would have to be absorbed over very few hours of gas utilization. At a 10% utilization factor, the average delivered gas price would climb from $5.00/dth (the Option 1 average price used in the model) to over $15/dth gas (refer back to **Figure 11**). For Option 3A, and other non-base case options, an assumed Citygate premium of $1.00/dth over the $5.00/dth for purchasing the gas as-needed from the local gas distribution utility. The Citygate gas premium was arrived at in consultation with the City of Ames Electric Department and is adjustable in the model.

Under Option 3A-1, Units 7 and 8 would be maintained by the City as capacity resources for the MISO when burning natural gas only. They would be bid into the Day Ahead (electric) Market (DAM) based on Citygate gas prices in effect at the time. It is estimated that Units 7 and 8 would be selected to operate less than 5% of the time. Gas purchases for Units 7 and 8 as capacity resources are excluded from the Waste-to-Energy economics as there would be no more co-firing with RDF in these boilers.

For Option 3A-2 there would be no electric sales, but rather steam would be sold to an industrial customer (host). Gas for startup, shutdown, and flame stabilization is included in the model for Units 9 and 10. All power generated by the back pressure turbine would be utilized by the MSW plant and PP. Should the host have a temporary interruption, a steam "dump" condenser would be provided with cooling tower to enable the continued operation of the RRP and power plant. Should the steam host's ability to take all of the steam all of the time be inconsistent, a condensing steam turbine with 150 psig extraction could be substituted for the back pressure steam turbine to add flexibility to generate power and/or steam. However, less steam can be sold with an extraction/condensing steam turbine since some minimal amount of steam (approximately 5-10%) must always be condensed, reducing the maximum steam sales possible. The need for this alternative equipment would be vetted with the contract negotiations with the host, including contract risk, guarantees, cost sharing etc. Additional infrastructure would also be required to export the electricity should the steam host default in the future. For the model and cost estimate, RRT assumed a back pressure steam turbine exhausting at 150 psig/535F steam conditions with all exhaust steam provided to the steam host. The steam is assumed priced at 80% of the $/MMBtu of natural gas as a proxy for the host's avoided production cost to produce the same steam from natural gas. A standby "dump condenser" and cooling tower is also assumed for times when the steam host's process is off-line and they cannot accept the steam.

3.4.9 Process Flow and Mass and Heat Balance

Figure 24 and **Figure 25** are the overall process flow diagrams for Option 3A-1 and 3A-2 respectively. Supporting mass and heat balance data is shown in ***Appendix F***.

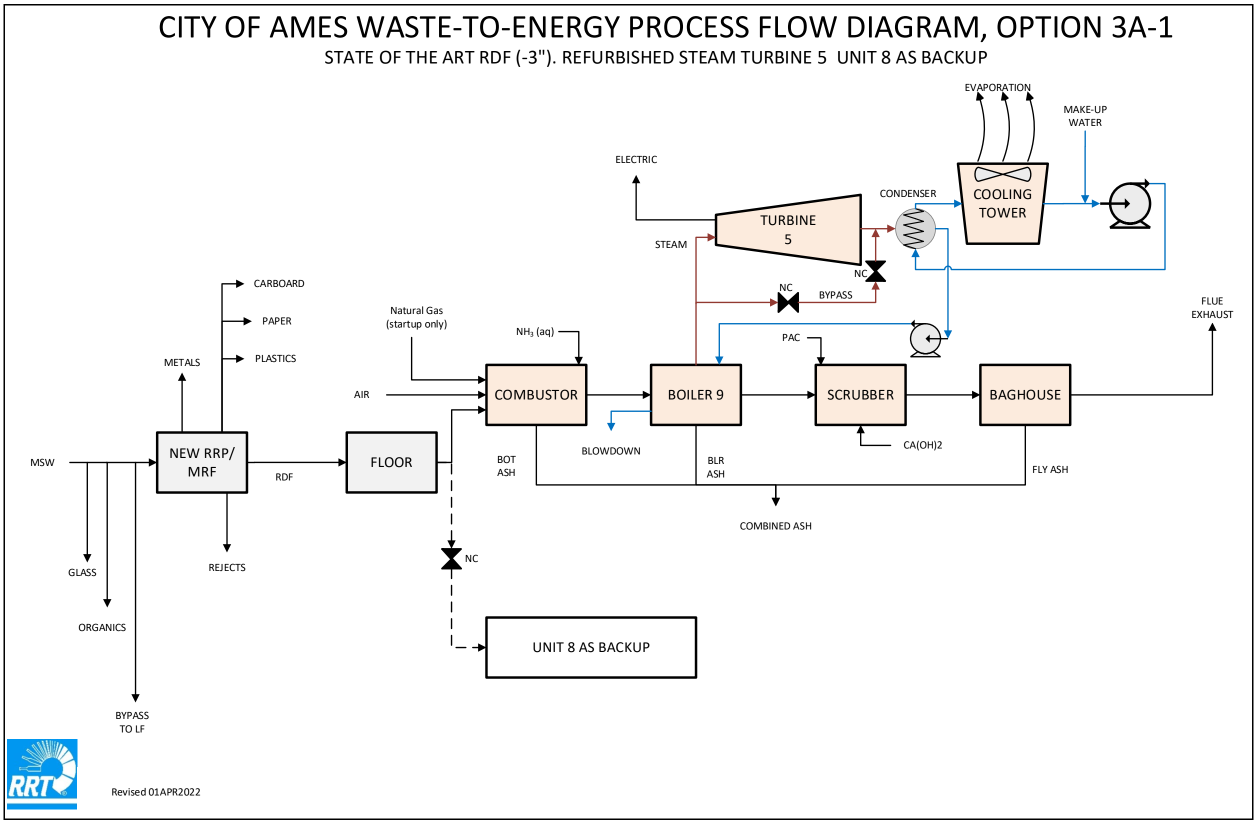

Figure 24: Option 3A-1 Overall Process Flow Diagram

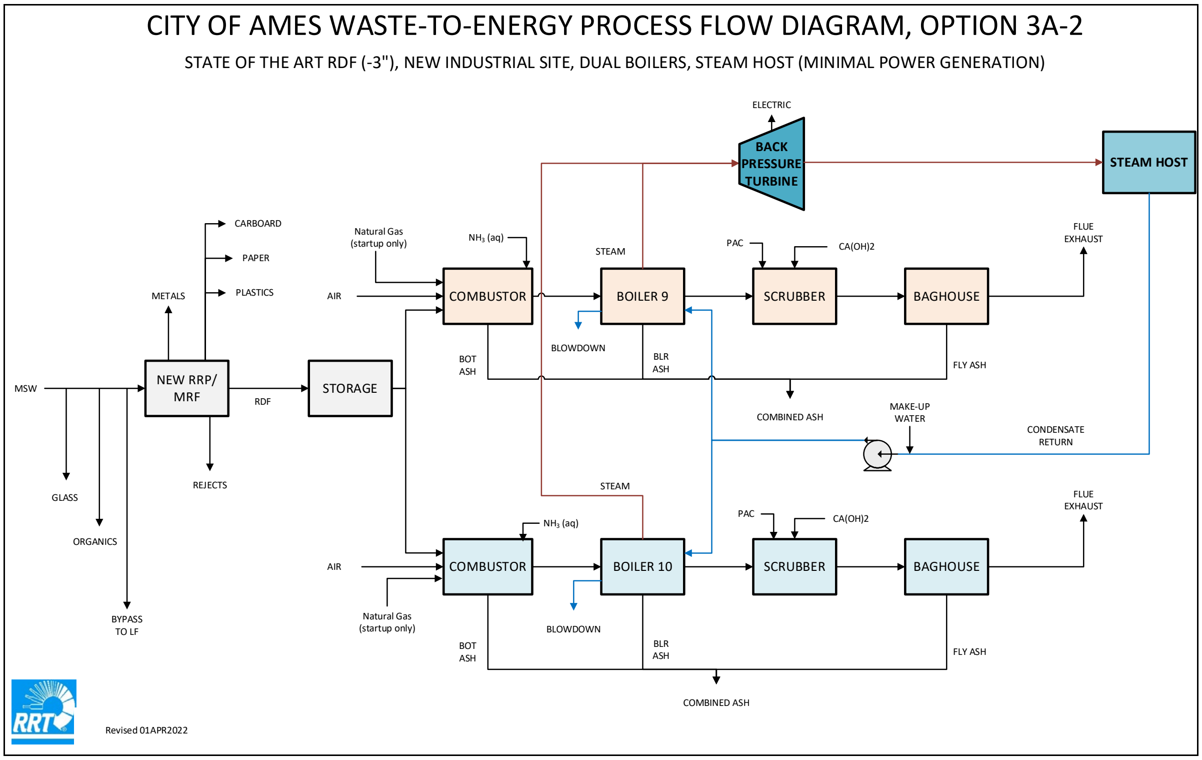

Figure 25: Option 3A-2 Overall Process Flow Diagram

3.4.10 Building/Facility Description and Considerations

For Option 3A-1 a new S-O-A RRP would be constructed in the coal yard in a new building. The existing RRP would remain operational and functional until the S-O-A RRP and associated new conveyance systems are commissioned. New parallel conveyance systems would be installed to send RDF to a new storage system (located at the coal yard) and to the existing storage bins. RDF from either storage system would be delivered to Unit 9 to be constructed at the coal yard. Once the new S-O-A RRP, a new storage system and associated conveyance systems are commissioned, the existing storage bin will be refurbished. The existing bin will be renovated to accommodate pneumatic conveyance from the S-O-A RRP. The old RRP could then be de-commissioned and re-purposed for a customer convenience center, additional recycling/recovery activities (e.g., organics), serve as supplement (bypass) storage by making the existing conveyance system bidirectional or some other beneficial use for the City.

3.4.11 Preliminary Conceptual Facility Layouts

The power plant layout for Option 3A-1 is shown below in **Figure 26 on page 66**. It includes a new dedicated RDF-only combustion-boiler, scrubber and baghouse in a stand-alone building located at the existing coal yard. The City is planning to remediate the coal yard and remove two underground oil storage tanks that are no longer used. New pneumatic conveyance lines would be installed to move the RDF from the new RRP to both storage bins, and then to the new boiler plant. The RRP will include additional storage which is shown in the preliminary conceptual layout. Parallel conveyance feeds system will be installed to provide flexibility and redundancy. The new facility will be equipped with additional equipment such as an ash silo, administrative area, control room, educational space, and a potential sustainability campus with drop-off areas for food waste, metal, glass and other desired diversion materials. The conveyance lines from the existing bin to the existing power plant would remain to enable operating Unit 8 (and possibly Unit 7) as a backup, as it is currently utilized. Steam produced would be piped over to the existing power plant on a new pipe rack. Condensate would be returned on the same rack. Other utilities such as communications, auxiliary power, fire and potable water, demineralized water and natural gas would also be included to take advantage of the close proximity of the existing power plant and available auxiliary services that would also be needed for the new steam turbine. ST5 will be refurbished with a new steam path and valves, pending an equipment internal inspection to confirm the current condition, and the generator will be rewound. It was confirmed with the supplier of the Unit 7 cooling tower that it can be upgraded to reject the heat of condensation from the steam from the refurbished steam turbine (ST5).

For Option 3A-2, which is based on thermal sales to an industrial, a new RRP, two parallel 200-ton (each) RDF storage systems, two boilers, pollution control equipment, back pressure steam turbine, associated support equipment and the building to house everything that is required at a new greenfield site. For Option 3A-2 there would be no electric sales. Should the host have a temporary interruption, a steam “dump” condenser would be provided with cooling tower to enable the continued operation of the RRP and power plant. Should the steam host’s ability to continuously take all the steam be a concern a condensing steam turbine with 150 psig extraction could be substituted for the back pressure steam turbine to add flexibility to generate power and/or steam. However, less steam can be sold with an extraction/condensing steam turbine since some minimal amount of steam (approximately 5-10%) must always be condensed, reducing the maximum steam sales possible. The need for this alternative equipment would be vetted with the contract negotiations with the host, including contract risk, guarantees, cost sharing, etc.

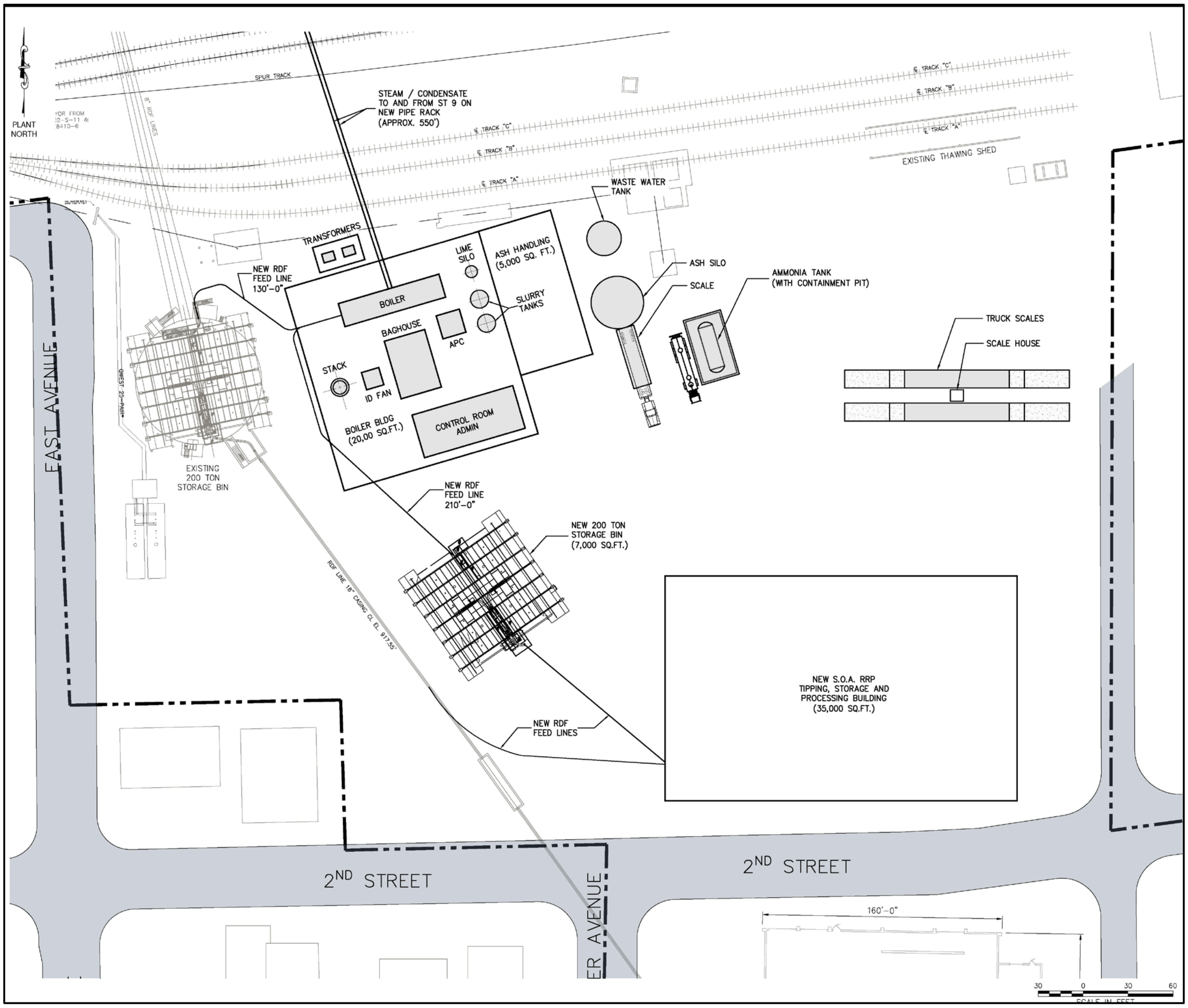

Figure 26: Option 3A-1 Preliminary Conceptual Layout of New SOA RRP and RDF Storage

The power plant layout for Option 3A-2 is shown below in **Figure 27**.

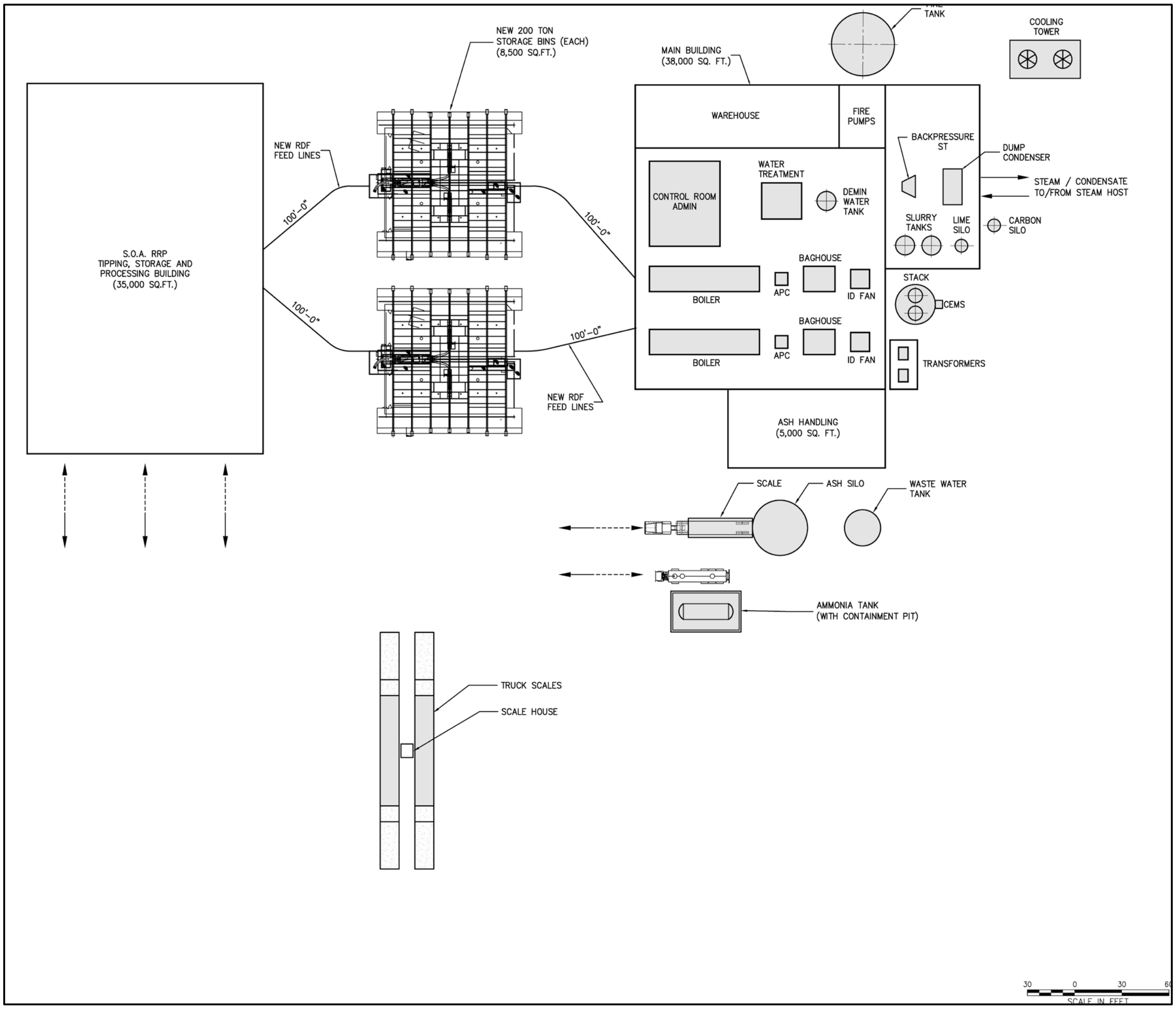

Figure 27: Option 3A-2 Preliminary Conceptual Layout for Industrial Site

3.5 Options 3B-1 & 3B-2 – Two New MSW Mass Burn Combustion Units

The following items characterize the key elements of Option 3B

- The facility includes front-end storage of approximately 4 days of MSW at the mass burn facility receiving floor (extra room required for manipulation of MSW). Two new MSW boilers designed to operate in parallel to consume the MSW. The boilers would each have a scrubber and baghouse for emissions controls.

- Units 7 and 8 would be maintained by the City as capacity resources for the MISO when burning natural gas only. They would not interface with Units 9 and 10.

- New Balance of Plant (BOP) equipment and systems would be installed to support the installation and operation of Units 9 and 10.

Option 3B-1 (Coal Yard)

- The boilers, scrubbers, and baghouse would be located at the coal yard, under the same roof as the MSW tipping floor. The ash handling and metal recovery system will be at the same location in an adjacent building/structure.

- Power would be generated from refurbished steam turbine 5 (ST5) and updated to utilize the steam from Units 9 and 10. A new electronic control system, new steam condenser and an electric generator rewind are also assumed. An internal inspection would be conducted to confirm the feasibility and cost of the steam path refurbishment and generator rewind. A cost-benefit analysis would compare the expected performance and cost of the refurbishments vs. installing a new steam turbine and generator of comparable size. Power would be delivered to the grid via the existing electrical infrastructure. Steam turbines 7 and 8 will not be able to accept the new MSW boiler steam conditions.

- Similar to Option 2B, steam would be piped to refurbished ST5 located at the existing steam plant and condensate will be returned to the new boilers at the coal yard

Option 3B-2 (Greenfield Site)

- A new dedicated facility that includes two combustors capable of burning unprocessed MSW, tipping floor storage, emissions equipment and steam turbine generator would be located on a new industrial site and thus totally detached from the existing power plant. The ash handling and metal recovery system will be at the same location in an adjacent building/structure. Therefore 3B-2 would require (a) two (2) new MSW boilers, (b) a new building, c) utility services (water, sewer, electric) and (d) all new auxiliary services. The boilers should be capable of consuming a minimum of ~100 TPD for a combined capacity of 200 TPD. The 100 TPD boilers would provide the lower installed cost without resulting in undesirable part load operation (below 70%) during parallel operation over the life of the model. This sizing would require 300 tons of storage to provide up to ~3 days of no combustion (includes buffer handling space) before bypassing is required (see the RDF/MSW Storage Analysis in ***Appendix B***). Alternatively, two 100% capacity boilers (178 TPD) could be installed to provide complete redundancy. The cost premium for the installation of the larger boilers would be minimally offset by reduced storage. Boiler sizing in between 100-178 TPD would result in years of undesirable part load operation during which the boilers would operate in parallel. Therefore, the lower cost configuration is included in the financial model for the purposes of this evaluation.

- The new facility would sell steam to a neighboring industrial user continuously (24 hrs./day and 7 days/week).

3.5.1 MSW Storage

The MSW receiving and storage for Options 3B-1 and 3B-2 will be on a new tipping floor with approximately 400 tons of MSW capacity in the same building as the new power plant. The front-end MSW storage will provide approximately 4 days of storage throughout the evaluation period (see Appendix B) to accommodate downtimes and maintenance issues during single combustor operation. Three to four days of storage is an industry standard for mass burn facilities. Storing MSW for longer periods could cause issues with potential generation of methane gas, spontaneous combustion through the reactions of various chemical compounds in waste, and bacteria and other sanitary hazards from the decomposition of waste. Moreover, the City's experience in the existing RRP plant and RRT's understanding of issues in other facilities show that spontaneous combustion can occur in piled MSW due to batteries and other ignition sources and therefore proper fire detection and suppression systems will be required.

3.5.2 MSW Pre-Processing System

An MSW pre-processing system is not being considered as part of Options 3B-1 and 3B-2. In both these options, the MSW will be received on a new tipping floor, located inside the power plant building. From the tipping floor, a front-end loader would push the MSW pile to the storage bunkers or to the boiler feeding system. In RRT's experience, a pit and crane would be more expensive, especially in light of the low throughput of the system compared to the industry. The site and soil conditions would also have a significant impact on final cost. A more detailed analysis investigating a tipping floor versus a pit design could be conducted once a site location and final option is selected.

The boiler feeding system will consist of an inclined belt conveyor with a drum feeder that will feed and meter the material into the boiler infeed hopper.

Metals will be recovered post-combustion using an ash handling and metal recovery system, as described in ***Section 3.5.7***.

Although the combustion technology used in Option 3B does not require pre-sorting of incoming MSW, RRT recommends considering a pre-processing system as an overlay option for long term financial and environmental benefits. Based on RRT`s experience, the addition of MSW pre-sorting in front of mass burn combustion could decrease the air emission concentrations and even moisture content at the stack due to the removal of fines, organics, batteries, and other electronic waste. The MSW pre-sorting system would also increase the calorific value of the material combusted by the removal of non-combustible matter. Lastly, the removal of fines and bulky items upstream is expected to reduce the wear and downtime of equipment, increase overall availability, and reduce the rate of slag buildup on the combustor walls.

RRT conducted a study analyzing the impact of MSW pre-sorting prior to combustion (results were presented at NAWTEC Conference in 2016 and published in Renewable Energy from Waste Magazine July – August 2016, Page 26 – 29 by N. Egosi, S. Ciuta, D. Huang, titled The Upsides of Front-End Processing) at one facility in Minnesota. The results showed that the average heating value of the MSW after pre-sorting increased by over 20%. Moreover, most air pollutants concentration reduced by more than 50%. Most significant were reductions in mercury, cadmium, lead, particulate matter, dioxins and HCl. Due to these reasons, the facility noticed reduced usage of chemicals, activated carbon and hydrated lime for the APC systems. Front-end metal recovery exhibits much higher metal recovery rates than metal recovery from bottom ash.

If the City decides to go with front end metal recovery in lieu of post combustion metal recovery (utilized in this study) the front end would consist of all new equipment installed in a new building connected to the combustion equipment building. The pre-sorting system would remove fines and rejects and recover ferrous and non-ferrous metals through a combination of trommel screening, magnets, ECS, disc screening and air classifier. The estimated capital cost for a system this size would be in the range of $19M - $20M and would include all the equipment, building requirements, as well as 3 days of MSW storage on the front-end and 4 days of pre-processed MSW on the back-end prior to feeding the boiler.

RDF/MSW Transport and Storage

Option 3B is unique in that it does not include MSW pre-sorting and does not generate RDF, therefore storage provisions on post-processing are not applicable.

3.5.3 MSW Combustion System

Similar to Option 2B, a mass-burn combustion system designed for unprocessed MSW would be used to combust the MSW in Option 3B. Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. These systems are offered by a number of proven suppliers including Martin, Hitachi Zosen INOVA, Detroit Stoker, B&W Volund, Keppel Seghers and Ruths. All of these suppliers offer inclined, reciprocating grate systems and although the equipment is somewhat different between the suppliers, the processes are essentially the same for the combustion of unprocessed MSW or large RDF. These systems were briefly described in ***Section 3.3.4*** and thoroughly discussed in ***Appendix G***.

3.5.4 Boiler Design

As with Option 2B, the recommended boiler for smaller mass-burn units would employ a modular design approach to maximize shop fabrication and reduce field construction cost and time. This type of boiler was previously described in Option 2B, with more details provided in ***Appendix H***.

As with the previous options, the detailed design of the boiler will consider the high fouling due to ash and corrosion driven by the high chlorine content of the material. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Protective alloys will also be used in select areas to prevent high corrosion rates.

3.5.5 Balance of Power Plant Equipment

For option 3B-1, the Power plant BOP equipment would be the same as in option 2B but is repeated here for thoroughness.

The following is a list of balance of power plant (BOP) equipment anticipated for two mass burn combustors, Unit 9 and 10:

- New boiler feed pumps, condensate pumps and cooling water pumps
- Modification and/or refurbishment of the existing ST5, and associated steam turbine condenser for re-use
- New steam, condensate, cooling water and makeup water piping
- New stack, CEMS and COMS systems.
- New generator step-up (GSU) transformer and associated high voltage electrical support and interconnect equipment
- New step-down transformer and power distribution system
- For Option 3B-1, the plant would be connected to the existing cooling tower serving Unit 7 which can be upgraded to handle both Unit 7 and refurbished ST5 heat rejection at a fraction of the cost of a new cooling tower.

- For Option 3B-2, a back pressure steam turbine would be utilized to generate some in-house power prior to delivering the steam to a steam host. The steam host is assumed to return 85% of the flow as condensate.
- New instrumentation and controls
- New foundations
- Platforms, ladders, stairs, and railings to enable maintenance and operation

In Option 3B-1, the existing plant systems listed below would be extended to the new equipment. For Option 3B-2 all these systems would be new.

- Natural gas supply (for startup and shutdown)
- Compressed air
- Un-interrupted power system (UPS)
- Distributed control system (DCS)
- Fire protection system
- HVAC

3.5.6 Emission Control

As with Option 2B, the Best Available Control Technology (BACT) for a mass-burn combustion system would be the combination of a dry scrubber and baghouse that treats the flue gas exiting the boiler. This system is proven to meet the EPA limits on particulates, SO_2, HCl, mercury, trace metals and dioxins. The scrubber / baghouse is typically augmented with the injection of powder activated carbon (PAC) into the flue gas at the entrance of the scrubber for additional control of both mercury and dioxins. CO and NOx are combustion-related emissions that are controlled by combustion control methods. Additional NOx control is typically achieved by Selective Non-Catalytic Reduction (SNCR) which injects aqueous ammonia or urea into the upper furnace of the combustor. The scrubber/baghouse, PAC injection and SNCR systems are described in more detail in ***Appendix I***.

3.5.7 Ferrous/Non-Ferrous Recovery

The ferrous and non-ferrous recovery for Option 3B-1 and Option 3B-2 will occur post combustion and will be part of the ash handling system. The resale value of post-combustion recovered ferrous and non-ferrous metal will be lower compared to pre-combustion metals. This is due to contamination, mixing of other metals and ash contamination, and sale value is expected to be approximately 30% less for this material. The bottom ash from the ash dischargers will combine on to a vibratory conveyor with Grizzly discharge section. The Grizzly finger deck section (**Figure 28**): will screen the material. The oversized residue material will be transferred by a front-end loader into a bunker and from there it will be loaded into trucks and shipped to a landfill.

The remaining material falling though the Grizzly deck will discharge onto another conveyor and will be conveyed by a drum magnet feeder conveyor to a rotary drum magnet for ferrous metals recovery. The stream ejected by the magnet will undergo an additional screening step, using a vibratory screen to separate the ferrous materials from any residue. The recovered metals will be transferred by conveyors to a storage bunker and then shipped off to scrap markets. The residue will be transferred to the residue storage bunker. The material not removed by the magnet will continue onto a series of conveyors to an eddy current separator for non-ferrous recovery into a storage bunker. This last step will separate non-ferrous metals from the residue. The residue will combine with the conditioned fly ash on a conveyor before being discharged into a storage bunker. Another option would be to load the combined material stream directly into trailers or roll-off containers.

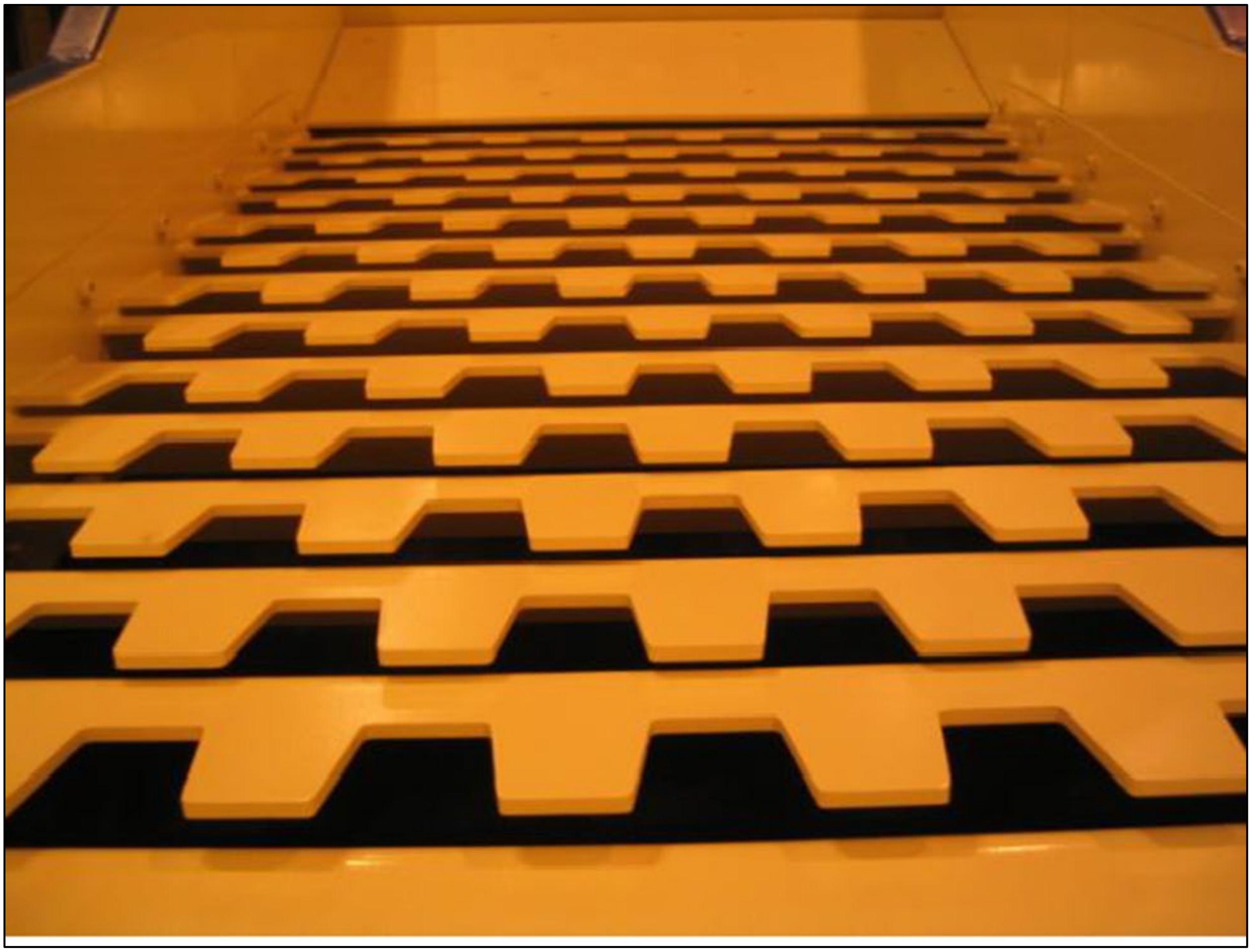

Figure 28: General Kinematics Grizzly Deck Design

3.5.8 Ash Handling/Disposal

Fly ash collected from the baghouse and boiler will be conveyed via screw conveyors to a fly ash storage silo. The fly ash will then be conditioned with water to control dusting before being combined with the bottom residue ash from the ash handing and metal recovery system described in ***Section 3.5.8***. This combining of the fly ash and residue bottom ash will occur on the belt conveyor prior to storage. The combined ash will then be loaded into trucks for transport and disposal in a landfill.

The combined ash will contain heavy metals of environmental concern, requiring regular sampling and testing to ensure it is below the EPA toxicity limits as determined by the Toxicity Characteristic Leaching Procedure (TCLP). A more detailed discussion on ash sampling and testing is provided in ***Section 5 - Environmental Impacts***.

3.5.9 Electric (Option 3B-1) or Thermal (Option 3B-2) Energy Sales

For Option 3B-1, electricity sales would continue as they are conducted today, however the supply of power from the PP to the City would be approximately 1/10th of the current electricity export. The reduced power is a result of elimination of the co-firing with natural gas. For the financial model, the difference between the electricity generated by co-firing natural gas in Option 1 and electricity generated in Option 3B-1 would be purchased on the day ahead MISO wholesale market price (i.e., the Location Marginal Price, LMP) for the Ames interconnect node. In 2020, the on-peak and off-peak average LMP for Ames was $30/MWh and $17/MWh respectively. This is significantly less than the power plant's current costs of $57.5/MWh to make electricity with natural gas at $5.00/dth (See Option 2A for math). Therefore, significant power supply cost savings are provided when natural gas consumption is eliminated.

Units 7 and 8 would be maintained by the City as capacity resources for the MISO burning natural gas only. They would be bid into the Day Ahead (electric) Market (DAM) based on Citygate gas prices in effect at the time. It is estimated that Units 7 and 8 would be selected to operate less than 5% of the time. The associated contracts for well head gas and firm transportation would be cancelled since the capacity utilization would be very small (Refer back to **Figure 11**). Citygate spot market gas purchases would be made as needed, for startup and shutdown of Units 9 and 10. Gas purchases for Units 7 and 8 as capacity resources would totally be excluded from the Waste-to-Energy economics as there would be no more co-firing with RDF in these boilers.

For Option 3B-2 there would be no electric sales. All power generated by the back pressure turbine would be utilized by the MSW plant and PP. Should the host have a temporary interruption, a steam "dump" condenser would be provided with cooling tower to enable the continued operation of the RRP and power plant. Should the steam host's ability to continuously take all of the steam be a concern, a condensing steam turbine with 150 psig extraction could be substituted for the back pressure steam turbine to add flexibility to generate power and/or steam. However, less steam can be sold with an extraction/condensing steam turbine since some minimal amount of steam (~5-10%) must always be condensed, reducing the maximum steam sales possible. The need for this alternative equipment would be vetted with the contract negotiations with the host, including contract risk, guarantees, cost sharing etc. Additional infrastructure would also be required to export the electricity should the steam host default in the future. For the model and cost estimate, RRT assumed a back pressure steam turbine exhausting at 150 psig/535F steam conditions with all exhaust steam provided to the steam host. The steam is assumed priced at 80% of the $/MMBtu of natural gas as a proxy for the host's avoided production cost to produce the same steam from natural gas. A standby "dump condenser" and cooling tower is also assumed for times when the steam host's process is off-line and they cannot accept the steam.

3.5.10 Process Flow and Mass and Heat Balance

Overall process flow diagrams for Options 3B-1 and 3B-2 are depicted in **Figure 29** and **Figure 30**, below. Supporting mass and heat balance data is shown in ***Appendix F***.

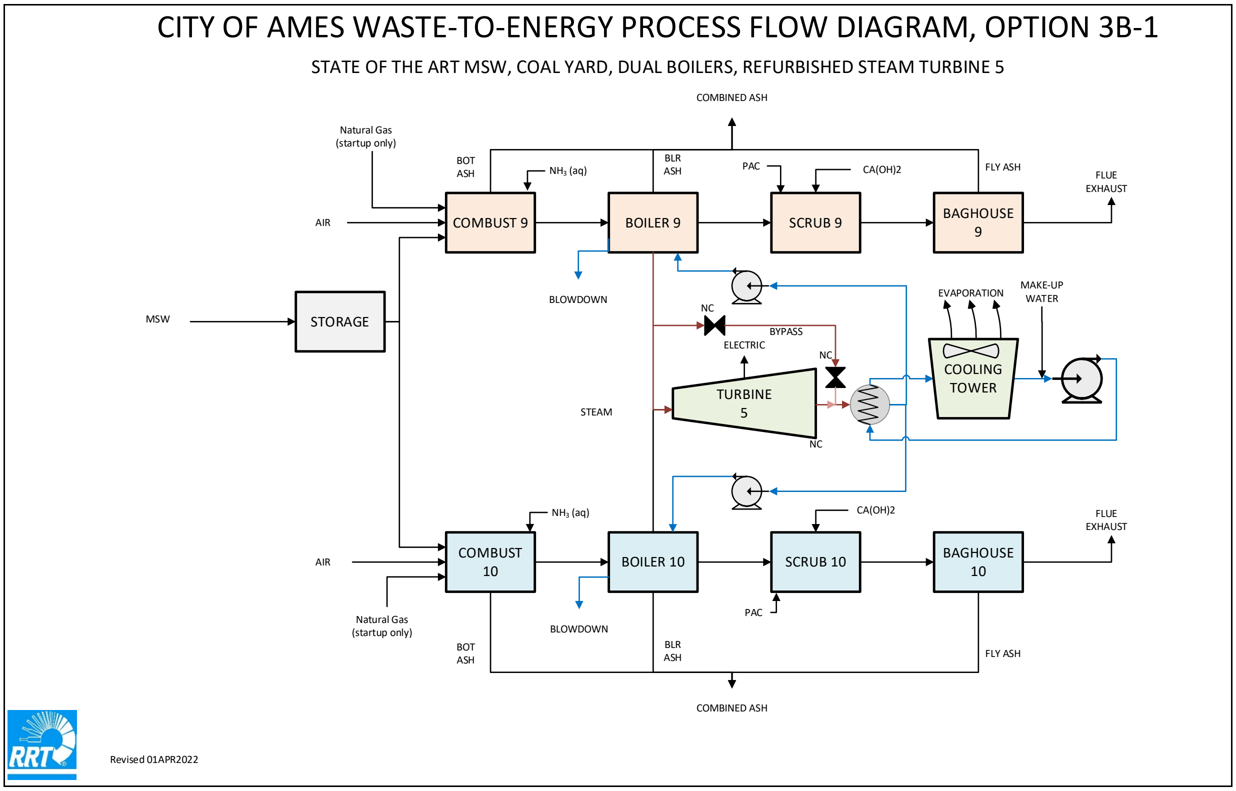

Figure 29: Option 3B-1 Overall Process Flow Diagram

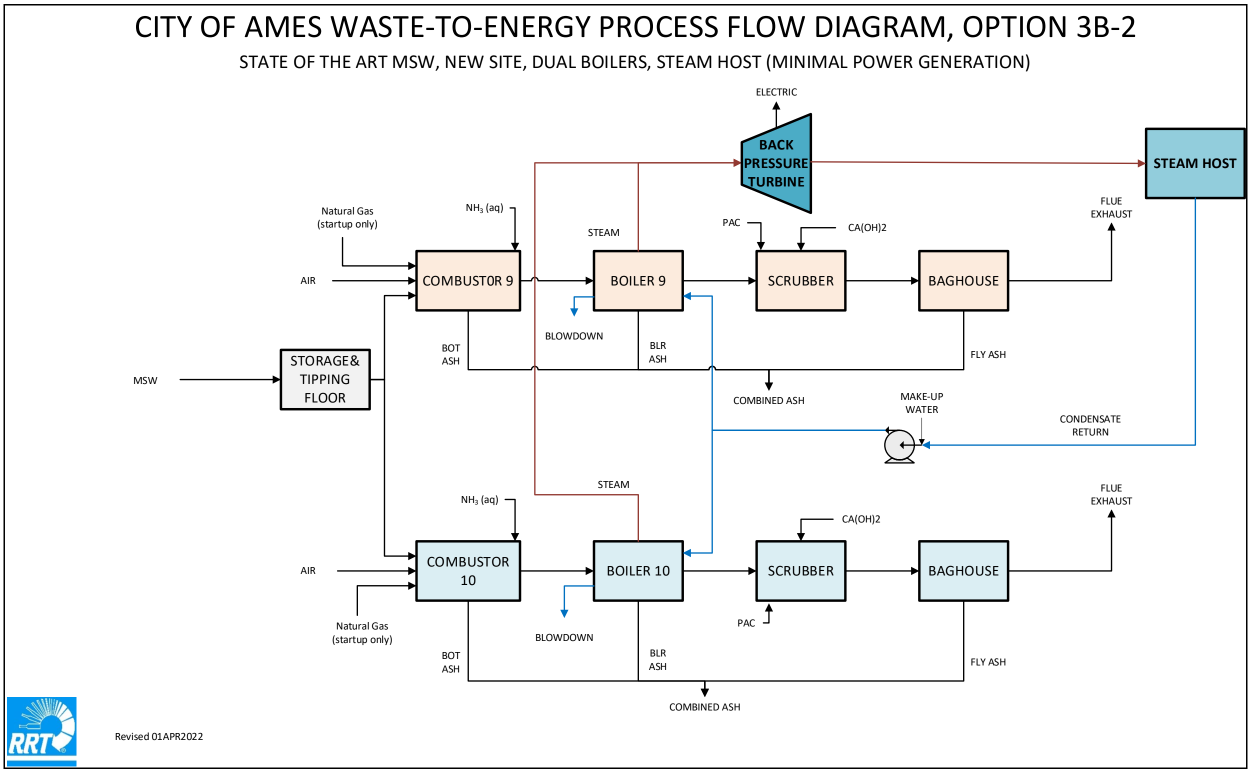

Figure 30: Option 3B-2 Overall Process Flow Diagram

3.5.11 Building/Facility Description and Considerations

The facility includes two new unprocessed MSW combustors and an air pollution control system for each. This option also includes an attached building that houses the post-combustion ash handling and metal recovery system. The MSW will be received at an up-front MSW receiving tip floor in the same building. The tipping floor has been designed for the industry standard of 3 days of storage to feed the combustor which avoids environmental and reduced fire risks. The new facility will also be equipped with an administrative area, control room, education space and potentially a sustainability campus with drop off areas for food waste, metal, glass and other desired diversion materials.

3.5.12 Preliminary Conceptual Facility Layouts

A layout has been provided for Option 3B-1 (**Figure 31**), which locates a new MSW combustion system at the existing coal yard. A similar preliminary conceptual layout on a new generic industrial site is provided in **Figure 32** for Option 3B-2.

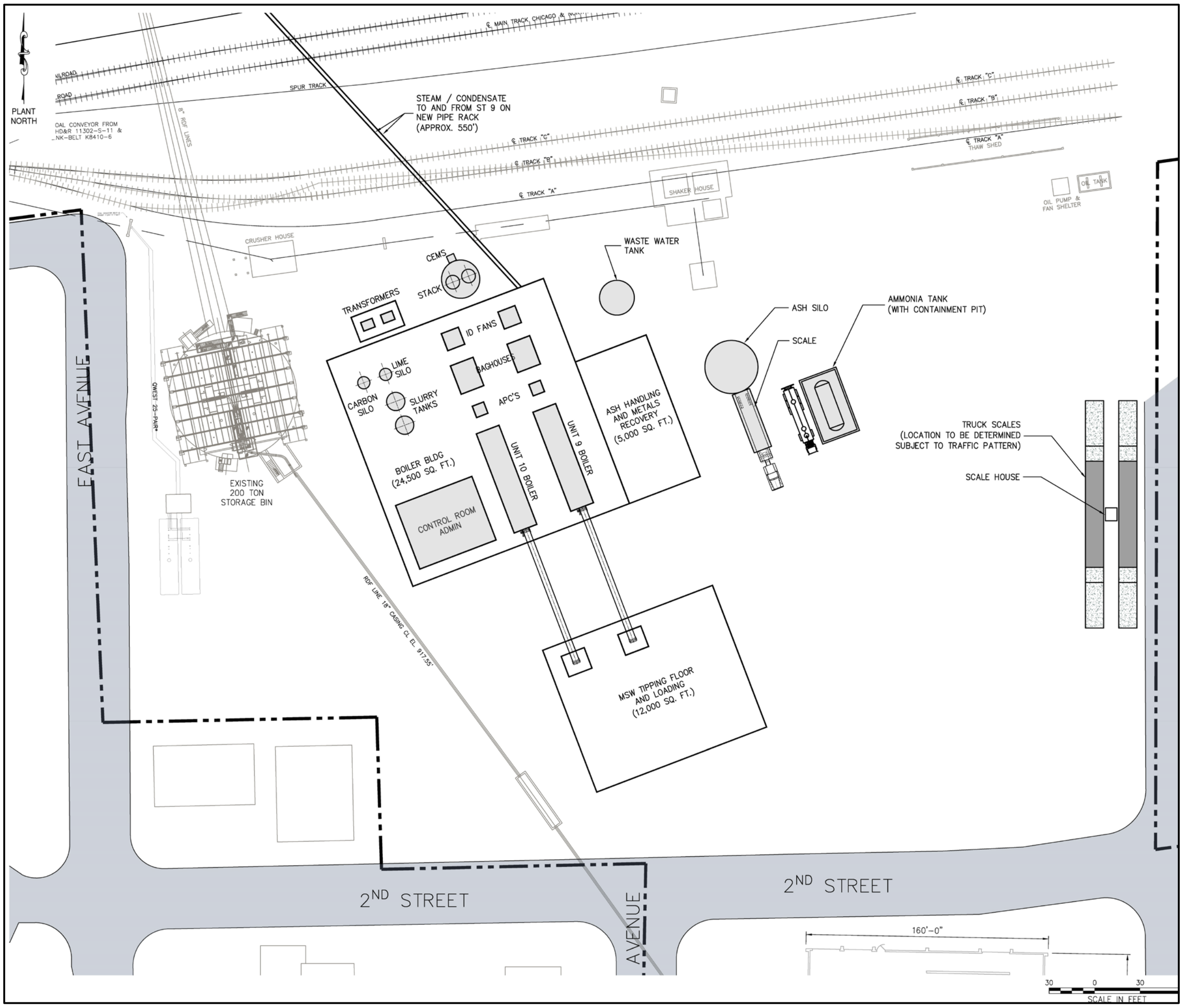

Figure 31: Option 3B-1 Preliminary Conceptual Layout at Coal Yard

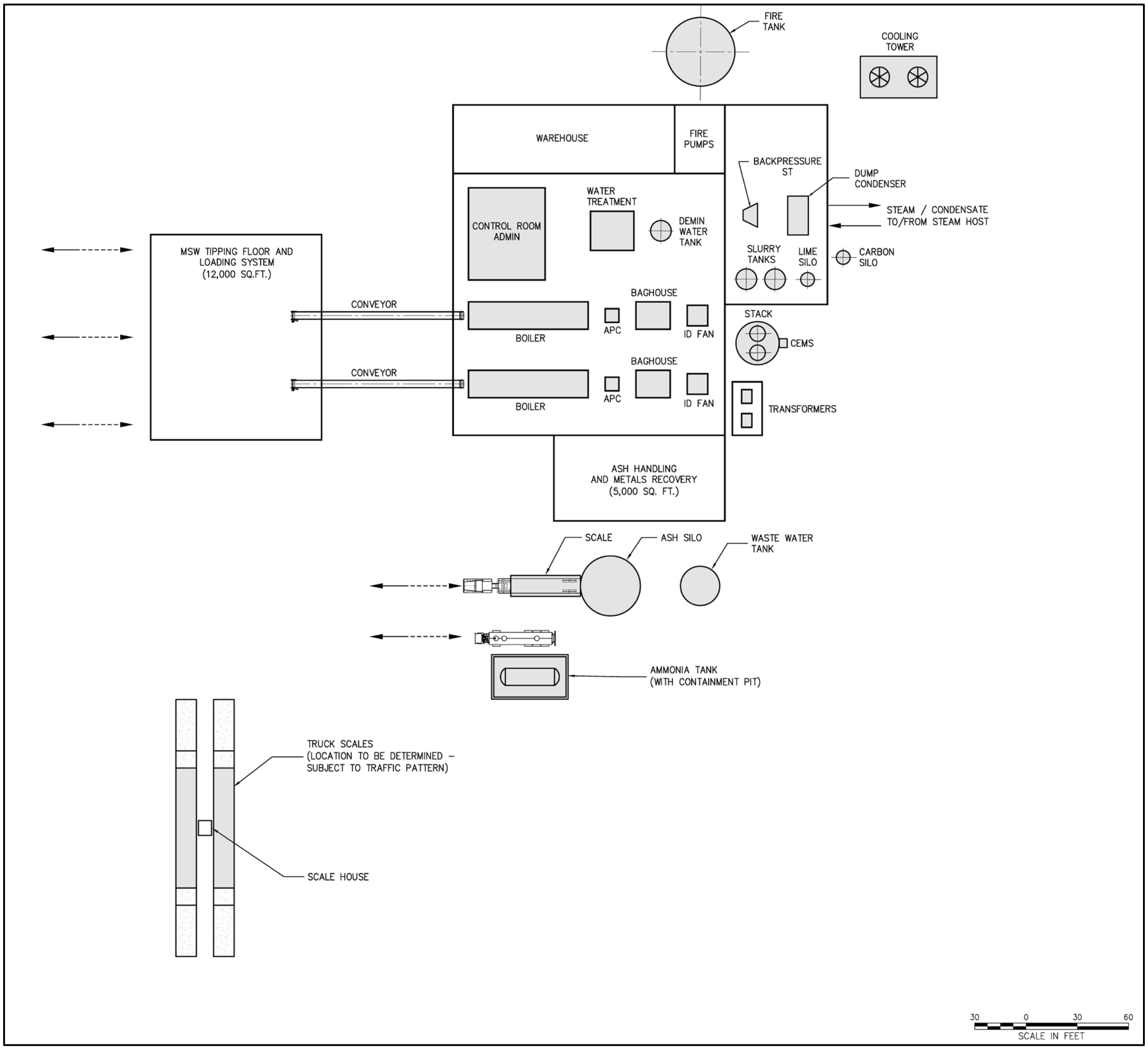

Figure 32: Option 3B-2 Preliminary Conceptual Layout for Greenfield Site

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4 FINANCIAL ANALYSIS

4.1 Overview and Methodology

A comprehensive financial model, using Microsoft Excel, was prepared to evaluate the seven options including the City's current operations (Base Case). This model is of critical importance to this study and for the City to utilize in their decision-making process. For each option, the model is structured to follow the flow of energy production starting with the collection of MSW at the RRP Plant (or PP in MSW combustion options) and culminating in the exportation (or sale) of electricity or steam by the Power Plant. Each option has its own color-coded tab in a common excel file and each has a 'waste handling' calculations section (RRP or MSW) which feeds into the power plant section. Both the RRP and PP sections of the model are then split into three main subsections: Production Information, Revenue, and Operating Costs. The City staff were provided an overview and walkthrough of the financial model to allow them to make adjustments in the assumptions tab, which will allow the City to consider the financial impacts of potential "what if" scenarios as key inputs are modified.

Based on the mass and heat balance for each option, the financial model utilizes the NPV to compare the operating costs, including fuel, O&M, debt payments and Capital Improvement Plan (CIP) expenses against the initial upfront capital costs for that option. Material recovery rates, sorting efficiencies, effectiveness of equipment are estimated by RRT based on RRTs extensive experience with sorting facilities, RDF and MSW handling, boiler characteristics, and energy conversion projects. Each option modeled within the excel file operates in its own tab and draws data from specific tabs in the excel file. Data tabs include assumptions, O&M budget, capital costs and debt service. For ease of use, the assumptions tab allows the user to adjust certain factors and their corresponding escalation rates that link to all the models to evaluate model sensitivities. This allows the City to evaluate the seven options with different external factors and allows for multiple "what-if" scenarios. Examples of user definable inputs include inflation indices, the price of natural gas, natural gas escalation rates, labor escalation rates, insurance escalation rates, tipping fees, metal recycling values and other key parameters. Each option also utilizes some unique, option-specific, set of assumptions that can be adjusted by the user, such as boiler efficiency and ash recovery rate. For each option the estimated capital cost of construction and financing was added in 2024 (year 2) and the project impacts are calculated 2 years later after construction is complete.

Debt service for each option's capital cost is included as part of the power plant operating cost. Debt payments are calculated based on a 20-year City bond (other than the base case, which has no additional capital financing) using the Electric Revenue Bond model and the respective capital cost for each option, prevailing 'Aaa' rates + historic 2015B spreads for Ames +160 bps. For a detailed description of the bond evaluation process developed by Capital Market Advisors (CMA) see ***Appendix J***. Other tabs included in the model provide reference data for each option for capital costs, operating costs, staffing, debt financing calculations and historic information for reference purposes.

4.1.1 Production Information (Waste Assumptions)

All models assume the exact same amount of MSW is available to be processed. This amount starts at 52,000 tons in 2021 and grows at an annual average rate of 1.1% to match the expected population growth of the City of Ames which results in a 27% total growth by the year 2044. All models assume the funded "at the curb" programs for organics and glass continue to divert material from the waste stream at the same success rate.

The production information of the RRP for the Base Case was obtained from the RRP's 2021 Operating data and 2022 budget projections. Some figures were then adjusted based on input from the RRP staff for what a "normal" year without system downtime and some operational issues experienced in 2020-2021. For the base case, the model reflects the current system capacity limitation to consume RDF in the boilers at a rate of 32,000 tons/year. This equates to a maximum input to the RRP of 49,005 TPY. Therefore, all MSW received over the limit bypasses the RRP and is sent directly to landfill. The 2021 recovery rates for the existing RRP are kept constant over the model time horizon for the base case (Option 1) by assuming that no system upgrades are made, but regular maintenance occurs on the system to keep it performing at current levels. The RRP effluents include rejects (large bulky items and hazardous materials), ferrous metals, non-ferrous metals, process rejects and RDF.

Each option differs in how effectively it converts the MSW received at the RRP (or in the case of Option 3B, the MSW plant) into kilowatt-hours (or steam in the case of Options 3A-2 and 3B-2) of energy exported. Processing rates were determined by RRT for each option based on the respective processing efficiencies of the equipment depicted in the RRP provided PFDs. As in option 1, these processing rates are kept constant for the entire time horizon for each model.

Once the RDF is processed, it is sent to the power plant where each option has combustion boilers of different sizes, types, and availability to accept RDF/MSW. The RDF/MSW that is consumed by the power plant is treated as a variable cost to the power plant.

A key City goal is to minimize material that goes to the landfill. However, in each case there is some material that must be directed to a landfill and that includes bulky items and for the RDF units, RRP process rejects. For Option 1 that also includes MSW beyond the current System capability. Note that for all options, should the larger (or both) combustors be off-line for an extended time such that the System storage is full, any incremental MSW would also be directed to landfill. Ash residue from the combustion process is sent to a separate landfill.

The assumed average annual inflation rate over the evaluation period is 2.13%. The model provides for unit rates (tipping, hauling, ferrous recovery value etc.) and is structured to enable custom escalation indices for each to easily conduct sensitivity analyses. The escalation rates utilized in the model for this report were determined with input from the City's RRP and PP managers.

4.1.2 Levelized Power Export

In order to accurately compare the options, one very important criterion was kept consistent across all options and that was the assumption to provide the same amount of electrical energy to the City as the base case provides. If the amount of electricity to the City is kept constant, each option can be evaluated on the net benefit to the City. The electricity supplied by the PP in Option 1 (the "Base Case") is calculated based upon RDF production assumptions and the permit requirement to co-fire 30% RDF with 70% natural gas. In all of the remaining cases the electricity generated is notably less due to the avoidance of co-firing with natural gas (note some gas is still burned in Unit 8 as a backup in options 2A and 3A and for boiler warmup in all cases). For each option's shortfall amount of electricity below the base case amount, the model assumes the shortfall is purchased from the MISO at the Location Margin Price (LMP) for the "Ames" node on the day-ahead market rates to make up the difference. The LMP used is the annual average for 2021 on-peak and off-peak periods during the respective hours of the year. On-peak hours are 46.58% of the year. For 2021, average on-peak and off-peak values were $0.030/kWh and $0.017/kWh respectively. MISO has also announced their intention to invest in transmission re-enforcements as a result of the "Texas Freeze," which occurred in February 2021. While the transmission re-enforcements are primarily targeted in the Southern MISO zone, these investment costs could affect the pricing in the Northern MISO zone which Iowa is a part of. Therefore, the variable cost of MISO LMP prices is assumed in the model calculations to grow modestly at 0.5% per year. The model allows the flexibility to apply different escalation/de-escalation rates for a sensitivity analysis. Due to the predominance of wind energy available in Iowa, the MISO electricity price is much cheaper than the cost to produce the same power from co-firing with natural gas in Units 7 and 8 in the base case. This operating cost savings is a primary factor for considering moving away from the current operations (Base Case).

4.1.3 Revenue Modeling

For each option the various applicable revenue streams were determined and are summarized in this section.

Variable revenue for the RRP included per capita charges of $10.50/person and MSW tipping fees of $62.50/ton. Due to capacity limitations, the MSW that cannot be accepted is turned away and no tipping fee is collected (Option 1). Revenue from the recovery of ferrous and non-ferrous metals were calculated at $65/ton and $980/ton respectively. For internal cost accounting, RDF transfer fees from the RRP to the PP are currently $30.31/ton. Since the RRP produces the RDF as a fuel for the PP, the RDF transfer fee is also a variable operating cost to the PP. For the model, this transfer cost is held constant across all options.

For the PP, a baseline electric revenue stream is utilized across all options. To calculate the revenue stream, RRT utilized the fundamental concept that the City's target profit is zero for all budget years. Therefore, the base revenue stream is calculated as the revenue from City's electricity sales and associated average annual escalation of that revenue to ensure the "revenue less expenditures" is at or above zero in the base case for all years being evaluated. For 2022 this revenue is calculated to be $37.9M and the average annual escalation required would be 1.76%. Because this revenue stream is fixed across all of the options, the non-base case options that have lower operating costs (including debt financing) than the base case will show annual "profits" (revenue less expenditures). Positive "profits" would indicate the City's opportunity to reduce revenues by lowering their electric rates, MSW tipping fees, or a combination of both. Negative "profits" would indicate an increase in one or more of the aforementioned revenues to cover the shortfall. For options 3A-2 and 3B-2 where there are steam sales to a steam host, the unit price for steam is 80% of the natural gas cost in $/MMBTU for the respective year.

4.1.4 Expenses Modeling, Including Debt Service

The variable and fixed operating cost for each option was determined in consultation with City RRP and PP managers and review of historic cost data.

RRP Expenses

RRP variable costs consists of post processing waste rejection hauling and tipping costs, ($15.68/ton and $52.00/ton respectively), electricity, and program waste diversion costs for organics and glass. The diversion program costs for both the glass and organics were $9,000 each in 2021 and their effective rate is carried forward across all options at $281/ton and $40/ton respectively. If the City decides to grow one or both of these programs, the model allows them to adjust these costs to see the impact on the overall budget. Fixed costs include labor, maintenance, capital improvements (CIP) and (existing) debt payments. Other diversion costs (e.g., hazardous waste and yard waste drop-off and handling) and other City overhead allocations remain unchanged across all of the options. The primary fixed cost for the RRP is the cost of labor. The RRP currently employs four administration personnel, 11 O&M, and 2.5 part time staff for a total of 17.5 Full Time Equivalents (FTEs). The RRP's other fixed costs are adjusted for each option including CIP and associated debt service. The total labor cost may differ case-to-case depending on the number of FTE necessary to operate the RRP Plant. Operating and maintenance costs for Option 1 were obtained from the 2022/23 Ames budgets. The O&M, including CIP costs, were extrapolated to 2044 in constant dollars. An annual CIP reserve for plant improvements of $304,500 was chosen to represent the estimated average cost that could be expected knowing the age, operating conditions, and historic experience with the existing operations.

PP Expenses

The PP's operating cost consists of both variable and fixed costs. PP variable costs includes natural gas, chemicals, emissions fees, parasitic electric loads, and ash hauling/tipping costs, and payments to the RRP for the RDF fuel. For Option 1, the largest variable operating costs, by a significant margin, is natural gas fuel. With the plant combusting RDF and running at design capacity, the natural gas fuel is estimated to cost approximately $18.5M annually assuming an all-in delivered cost of gas to the plant of $5.00/dth. Fuel pricing has been exhibiting an upward volatility in recent months as shown in **Figure 33** below (red circle). The model enables inserting different fuel rates and different escalations for sensitivity analyses. The annual escalation used in the model for natural gas fuel is 1% per year.

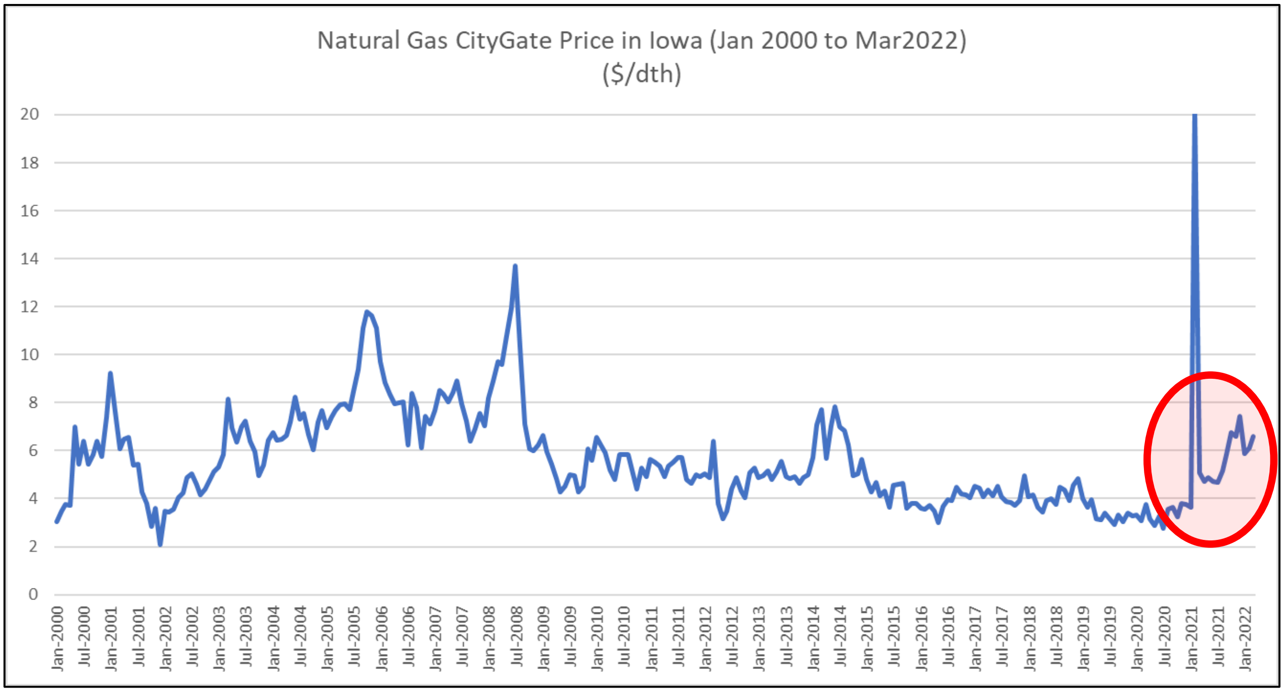

Figure 33: Natural Gas Citygate Price in Iowa, U.S. EIA

Currently the natural gas fuel cost to Ames is composed of a combination of various fixed transportation components and a well-head commodity component. The City's natural gas transportation costs are fixed costs to transport 12,000 dth/day to the City, which is the amount required for the co-firing of natural gas in Unit 8 in Option 1. This cost structure would continue in the base case (Option 1). Under all of the other options gas is only required for (a) startup, shutdown, and flame stabilization and (b) to co-fire with RDF in Unit 8 as a backup boiler (<10% of year in cases 2A and 3A). The small amount of gas for startup and shutdown gas is calculated in the model for all options. This volume of gas is fairly uniform across all of the options and therefore not a differentiator. The very low utilization factor of the fixed transportation in the non-base cases (see **Figure 11**) would drive the need to terminate the well-head and transportation contracts because they would be uneconomical to maintain for the non-base cases gas purchases. For options other than the base case it would be most economical to purchase gas from the local distribution company (LDC) at the industrial firm tariff rate or Citygate prices. The Option 1 gas price used in the model is $5.00/dth and assumes a 95% utilization rate of the gas transportation contract, Using the data from **Figure 33** above, the monthly average Citygate price premium from the LDC) is estimated to be $1.00/dth over the effective Option 1 "burner tip" price. Therefore, Options 2A, 2B, 3A and 3B have a burner tip gas price of $1.00/dth over that of Option 1.

One other PP variable cost is ash hauling and tipping costs of $15.68/ton and $52.00/ton respectively, which was included in the model for all options.

The PP fixed costs include labor, maintenance, insurance, debt payments and CIP. The RDF bin O&M costs are also included in the power plant values. Operating and maintenance costs for Option 1 were obtained for the Power Plant from the 2020/21 and 2021/22 budgets. For Option 1, labor costs are approximately $6.1M based on 41 Full Time Equivalents (FTEs) and an historic allocation of overtime. Other fixed costs for the base case are $7.0M for maintenance, $0.46M in insurance, $1M in existing debt, and $4M in CIP. In consultation with the plant manager, the O&M, including CIP costs of all applicable options includes the labor and maintenance to maintain the existing Units 7 and 8 as capacity resources for the City. These values for the on-going O&M of the capacity resources were developed with significant input from the PP manager. A CIP of $4M for all applicable options was chosen to represent the estimated average CIP dollars that could be expected knowing the age, operating conditions, and historic experience with the existing operations. For the new facilities the CIP would cover plant improvements and for the existing equipment the CIP would cover equipment replacements and major repairs over $130k. Note that the fixed O&M costs for all options also include the estimated costs needed to maintain Unit 7 and Unit 8 in serviceable condition to serve as capacity resources to the City of Ames. This includes, in particular, the off-site options 3A-2 and 3B-2 where the new and existing generating plants are not adjacent to each other.

Debt Service

For all options except the base case, the debt service (loan repayment) is calculated assuming City Electric Revenue Bond in 2024 at prevailing 'Aaa' rates + 2015B spreads + 160 bps, for 20-years. This project financing would support pre-ordering of equipment and commencement of construction in 2024 with commercial operation occurring sometime in 2026. For a detailed description of the bond evaluation process developed by Capital Market Advisors (CMA) see ***Appendix J***.

4.1.5 Capital Costs

For each option, an AACE Level 4 opinion of probable capital cost to implement each WTE option was prepared by RRT. RRT leveraged its experience as both an engineering firm and constructor to provide a functional and accurate cost estimate for a project at this early conceptual phase. An explanation of the methodology used to develop the capital costs as well as a capital cost summary table are provided in ***Appendix K***. It should be noted that current material market volatility makes estimating project and equipment costs extremely difficult and current indications show that this market volatility may not regulate in the next 12 months. Ideally, by the time this project is initiated by the City, there will be better supply chain and material cost stabilization to provide an even more accurate cost estimate.

4.1.6 Net Present Value

The Net Present Value (NPV) for each option is then calculated using capital costs and "profit/loss" (revenue vs. total expenses) which includes bond payments over the 20-year bond term between 2025 and 2044. The options are best compared to each other using the NPV. The higher the NPV compared to Option 1, the more attractive the option. For each case, the NPV for the RRP-only and PP-only are also calculated in the model to show the respective impact on the two cost centers, but the overall NPV is of primary importance to the City.

4.1.7 Internal Rate of Return

Another parameter to evaluate alternative options is the use of Internal Rate of Return (IRR). The IRR is the interest rate at which the total present value of the investment cost equals the total present value of the resulting annual cash flows. In other words, the IRR is the interest rate that equates the project investment cost (negative cash flow) to the stream of resulting annual net benefits (usually positive cash flows) as a result of implementing the project. The term 'internal' refers to the fact that the calculation excludes external risk factors. Corporations use IRR in capital budgeting to compare the profitability of capital projects in terms of the rate of return. The higher a project's IRR, the more desirable it is to undertake the project.

4.1.8 Impacts Not Modelled

It should be noted that the financial model does not currently consider outside-the-fence costs (such as transportation) associated with the implementation of any of the Options. For example, Options 3A-2 and 3B-2 include a new RDF boiler or MSW combustor built at a new industrial site. To get the waste to this remote site (potentially outside the City), it will likely require some level of change in hauling costs which could impact collection pricing. This analysis was not part of the study and may need to be evaluated further if an industrial user is identified and the City selects either Option 3A-2 or 3B-2. These costs are related to implementing the new options but not inherent to developing or operating the boiler or combustor and therefore were outside the scope of this study. This additional transportation specific study could also consider costs for potential increased maintenance of transportation infrastructure caused by the new trash hauling traffic patterns created due to a remote RRP and PP. The results of this further analysis could later be added as inputs to the financial model.

Additional costs not currently included in the financial model are items such as public education or outreach efforts, which could be added when they are determined by the City.

4.2 Financial Model Results

For each year of the analysis period and for each option analyzed, the revenue, operation and maintenance costs are calculated for the respective plants. Capital costs developed for each option were developed along with the costs of debt in the form of City of Ames 20-year Electric Bonds issued in 2025 to support the estimated construction. In addition, the NPV and IRR are calculated assuming $5.00/dth for the base case. The impact of a range of natural gas prices on Profit, NPV and IRR are presented in **Tables 7, 8 and 9**.

Revenue less Expenditures (Profit)

The average annual 'Revenues less Expenditures' ('Profit')[8] from 2025 to 2044 is plotted in **Figure 34**. This is the period from financing to the end of the 20-year bond repayment period for all six new options. The base case is slightly greater than zero since, as previously explained, the common revenue stream was specifically selected so that no single year resulted in a negative cash flow in the Base Case. All of the average annual Profit values also include the respective debt repayments. The Profit shown in **Figure 34** is based on an average gas price of $5.00/dth for Option 1 (Base Case). Other options would not utilize the gas transportation contracts (due to very low gas transportation contract utilization) and are assumed to have a $1.00/dth gas premium to purchase gas at the Citygate.

Option 2A has notably the highest annual average Profit. A principal driver of the higher Profit is that Option 2A has the lowest estimated capital cost and therefore the lowest debt service. In contrast, Option 3A-2 has the lowest average annual Profit, due in large part to this option having the highest capital costs. Since the Profit is less than zero, the operation of Option 3A-2 would require an increase in revenue (i.e., rate increases) above the base case revenue stream to achieve break-even operations within the City.

8 Even though the City Electric Department operates as a non-profit, the word "Profit" in this report is used as a synonym for 'Revenue less Expenses' in the Options model calculations.

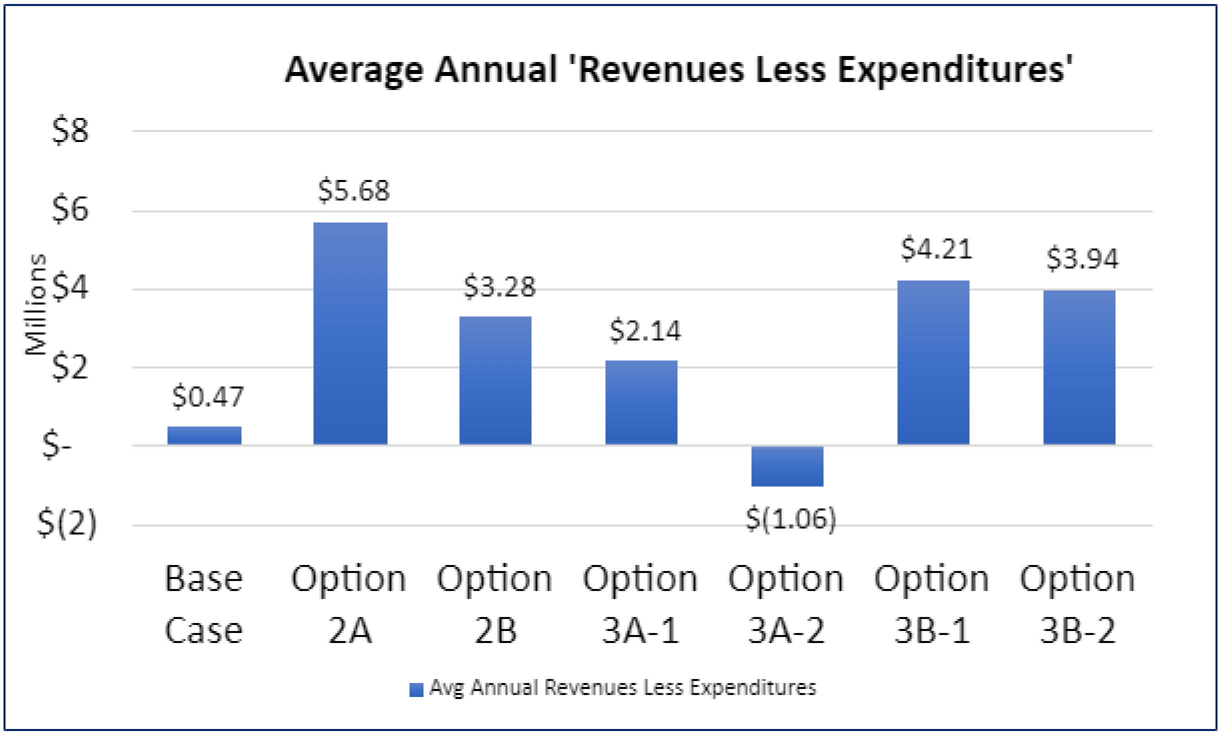

Figure 34: Average Annual Profit for Each Option (@$5.00/dth)

Net Present Value (NPV)

The Net Present Value is a key financial metric to consider in evaluating all the options over the entire 20-year bond period from 2025 to 2044. The NPV is used to calculate today's value of cash inflows and outflows of each option. A positive NPV indicates that the project has a positive overall value and therefore is an attractive option for the City versus the Base Case. The NPV improvement of each option over the base case is plotted in

Figure 35, using an Option 1 gas price of $5.00/dth. Consistent with the average annual Profit of each option, Option 2A exhibits the highest NPV, followed by the MSW mass burn options, 3B-1 and 3B-2. The higher NPV of Option 2A is driven by the lower debt service, despite the need to burn natural gas when utilizing Unit 8 as backup.

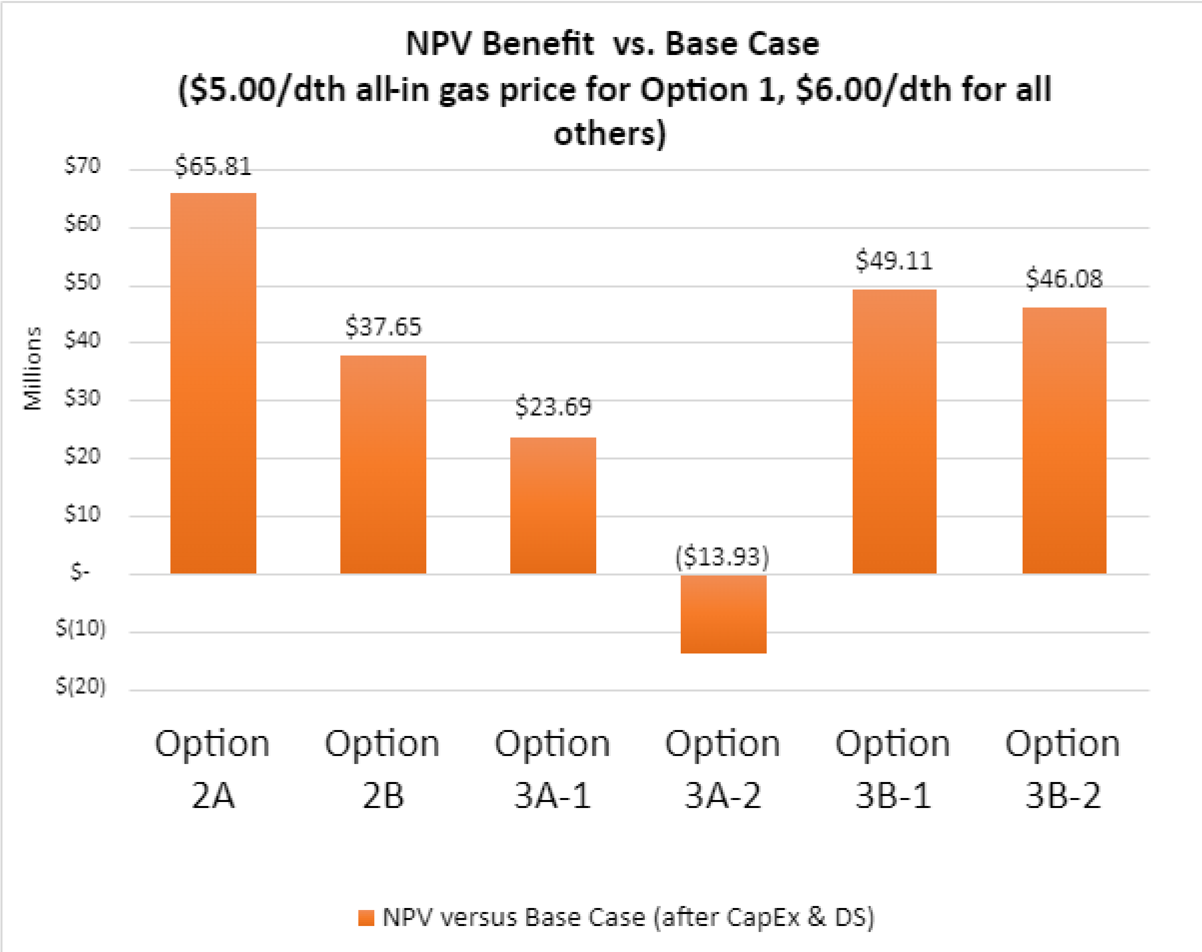

Figure 35: NPV of Each Option vs. Base Case

Internal Rate of Return

Another parameter to evaluate alternative options is the use of Internal Rate of Return (IRR). The IRR is the interest rate at which the total present value of the investment cost equals the total present value of the net future benefits. In other words, the IRR is the interest rate that equates the project investment cost (negative cash flow) to the stream of resulting annual net future benefits (usually positive cash flows) as a result of implementing the project. The term 'internal' refers to the fact that the calculation excludes other external factors, such as inflation, etc. For these calculations, the cost of interest as part of the bond financing is included. A comparison of the IRR for each Option is presented in **Figure 36** assuming a base case gas price of $5.00/dth. As previously explained, all other cases assume a $1.00/dth premium to reflect Citygate gas purchases instead of wellhead and transportation contracts utilized in the base case.

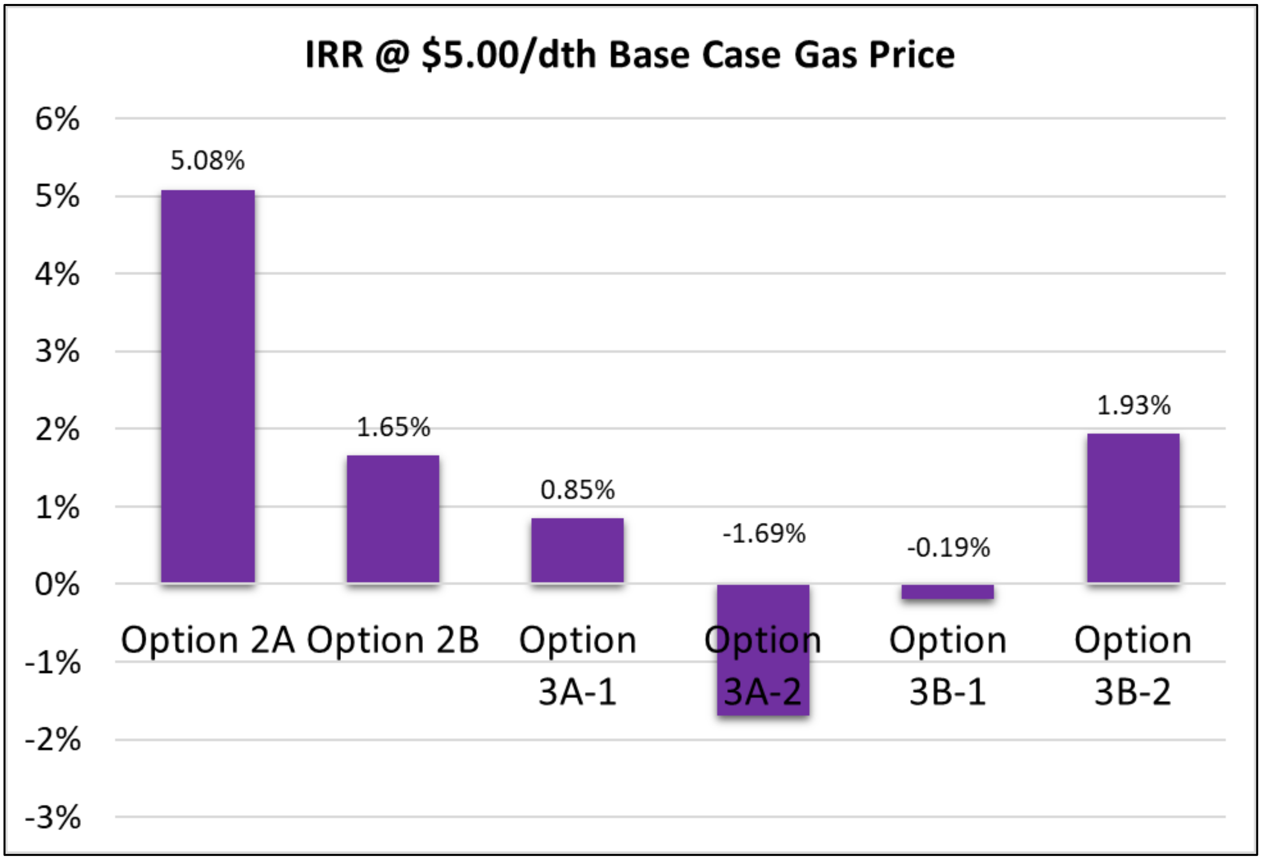

Figure 36: IRR for Alternatives to Base Case [@ $5.00/dth]

4.3 Effect of Natural Gas Pricing

RRT performed a sensitivity analysis to determine the impact of natural gas prices on Profit, NPV. and IRR. The financial results are shown in **Tables 7, 8** and **9** and are graphed in **Figure 37, 38 and 39** respectively. It should be noted that there are secondary impacts of alternate gas prices that may also affect the economics of each option, such as the replacement cost for electricity (energy and capacity), price of other commodities, price of consumables, transportation costs, etc. These impacts are not modeled as they are outside the scope of this study.

From **Table 7** and **Figure 37**, it can be seen that the price of natural gas significantly impacts the operating cost of the Base Case (Option 1) and only slightly impacts Options 2A and 3A. Options 3A-2 and 3B-2 profits improve with higher natural gas prices because the unit price of steam sold to an industrial user is linked to the avoided cost of natural gas to the host.

Table 7: Sensitivity of Average Annual Profit to Base Case Natural Gas Price ($M/yr)

Base Case Gas Price	Base Case	Option 2A	Option 2B	Option 3A-1	Option 3A-2	Option 3B-1	Option 3B-2
$4.00/dth	$4.6	$6.3	$3.3	$2.8	($1.6)	$4.2	$3.6
$5.00/dth	$0.5	$5.7	$3.3	$2.1	($1.1)	$4.2	$3.9
$6.00/dth	($3.7)	$5.1	$3.3	$1.5	($0.6)	$4.2	$4.3
$7.00/dth	($7.8)	$4.5	$3.3	$0.9	($0.1)	$4.2	$4.7
$8.00/dth	($12.0)	$3.9	$3.3	$0.2	$0.4	$4.2	$5.1

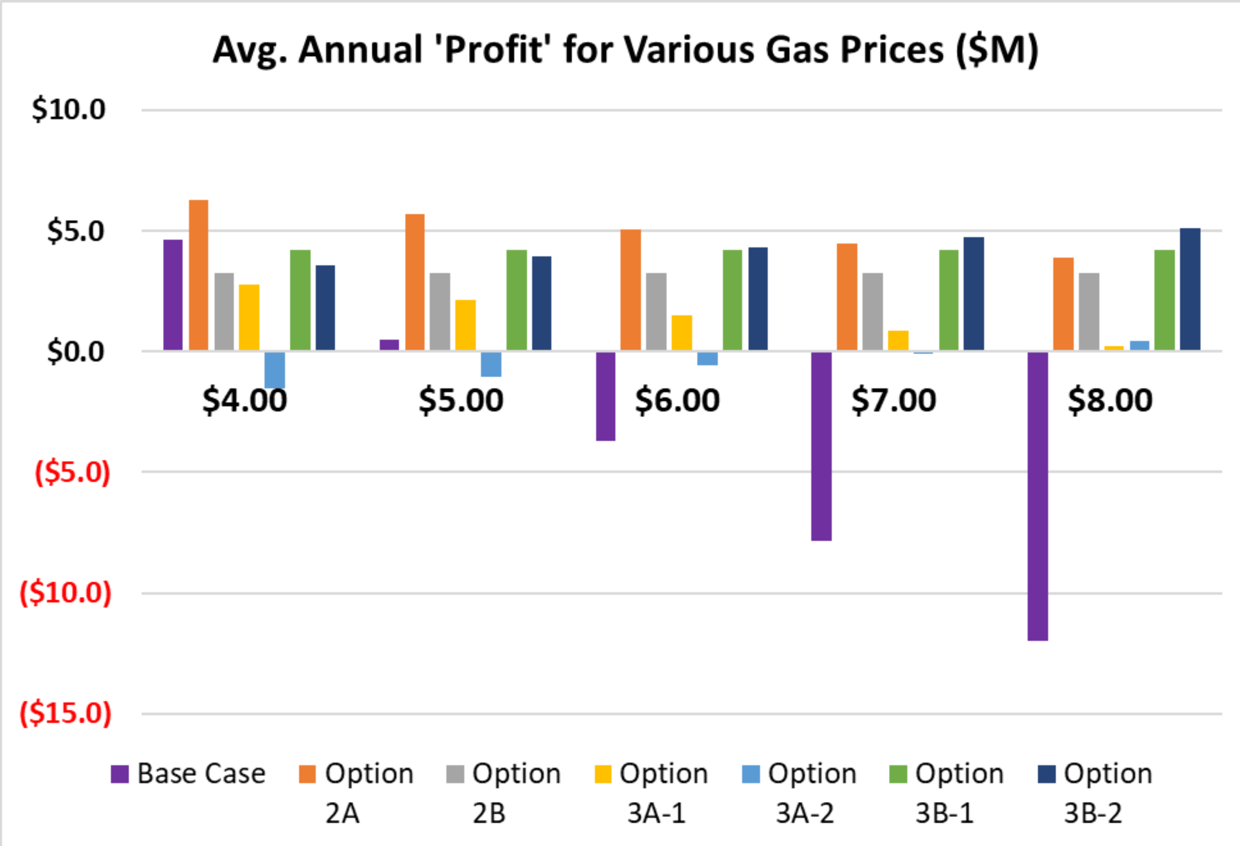

Figure 37: Option Profit Sensitivity to Gas Prices ($M)

From **Table 8** and **Figure 38**, it can be seen that Option 2A is the only Option with a consistently positive NPV across all gas prices modeled in this analysis. When the base case "all-in" contract gas price rises to $7.00/dth, the NPV of Option 3B-2 surpasses the NPV of Option 2A. This is driven by increased revenue from steam sales (which is linked to the industrial steam user's price of natural gas). This increased revenue is applicable for both Option 3B-2 and 3A-2.

Table 8: Sensitivity of 'NPV vs. Base' Case to Gas Prices ($M)*

Base Case Gas Price	Option 2A	Option 2B	Option 3A-1	Option 3A-2	Option 3B-1	Option 3B-2
4.00/dth	22.3	(13.1)	(19.3)	(70.7)	(1.6)	(9.5)
5.00/dth	65.8	37.6	23.7	(13.9)	49.1	46.1
6.00/dth	109.3	88.4	66.7	42.8	99.9	101.6
7.00/dth	152.8	139.1	109.7	99.5	150.6	157.2
8.00/dth	323.0	371.2	318.5	396.4	380.6	413.3
*Highest NPV for each base gas price shown in blue						

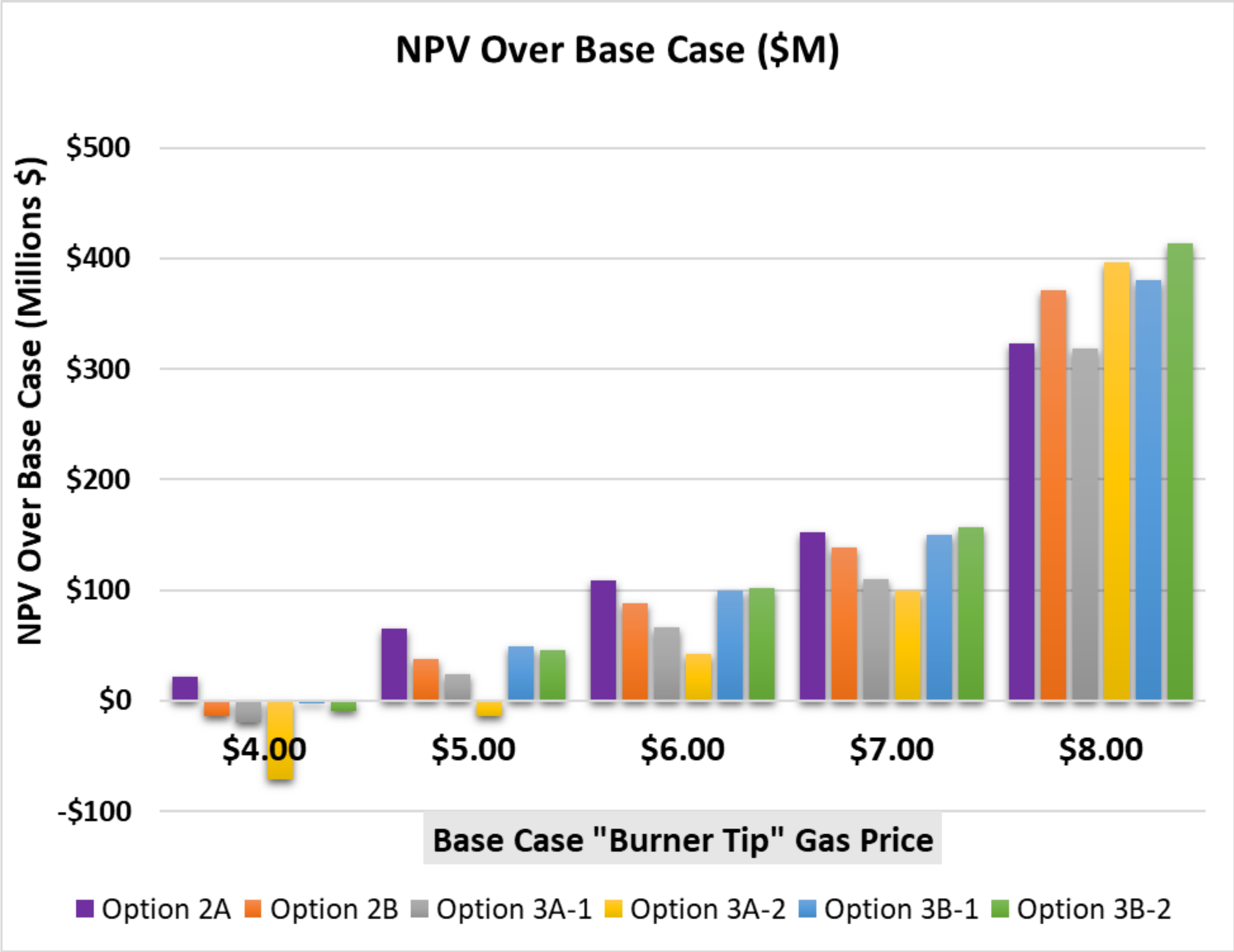

Figure 38: Option NPV over Base Case for Various Gas Prices

The IRR calculation for each non-base case option determines the interest rate that would yield the incremental cash flow over the base case given the capital investment associated with that option. Similar to the NPV sensitivity analysis, the calculated IRR for Option 2A is consistently positive for all of the gas prices modeled in this analysis. The IRR sensitivity results in **Table 9** are graphically depicted in **Figure 39**.

Table 9: Sensitivity of Option IRR to Gas Prices (% IRR)*

Base Case Gas Price	**Option 2A**	**Option 2B**	**Option 3A-1**	**Option 3A-2**	**Option 3B-1**	**Option 3B-2**
$4.00/dth	1.34%	-1.88%	-2.48%	-5.30%	-4.84%	-1.55%
$5.00/dth	5.08%	1.65%	0.85%	-1.69%	-0.19%	1.93%
$6.00/dth	8.38%	4.67%	3.70%	1.26%	3.40%	4.91%
$7.00/dth	11.41%	7.36%	6.24%	3.82%	6.47%	7.58%
$8.00/dth	14.27%	9.86%	8.60%	6.13%	9.23%	10.06%
*Highest IRR for each base case gas price shown in blue						

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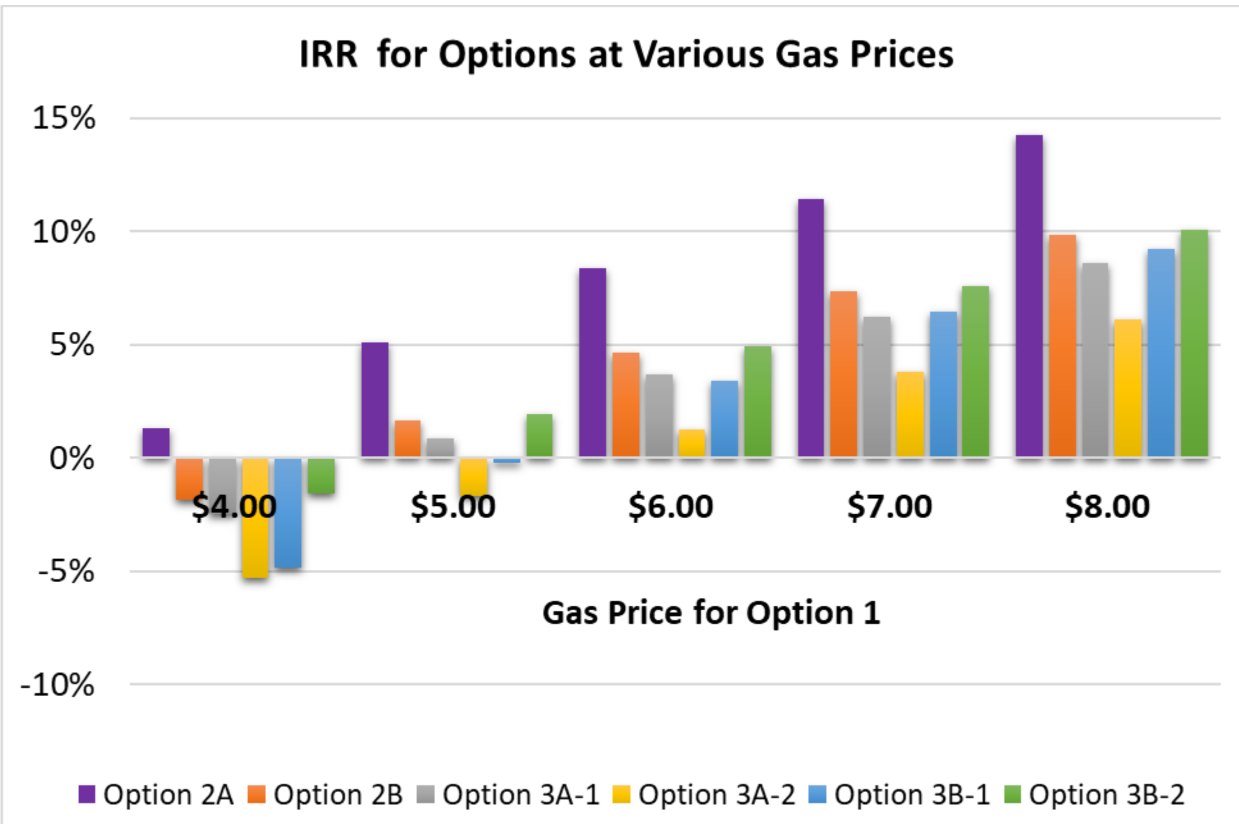

Figure 39: IRR for Options at Various Gas Prices

5 ENVIRONMENTAL IMPACTS

5.1 Federal and State Air Permits

5.1.1 Title V Operating Permits[9]

Congress established the Title V Operating Permit program as part of the 1990 Clean Air Act Amendments. The operating permits are legally enforceable documents designed to improve compliance by clarifying what facilities (also called “sources”) must do to control air pollution. Title V Permits are issued to all “major” sources, with “major” being a regulatory term defined by the type of fuel used, the size or capacity of the facility, and the emissions outputs of specified pollutants on an annual basis. In particular, a facility is a “major source” if its annual emissions for any air pollutant is 100 tons per year (TPY) or more. There are a few other defining criteria such as being located on Indian Land or within an air quality non-attainment area.[10] Most Title V Permits are issued by state or local agencies as “Clean Air Act part 71” permits. The Permits include pollution control requirements from both the EPA and the state (if any apply). Of special note, in Iowa each *source* of emissions is permitted, and a given plant or facility might have more than one source at a single location. For example, even though a MRF might not require an air permit by rule or definition, there might be other equipment or emissions sources at the facility which do require a permit.

Notwithstanding the above, solid waste incineration units are particularly identified as being required to have a Title V Permit regardless of size under Section 129 of the Clean Air Act. Relevant to this project, both a mass-burn incinerator and an RDF boiler[11] would be categorized as a solid waste incineration unit, or Municipal Waste Combustor (MWC). All MWCs are categorized as one of the following:

- “Large” (greater than 250 TPD combusted),[12]
- “Small” (35 to 250 TPD combusted),[13] or
- “Other” (fewer than 35 TPD combusted).[14]

Within the “Small” category, there are two classes, and the classes have to do with the aggregate plant combustion capacity where the unit(s) are located[15]: Class I units are small MWCs located at municipal

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[9] Much of the information in this passage sourced from the U.S. EPA via https://www.epa.gov/title-v-operating-permits/basic-information-about-operating-permits and https://www.epa.gov/title-v-operating-permits/who-has-obtain-title-v-permit

[10] In air quality non-attainment areas, the thresholds are even lower than 100 TPY; however, that condition does not apply in Ames.

[11] 40 CFR §60.51b defines all types of refuse-derived fuel as a type of municipal solid waste which is produced by processing municipal solid waste through shredding and size classification, and refuse-derived fuel stokers as a type of MWC technology.

[12] https://www.epa.gov/stationary-sources-air-pollution/large-municipal-waste-combustors-lmwc-new-source-performance

[13] https://www.epa.gov/stationary-sources-air-pollution/small-municipal-waste-combustors-smwc-new-source-performance

[14] https://www.epa.gov/stationary-sources-air-pollution/other-solid-waste-incinerators-oswi-new-source-performance

[15] Aggregate plant combustion capacity means all MWCs at a plant location, combined. An individual combustor might itself be “Small,” but part of a larger plant combusting greater than 250 TPD.

waste combustion plants with an aggregate plant combustion capacity greater than 250 TPD and Class II units are located at municipal waste combustion plants with an aggregate plant combustion capacity less than or equal to 250 TPD. The requirements for Class I and Class II units are identical except that Class I units have a nitrogen oxides emission limit and require continuous emission monitoring, recordkeeping, and reporting requirements for nitrogen oxides. Class II units do not have a nitrogen oxide emission limit. Additionally, Class II units are eligible for the reduced testing option provided in the code.

5.1.2 Section 129, Section 111, and New Source Performance Standards

To repeat, all MWCs regardless of size are required to have a Title V air permit under Section 129, which directs the EPA Administrator to develop regulations under Section 111 of the Act limiting emissions of nine air pollutants from four categories of solid waste incineration units, including MWCs. The pollutants are:

- Particulate matter,
- Carbon monoxide,
- Dioxins/furans,
- Sulfur dioxide,
- Nitrogen oxides,
- Hydrogen chloride,
- Lead,
- Mercury, and
- Cadmium.

The new source performance standards (NSPSs) and Emission Guidelines for new and existing MWCs fulfill the requirements of Sections 111 and 129. The NSPSs consist of five major components:[16]

a) Preconstruction requirements.

   1. Materials separation plan.
   2. Siting analysis.

b) Good combustion practices.

   1. Operator training.
   2. Operator certification.
   3. Operating requirements.

[16] https://www.govinfo.gov/content/pkg/CFR-2015-title40-vol7/pdf/CFR-2015-title40-vol7-part60-subpartAAAA.pdf

c) Emission limits.

d) Monitoring and stack testing.

e) Recordkeeping and reporting.

It is in the application of the NSPS that the facility sizes ("Large" or "Small") come into consideration and where the fulfillment of the five major components varies as provided for in the laws and regulations. Relevant to this project, all of the MWCs in the Options are designed for less than 250 TPD combustion, meaning they would each be categorized as a "Small" MWC. If any of them are part of a facility with an aggregate plant combustion capacity of greater than 250 TPD, they would be Small Class I; if not, they would all be Small Class II.

5.1.3 Iowa DNR Permitting

Air and Construction

As noted above, in Iowa, each individual smokestack or emission point receives an air permit. New facilities must be designed to meet emissions standards and not result in a violation of ambient air quality standards. Prior to construction, an IDNR Air Quality Construction permit will also be required. Facilities meeting state and federal requirements are issued construction permits, which also include operating requirements to assure continued compliance.

Projects which are large or complex require more detailed analysis. Under the Clean Air Act and/or due to the impact large emission sources can have on a region, this includes those that involve the following:

- Major Source Non-Attainment Area permitting,[17] for facilities located in air quality non-attainment areas (not applicable to Ames);
- State Implementation Plan (SIP) maintenance areas,[18] where an area was redesignated from non-attainment to attainment (not applicable to Ames);
- Prevention of Significant Deterioration (PSD), [19] for new facilities or modifications in areas with air quality attainment status (likely applicable to Ames); and,
- Brand new (greenfield) facilities (applicable to some of the Options in this study).

Other permits such as drinking water, flood plains, storm water and wastewater might also be required. That determination cannot be made within the scope of this project and would be completed once detailed design engineering and site selection is performed.

Solid Waste

The DNR is also the agency which implements the state's solid waste regulations, Chapter 455, Division IV, Part I, Sections 455B.301-455B.316 of the Iowa Code. The DNR has the authority to issue solid waste permits to various facilities, one of which is for a sanitary disposal project (SDP). In the past, the Ames RRP had a permit as an SDP; however, a regulatory review by the DNR determined that the SDP permit is only

[17] https://www.epa.gov/nsr/nonattainment-nsr-basic-information

[18] https://www.iowadnr.gov/Environmental-Protection/Air-Quality/Implementation-Plans

[19] https://www.epa.gov/nsr/prevention-significant-deterioration-basic-information

for landfills, incinerators without resource recovery, and transfer stations which send material to such facilities. The SDP permit which had previously been in place at the RRP was not renewed.

The regulatory review noted the following reasons, among others, for why a resource recovery facility with combustion was not an SDP:

- The nature of resource recovery means the act of combustion is not the “final” disposition of the waste, and without such finality (a defining factor of SDPs) a resource recovery facility cannot be an SDP.
- By the same accounting, combustion with energy recovery is more akin to recycling, in that it takes “an otherwise discarded material and create[s] something new with it.”
- The solid waste hierarchy in Iowa Code section 455B.301A establishes clearly that combustion with energy recovery is different than and preferred to landfilling or incineration; this leads to the reasoning that an energy recovery facility should not be regulated as a landfill.
- Similarly, it is the stated and the apparent intent of the state’s solid waste laws and regulations to encourage reduction, recycling, and otherwise diverting and recovering resources as opposed to disposal.[20] The DNR has stated that imposing the burden of an SDP permit on a resource recovery facility would be in opposition to that intent.
- Case law[21] has established that “If the primary purpose of the facility is to manufacture a product, then it would not be a sanitary disposal project. When applying this reasoning to the determination of whether an energy recovery facility is required to obtain a sanitary disposal project permit it is clear, so long as the purpose of the facility is not “final disposition” (disposal)…the facility does not constitute a sanitary disposal project.”
- Iowa is delegated to implement RCRA Subtitle D, which does not require the state to permit recycling or resource recovery facilities.

By definition, the Options explored in this project involve resource recovery systems and waste conversion technologies:[22]

> “*Resource recovery system*” means the recovery and separation of ferrous metals and nonferrous metals and glass and aluminum and the preparation and burning of solid waste as fuel to produce electricity.
>
> “*Waste conversion technologies*” means thermal, chemical, mechanical, and biological processes capable of converting waste from which recyclable materials have been substantially diverted or removed into useful products and chemicals, green fuels such as ethanol and biodiesel, and clean, renewable energy. “Waste conversion technologies” includes but is not limited to anaerobic digestion, plasma gasification, and pyrolysis, except the term does not include gasification and pyrolysis facilities that process post-use polymers or recoverable feedstocks.

Besides SDPs, the DNR has twenty-three other types of solid waste permits, including Incinerators (INC), MRFs (MRF), Processing Facilities (PRO), and Recycling Facilities (REC). Clearly, a resource recovery

[20] 455B.301A “Declaration of policy”

[21] ABC Disposal v. Iowa Dept. of Natural Resources, 681 N.W.2d 596, 605-606 (Iowa 2004)

[22] 455B.301 Definitions

facility and a waste conversion technology are neither INC nor MRF. At present, there are no active permits for PRO or REC.

While the information herein is not intended to construe that a solid waste permit would not be required for any of the Options in this project, there is currently no apparent regulatory, policy, or case law precedent indicating such a requirement.

5.1.4 Other Permitting and Regulatory Considerations

Options 3A-1 and 3B-1 involve the re-development of the Coal Yard, and Options 3A-2 and 3B-2 involve development of an unspecified Greenfield site. Once a site is selected and the conditions of the Coal Yard are more fully understood, through detailed site investigations, more will be known about what other permits, actions, and uses of the sites can be expected. However, the commercial development or re-development of any site for any purpose will require a number of permits and regulatory allowances.

In the City of Ames, a Major Site Development Plan[23] will likely be required by the Planning Division, including review by the Development Review Committee (DRC). Depending on the outcome of that process, a Special Use Permit or a Conditional Use Permit might be required. Factors influencing the development of the site also include flood plains, land use, and many other policies and priorities of the City as a governing body.

For construction of the facility, there will be various permits required from the City of Ames Inspections Division. According to information immediately available,[24,] the following are some of the permits that may be required for developing a site or constructing a building:

- Building Permits, of which there are several types including code modification, site erosion and sediment control, demolition, driveways and curb cuts, changes to meters, new building, ramps, signage, and stairs.
- Electrical Permits
- Plumbing Permits
- Mechanical Permits

The City of Ames and the State of Iowa have adopted model codes and standards, with local amendments as appropriate to address local conditions. The adopted codes are part of state and local law and are enforceable.[25] These codes include:

- 2015 International Building Code
- 2015 International Existing Building Code
- 2015 International Fire Code
- 2021 Uniform Plumbing Code
- 2021 International Mechanical Code
- 2012 International Energy Conservation Code
- 2020 National Electrical Code

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[23] https://www.cityofames.org/home/showpublisheddocument/57857/637328251268000000

[24] https://www.cityofames.org/government/departments-divisions-i-z/inspections/building-permits

[25] https://www.cityofames.org/government/departments-divisions-i-z/inspections/building-permits/building-codes

- Accessibility ICC A117.1-2009
- Current National Fire Protection Association Standards

There may be Federal programs or requirements which are administered at different levels of government which will have particular application (like with Air Permits) to the selected option; however, absent a selected site, details should not be speculated.

5.2 Comparative Analysis of Environmental and Program Impacts

5.2.1 Air Emissions Summary

The EPA Maximum Achievable Control Technology (MACT) emission standards for MWCs are listed in **Table 10** below. As a new facility is permitted, some State regulatory authorities may look to further tighten the standards for some or all of the pollutants and could potentially utilize the most recently developed WTE facilities, in the country or even around the world, as a baseline for the new facility's air emissions requirements.

Table 10: MSW Combustor Emission Limits

Pollutant	Symbol	Units	EPA	Typical Performance With SOA APC Performance
Particulate Matter	PM	mg/dscm	25	12
Sulfur Dioxide	SO2	ppm	30	24
Hydrogen Chloride	HCl	ppm	25	20
Nitrogen Oxides	NOx	ppm	205	50
Carbon Monoxide	CO	ppm	100	100
Dioxins / Furans	PCDD/P	ng/dscm	30	10
Mercury	Hg	µg/dscm	50	25
Cadmium	Cd	µg/dscm	35	10
Lead	Pb	µg/dscm	400	125

Note: All concentrations are measured at the standard conditions of 7 vol% O_2.

The scrubber/baghouse emission control system that would be used in the waste combustion systems for Options 2A, 2B, 3A and 3B is proven and reliable for meeting the EPA emission standards for PM, SO_2, HCl, Cd, Pb and dioxins / furans. Mercury is somewhat unique relative to other trace metals in that it is a very volatile metal and largely present in the vapor phase at the boiler outlet and through the scrubber/baghouse system. Significant amounts of mercury are adsorbed by the $Ca(OH)_2$ in the scrubber, as well as by excess $Ca(OH)_2$ and fly ash unburned carbon in the baghouse. This level of mercury control is often adequate to meet the Federal mercury emission limit, although the pneumatic injection of powder activated carbon (PAC) into the flue gas prior to the scrubber is often added to achieve lower levels of mercury control and ensure compliance with the emission standard. PAC injection also enhances the control of dioxins, further reducing these emissions relative to the EPA limits.

CO and NOx are combustion-related emissions that are not controlled by the scrubber/baghouse system. CO is controlled by combustion control methods that would easily meet the EPA standard of 100 ppm for both the combustion of RDF and MSW. NOx is also partially controlled by combustion control methods that may be adequate to meet the EPA standard of 205 ppm, depending on the combustor design. However, most modern waste-to-energy facilities also employ Selective Non-Catalytic Reduction (SNCR) systems to further reduce NOx emissions and ensure compliance with the Federal MACT standard. An SNCR system can easily be added to the combustor design and injects aqueous ammonia or urea into the upper furnace of the combustor at a flue gas temperature range of 1650 to 1800 F. In this temperature range, NOx reacts with NH_3 to produce N_2 and H_2O. SNCR is sometimes called Thermal DeNOx because the reduction reactions are driven by the high flue gas temperatures and do not require a catalyst. SNCR systems can typically achieve 40–60% reductions in NOx exiting the combustor. Combined with combustion control measures, an SNCR system would typically achieve NOx emissions in the range of 100 to 150 ppm. More advanced SNCR systems have also been developed that, when combined with staged combustion approaches, can achieve NOx levels below 100 ppm.

For the Small MWCs systems being evaluated by the City of Ames, it is unlikely that the emission control standards will be significantly below those of the Federal MACT standards. However, should lower emission standards be required, it is even more unlikely that they would be lower than those for PBREF No. 2 listed in **Table 4 on Page 13**, above. A modern waste-to-energy facility employing a scrubber/baghouse system, powder activated carbon injection, SNCR and good combustion controls would be able to reliably meet all of the PBREF No. 2 emission standards, with the exception of the NOx standard of 50 ppm. Should this lower NOx standard be required, additional control in the form of a selective catalytic reduction (SCR) system would be required and would add significant capital and operating costs to the project. An SCR system would have to be placed on the clean flue gas following the baghouse and require reheating of the flue gas to temperatures in the range of 500 to 700 F for the NOx reduction reactions to take place. The system would also require additional fan power and steam to reheat the flue gas, reducing the net power output of the WTE facility. Expensive catalyst replacements every 3 to 5 years would also contribute to the high operating costs of an SCR system. Again, for the Small MWCs being evaluated by the City of Ames it is unlikely that this more stringent NOx standard would be required, and therefore not included in the analysis.

The estimated emissions for each of the Options being evaluated were calculated based on typical waste elemental composition, expected emissions control efficiencies and stack gas flow rates. The estimate emissions for the Options are presented in **Table 11**, below. The emissions from the existing Units 7 and 8 in Option 1, and from Unit 8 back-up operation in Options 2A and 3A-1, are estimated to be from the contribution of the RDF fuel only, and not including any emissions from the natural gas combustion, which would only contribute to CO and NOx.

Table 11: Expected Actual Emissions - All Options

Pollutant	Units	Option 1 Base Case	Option 2A 4"RDF 5/6 building	Option 2B 20" RDF Coal Yard	Option 3A-1 4"RDF Coal Yard	Option 3A-2 4"RDF Industrial Site	Option 3B-1 MSW Coal Yard	Option 3B-2 MSW Industrial Site
SO2	TPY	129.7	29.6	18.7	32.1	19.5	31.2	31.2
HCl	TPY	333.3	44.0	9.6	45.3	10.0	12.8	12.8
NOx	TPY	71.7	67.9	143.1	77.5	75.1	149.3	149.3
CO	TPY	2.2	3.3	22.9	3.8	3.8	25.2	25.2

The emission quantities of PM, SO_2, HCl, Hg, Cd and Pd are primarily dependent on the quantity of RDF or MSW being combusted in the various options, along with some impact from the estimated reduction of the sulfur and chlorine content in the RDF vs. MSW. The emission quantities of CO and NOx also depend on the type of combustor, with bubbling bed combustion of 4” RDF having lower CO and NOx levels exiting the combustors relative to inclined grate combustors for MSW and 20” RDF.

The dioxin/furan (PCDD/PCDF) emission quantities are also dependent on the quantity of waste being combusted, with an estimated removal efficiency across the scrubber/baghouse system. The formation of dioxin/furans in the existing Units 7 and 8 in Option 1, and from Unit 8 back-up operation in Options 2A and 3A-1 are estimated to be the same as for typical waste combustors, however these units do not have scrubber/baghouse control systems to remove the dioxin/furans that are formed.

5.2.2 Greenhouse Gas (GHG) Emissions Summary

When evaluating the greenhouse gas emissions from the waste-to-energy options being evaluated by the City of Ames, there are four contributing components that must be considered, as follows:

1. **CO2 generated from the combustion of the non-biogenic fraction of the waste.** The U.S. EPA has determined that 35% of the organic content in municipal waste is non-biogenic, coming from fossil sources made up mainly of plastics. The remaining organic content in waste is biogenic, made up mainly of paper, cardboard, wood and food waste, and represents a renewable source of CO2 emissions.

2. **CO2 generated from the combustion of natural gas in Units 7 and 8.** Natural gas is used for the co-combustion of RDF in the existing Units 7 and 8. This occurs to the largest extent in Option 1, where natural gas is consumed for the co-combustion of all of the RDF, and to lesser extents in Options 2A and 3A, where natural gas is only consumed for back-up operation approximately 10% of the time.

3. **Equivalent CO2 generated by the landfilling of by-passed waste.** Landfilled waste generates methane emissions as it decomposes, which is a much more potent greenhouse gas than CO2. For the City of Ames, by-passed waste will go to the Boone County Landfill that currently does not have plans to add a methane recovery system, leading to an equivalent CO2 emission factor of 1.3 tons of equivalent CO2 for every ton of waste landfilled. This equivalent CO2 emission factor was determined by paleBLUEdot and Orange Environmental in the Ames Community Greenhouse Gas Inventory Study completed in August of 2020. Should the Boone County Landfill add methane recovery in the future, or if the City were to send the by-passed waste to another landfill with methane recovery, this emission factor would be reduced to 0.88 tons of equivalent CO2 per ton of waste landfilled.

4. **CO2 generated by the production of purchased, replaced power**. The City of Ames currently generates power from the operation of Units 7 and 8. If the City were to install new units for the dedicated combustion of RDF or MSW, the reduced power generation would have to be replaced by purchasing that power from external sources. This occurs in all cases except Option 1, which is the base case for this analysis. The CO2 emissions associated with the purchased power from MISO for Zone 3 will average 611.1 pounds per MWhr (EPA Egrid for the State of Iowa in 2020).

Table 12 below details the CO_2 emissions from each of the four components discussed above for the options being evaluated by the City of Ames. The results show that Option 1 has the highest greenhouse gas emissions of CO_2 due to the high level of natural gas combustion in existing Units 7 and 8. The results are also graphed in **Figure 40**. All of the other options would yield similar greenhouse gas emissions, ranging from approximately 45% to 50% below the CO_2 emissions of Option 1. Option 3B-1 would have the lowest CO_2 emissions, but within a range of about 10% of the other options with a new dedicated waste combustion system. It should be noted that for each of these options with a new waste combustion system (Options 2A, 2B, 3A and 3B), the major component of their CO_2 emissions comes from replaced power, from the MISO grid, which is based on the EPA GHG value for power produced in Iowa of 611.1 pounds per MWhr. If the City were able to replace this power from renewable sources, it would eliminate this additional CO_2 emission from this component and significantly reduce the greenhouse gas emissions for these options.

Table 12: Net GHG Annual CO2 Emissions Based on Avg. Annual Waste Flows[26]

Option	1	2A	2B	3A-1	3A-2	3B-1	3B-2
CO_2 from Combustion of Non-Biogenic Fraction of Waste (TPY)	15,070	19,133	22,368	22,904	22,763	22,000	22,000
CO_2 from Combustion of Natural Gas (TPY)	221,760	24,283	0	24,283	0	0	0
Equivalent CO_2 from Landfilling of By-Passed Waste (TPY)	16,194	2,718	5,639	6,283	6,291	776	776
CO_2 from Replaced Fossil-Based Power (TPY)	0	89,086	98,109	90,012	107,138	100,053	107,516
Total Equivalent CO_2 Emissions (TPY)	**253,024**	**135,220**	**126,116**	**143,481**	**136,192**	**122,829**	**130,292**

[26] CO_2 from Replaced Fossil-Based Power provided by US EPA Egrid CO_2 output emission rate for all fuels value for Iowa, 2020 (MISO Zone 3)

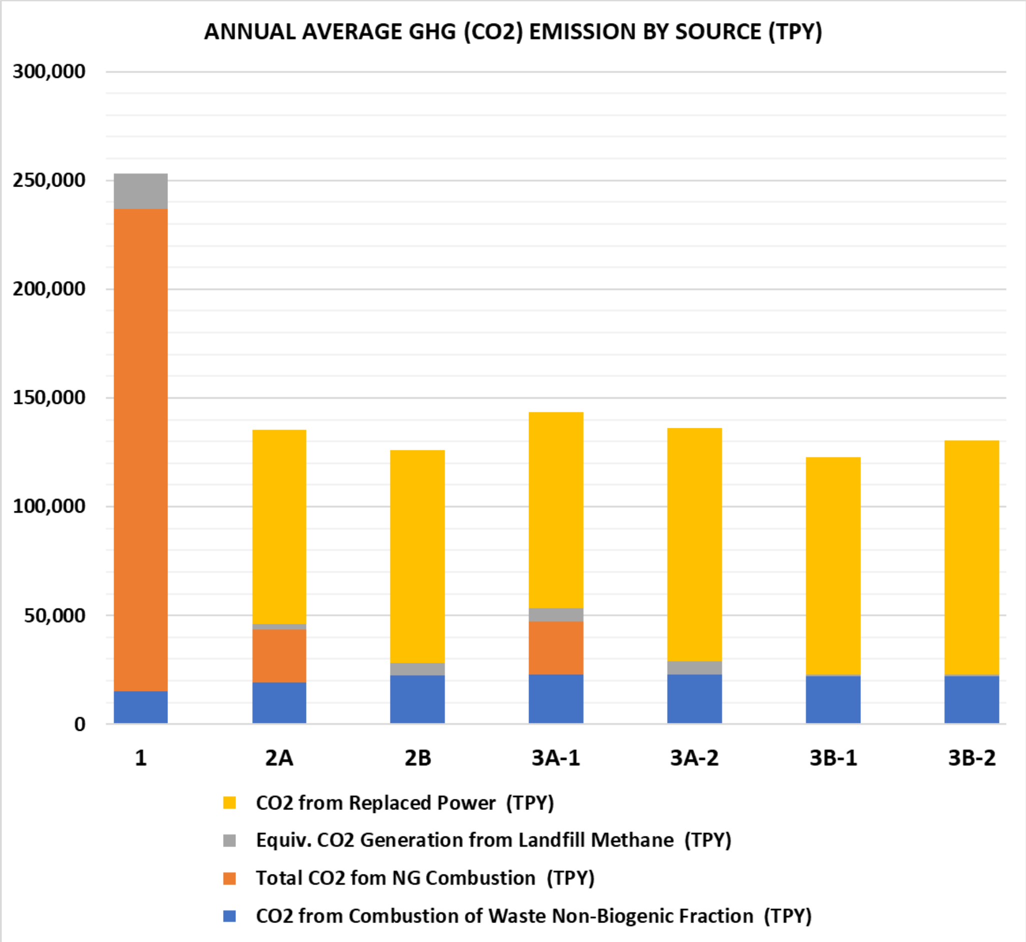

Figure 40: GHG Equivalent Emission for Each Option

5.2.3 Water, Utilities and Processing System Requirements

In all options, water is used in two forms: (a) makeup of water discharged from the boiler steam system for blowdown and (b) makeup water to the cooling tower which is lost due to evaporation caused by rejection of the residual Rankine cycle heat. The boiler water makeup is sourced from the City of Ames and treated through a reverse osmosis system to remove impurities, with the discharge concentrate going to City sewer along with the blowdown from the boilers. The cooling tower makeup water is provided from well water.

In all the Options except Option 1, water consumption will be approximately 10% of the current water usage due to the operation of RDF-only or MSW-only boilers, which have a significantly smaller steam cycle than the current co-fired boilers. For the limited times that Boiler 8 would be operating as a backup in Option 2A or 3A-1, the hourly water usage rate would be the same as in Option 1 Base Case.

5.2.4 Ash

The ash from the combustion of RDF or MSW contains heavy metals of environmental concern, requiring regular sampling and testing to ensure the leachability is below the EPA toxicity limits as determined by the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP test involves the mixing of a sample of ash with an acidic solution for 18 hours. The solubility of heavy metals in the ash will be a function of the final alkalinity of the leaching solution, which in turn, is a function of the alkalinity content of the ash. The majority of the alkalinity content in ash from the combustion of MSW comes from excess $Ca(OH)_2$ from the scrubber, which is collected with the fly ash in the baghouse. The fly ash will then be mixed with the bottom ash from the combustor to produce a combined ash stream for disposal.

The two metals of primary concern in ash from the combustion of MSW are lead and cadmium. Cadmium is only soluble in acidic conditions, but lead is amphoteric, meaning it is soluble in acidic conditions, as well as very alkaline conditions. Both metals are insoluble at neutral to slightly alkaline conditions. To ensure waste-to-energy ash is non-toxic and passes the TCLP test, the alkaline content must be monitored and controlled to ensure the final pH of the TCLP test falls in the neutral to slightly alkaline range of 7.0 to 10.0. The excess $Ca(OH)_2$ required in the scrubber to achieve efficient SO_2 and HCl removal is typically adequate to achieve the necessary alkalinity content in the combined ash exiting the waste-to-energy plant. But it will be important to monitor this alkalinity content through a regular ash sampling and analysis program.

Iowa regulations may require a regular ash sampling and analysis program to demonstrate compliance with the TCLP test. These ash sampling and analysis requirements vary widely between states, from a single ash sampling and analysis after start-up of the facility, to annual, quarterly or monthly sampling and analysis frequencies. Regardless of the States requirements, it is recommended that the owner/operator of a WTE facility establish a regular ash sampling and analysis program to demonstrate ongoing compliance with the Federal requirements on ash toxicity.

5.3 Program Impacts and Considerations

The City of Ames possesses a progressive waste management program and has been an industry leader for decades by its approach to utilizing waste as a resource. As the City reviews its options for the next 20 or more years, there are other program enhancements and modified approaches that could be considered, which are beyond an upgraded RRP and PP. Most of the following program considerations would require policy changes or revisions to how waste is managed throughout the area. This narrative is provided to allow for consideration by the City, but detailed analysis of the impact of each of these programs goes beyond the scope of this study and would require the City to make specific policy changes to implement.

5.3.1 Increased/expanded recycling program

Stakeholders in Ames have expressed interest in growing curbside recycling and drop-off programs in the city. There are some parties active in the recycling and solid waste management industry who have expressed the viewpoint that recycling and waste-to-energy are incompatible. This viewpoint argues that the demand for combustible, high heating value materials at combustion facilities competes with recycling programs and the diversion of paper and plastic. There are many long-standing programs in the U.S. and abroad where robust recycling programs and combustion-based disposal facilities thrive together. The following are two regional examples, but there are more across the country and in Canada:

- Pope/Douglas Solid Waste Management in Alexandria, MN, operates a waste-to-energy facility serving the two counties in its agreement in addition to several other surrounding counties. At the same time, a 2015 report by the Minnesota Pollution Control Agency on the state's Recycling and Solid Waste Infrastructure[27] showed that Pope and Douglas Counties recycled in excess of 14,000 tons of typical recyclables (paper, plastic, metal, and glass) from a combined jurisdiction of about 49,000 people, or 1.6 pounds per day. This is a commendable performance level.

- Olmsted County, MN, operates a WTE facility and is currently working with RRT to replace its existing recycling capacity with a more robust facility that is closer to the customers there—i.e., they need their own capacity rather than relying on farther-away capacity, despite having a WTE plant.

[27] https://www.pca.state.mn.us/sites/default/files/w-sw1-09.pdf

In energy recovery, one of the highest-value materials is plastic. Iowa's container deposit system means that many plastic containers are diverted from disposal for redemption. Many aluminum containers are also redeemed, as are glass. The net impact of a curbside and/or drop-off recycling program in Ames, which would presumably siphon more metal, glass, and plastic from the material going to the WTE facility, would be marginal. Glass is actually undesirable in the boilers, and there is plenty of plastic still available in the waste stream despite additional plastic containers being recycled. In actuality, the loss of metal and its revenue stream to recycling is just as impactful to a WTE facility as the "loss" of plastic. These impacts are the same for all the Options discussed in this report.

Another consideration in starting or expanding a recycling program is the availability of MRF capacity. The return on investment for developing MRF lines is largely dependent on the volume of material to be processed, in addition to the quality. If the City wants to expand and develop a recycling program, it must consider both the availability of MRF capacity within economical hauling distance and/or the return on investment of building its own processing capacity.

5.3.2 Organics Diversion

The City has a program for diverting organic material from disposal. This is directly supportive of resource recovery. Combustion does not benefit from wet, heavy material. In addition to the moisture content, the material adds to the weight of each load in an economic system which uses tonnage as its primary cost driver. The Olmsted and Pope/Douglas programs mentioned above both have organics diversion as major parts of their programs. The Pope/Douglas program has 10 drop off sites for organics recycling,[28] and in August 2021 broke ground on an engineered composting facility to serve its two member counties along with four other surrounding solid waste agencies.[29]

5.3.3 Outreach and Education Programs

A robust and valuable outreach and education program regarding conservation and waste reduction is possible in a community which uses WTE for disposal. After thirty years, the American public is acquainted with and accustomed to recycling. Whereas many legacy programs used aversion to landfilling as a motivator for recycling, individuals with lifelong familiarity with recycling know and/or can understand other reasons such as the per-ton costs of WTE and the climate impacts of using virgin materials in manufacturing. This knowledge and activism can also be harnessed to encourage organics diversion. While opponents of mixed waste processing, single stream recycling, and WTE have argued for decades that a waste system that is "too easy" discourages individuals from thinking about their waste and discards, this has proven untrue in communities across North America, Europe, and Asia. For example, Sweden, Denmark, and the Netherlands are among the countries with the most waste-to-energy facilities, and also possess some of the highest recycling rates in the world.[30]

Information about emerging Federal grant funding opportunities for outreach and education is found in the subsection related to the RECYCLE Act of 2021 below.

5.3.4 Grant Funding Opportunities

State of Iowa Solid Waste Alternatives Program (SWAP)

SWAP works to reduce the amount of solid waste generated and landfilled in Iowa. Through a competitive process, financial assistance is available for a variety of projects, including source reduction, recycling and education. The program provides financial assistance in the form of forgivable loans, zero interest loans,

[28] https://popedouglasrecycle.com/waste-type/organics-recycling-drop-sites/

[29] https://popedouglasrecycle.com/composting-facility-breaks-ground/

[30] https://news.climate.columbia.edu/2016/10/18/putting-garbage-to-good-use-with-waste-to-energy/

and 3 percent interest loans. A 25% minimum cash match is required for each budget line item requesting funding assistance. Projects are selected through a competitive process. Emphasis for selected projects is placed on tonnage avoided or reduced, sustainability and ability to replicate.

Any unit of local government, public or private group or individual is eligible to apply for program funds. The City of Ames has been awarded SWAP grants three times in the past:

- In 1990 for a recycling drop-off center.
- In 2011 to purchase and put into service at the RRF an electronically driven transfer auger for the collection and processing of combustible fine materials.
- In 2016 for consulting work to develop and implement a 2-part study leading to enhanced waste diversion, increased efficiency, and increased awareness and understanding of citizen value and interest in additional waste management related services.

Funds can be used for such items as:

- Waste reduction equipment and installation
- Recycling, collection, processing, or hauling equipment (including installation)
- Development, printing and distribution of educational materials
- Planning and implementation of educational forums, workshops, etc.
- Purchase and installation of recycled content products
- Salaries directly related to implementation and operation of the project

Extra consideration is given to applications addressing large or hard-to-manage targeted waste streams.

Federal Legislation

Recently, two major pieces of Federal legislation have been passed which prioritize the recovery of recyclable materials as part of rebuilding the economy in this country to be less linear and more circular. The first is the Save Our Seas 2.0 Act of 2020 (sometimes abbreviated SOS 2.0) and the second is the Recycling Enhancements to Collection and Yield through Consumer Learning and Education Act of 2021 (usually referred to as The RECYCLE Act). Both of these programs have the stated purposes of improving recycling infrastructure, reducing waste, developing a circular economy, and building sustainability from a different perspective than in the past. Rather than setting performance measures along a linear economy, these two Acts aim to incentivize and support innovations and call for the development of infrastructure to support a more circular and sustainable approach. The intended result is both environmental protection and economic stability and prosperity.

<u>Save Our Seas 2.0 Act of 2020</u>

As the name would imply, Save Our Seas 2.0 has a stated purpose of reducing marine debris and ocean-bound plastics. It has three main Titles, or topics:

- Title I — Combating Marine Debris
- Title II — Enhanced Global Engagement to Combat Marine Debris
- Title III — Improving Domestic Infrastructure to Prevent Marine Debris

Title I is about "strengthening the United States' domestic marine debris response capability." It primarily establishes a "Marine Debris Foundation" (Subtitle B) which is to be a charitable non-profit organization and not an agency of the U.S. government. The purpose of the Foundation will be to support the efforts of Federal agencies using private funds and to administer a newly-created "Genius Prize," including developing the details of it and raising some of the funds associated with the effort. The description in the Act does not state who is eligible for entering the competition. Perhaps the Foundation would decide that when designing the competition.

Title II of SOS 2.0 is about "enhancing global engagement to combat marine debris, including formalizing U.S. policy on international cooperation, enhancing federal agency outreach to other countries, and exploring the potential for a new international agreement on the challenge." It is mostly a policy statement, declaring that it is a priority of the U.S. Government to work with partners around the globe on these issues. These measures are more about activity at sea and working with other nations on the global problem of marine debris and ocean-bound plastics.

Title III provides for "improving domestic infrastructure to prevent marine debris through new grants for and studies of waste management and mitigation." The concept is that, if plastics are more greatly valued because of improved ability to collect them, recover them as a commodity, and utilize them as a feedstock, then there should be less of them making their way into waterways. In essence, the economic system will want to retain something valuable rather than allowing it to be lost and end up in the oceans.

Although an act aimed at controlling marine debris might not seem immediately relevant to Ames, Title III of SOS 2.0 explicitly ties the urgency of marine debris and ocean-bound plastic to the need for improved domestic infrastructure to recover plastics and re-integrate them into the economy. It sets the stage for future innovative diversion programs to be part of an emerging new national strategy.

RECYCLE Act of 2021

The RECYCLE Act is part of a much larger legislative action, the Infrastructure Investment and Jobs Act and does two primary things: creates four new grant programs for recycling infrastructure and allocates funding for them, along with millions of dollars in new funding for the EPA's existing Pollution Prevention (P2) grants program. In resource documents issued by the White House and as reported in industry and legal publications, the grant funding allocations for FY22 to FY26 (five years) are:

- $20 million per year for Pollution Prevention grants (supplements existing program)
- $55 million per year for the new SOS 2.0 Solid Waste Infrastructure for Recycling (SWIFR) grant program
- $15 million per year for new Education and Outreach on prevention and recycling
- $25 million, combined, for a new battery collection best practices program ($10 million) and new voluntary labeling program ($15 million)

A brief description of these grant programs is listed below. Where not otherwise cited, sources are the Administration guidebook and the EPA fact sheet.

Pollution Prevention Grants

Abbreviated P2, this is a long-time program at EPA and is open only to States, Tribes, State-Sponsored Institutions, or Tribal Institutions. It is not open to the City of Ames, but the State of Iowa could apply and support the City. The grantees use the funds to provide technical assistance to businesses so they can adopt source reduction practices and technologies which benefit their businesses and their communities. P2 grants are not limited to solid waste programs, and past projects have addressed water consumption, wastewater release, air emissions, and more.

SOS 2.0 and RECYCLE Act Grants

In introducing the new grant programs, the Administration's guidance describes how the funding falls into four major areas: the SWIFR grants, the Reduce, Reuse and Recycle Education and Outreach Grants, and the two Battery programs (Best Practices and Voluntary Labeling). For each of these new programs, the guidance notes that stakeholder outreach and engagement to inform development of grant program will begin in the 2nd quarter of 2022 and advises eligible recipients to begin thinking about solid waste management infrastructure needs to advance their programs. Because these are new programs, the level of specificity for eligible projects is not available as it is for the P2 grant program. For the SWIFR and Recycling Education grants, the funding opportunity is estimated to be available in the 4th quarter of 2022.

The SWIFR grants—$55 million per year for five years, available until expended—are provided for in section 302(a) of the Save Our Seas 2.0 Act (Public Law 116–224). The grants are for projects to implement the National Recycling Strategy (prepared by the EPA), or other projects which support improvements to local post-consumer materials management, including municipal recycling programs. Importantly, the EPA has confirmed in public meetings that cities are eligible recipients of these grants. Thus, this is an entirely new grant funding opportunity.

The Reduce, Reuse, Recycle Education and Outreach Grants—$15 million per year for five years, available until expended—will be focused on improving the effectiveness of residential and community recycling programs through public education and outreach. As with the SWIFR grants, cities are eligible recipients. The projects should inform the public about residential or community recycling programs, provide information about the recycled materials that are accepted, increase collection rates and decrease contamination.

5.3.5 Other Impacts and Considerations

Whenever new facilities are developed, regulatory agencies are not the only parties with concerns. Both individuals and organizations in the public will need to be engaged and their questions and apprehensions addressed. For example, while combustion is not new to Ames, there may be concerns about noise, odor, vehicle traffic, emissions, dust, and other “good neighbor” items, when developing a new facility, modifying structures/systems, or expanding the existing facility’s capacity. Options 3A-2 and 3B-2, where new facilities are being provided at a yet to be determined industrial site, will likely require a greater level of environmental assessment due to the change in location and operations for the City.

To address these concerns (at both a potential new site and the existing site), the City may need to perform a public outreach process to gather information, concerns, and key considerations for the siting and design of the selected option. In addition, a transportation study (as discussed in ***Section*** 4.1) could be performed to identify and describe environmental impacts due to additional or altered trucking, transfer, or right of way modifications necessary for implementing a specific option. This resulting information can help inform the public and decision-makers. There are also usually larger contextual impacts of development which will be important to various individuals and stakeholders, including the benefit of remediating brownfields, the value of economic development, environmental justice, user habits and expectations, etc. Other studies that might be helpful or required could include impacts on stormwater, soil conservation, wildlife habitat, or other environmental considerations.

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6 TIMELINE OF COMPLETION

Option 1, the existing and currently operating RRP and PP, serves as the base case. There is no construction or timeline of completion of work required for the continued functioning of the plant.

In the various options evaluated, the new Resource Recovery Plant and new power plant will be constructed on one of three sites, depending on the option.

The three site options are listed below:

1. Installing new equipment in the renovated structures sections of the existing power plant and RRP, while using much of the existing structure and existing support facilities and equipment.

2. Constructing a new facility on the site of the existing coal storage yard. A significant portion of the existing refuse conveying, storage equipment, power production and power delivery infrastructure would be integrated and continue to be utilized.

3. Constructing an entirely new facility on a “green field” site located in or near an industrial area adjacent to a steam host to enable the sale of steam.

An estimated timeline of completion for key engineering, bid, permitting and construction activities is shown in **Figure 41**. A copy of the schedule is also found in ***Appendix L***. Due to the details of the individual options not being fully designed, there will be some variance of activity durations between the new versus modified system options, but these were not included within this high-level assessment. It should be noted that the permitting activity, which will likely have a significant impact on the selected option’s overall timeline, is not included in the schedule below as it was specifically precluded in the City’s RFP document.

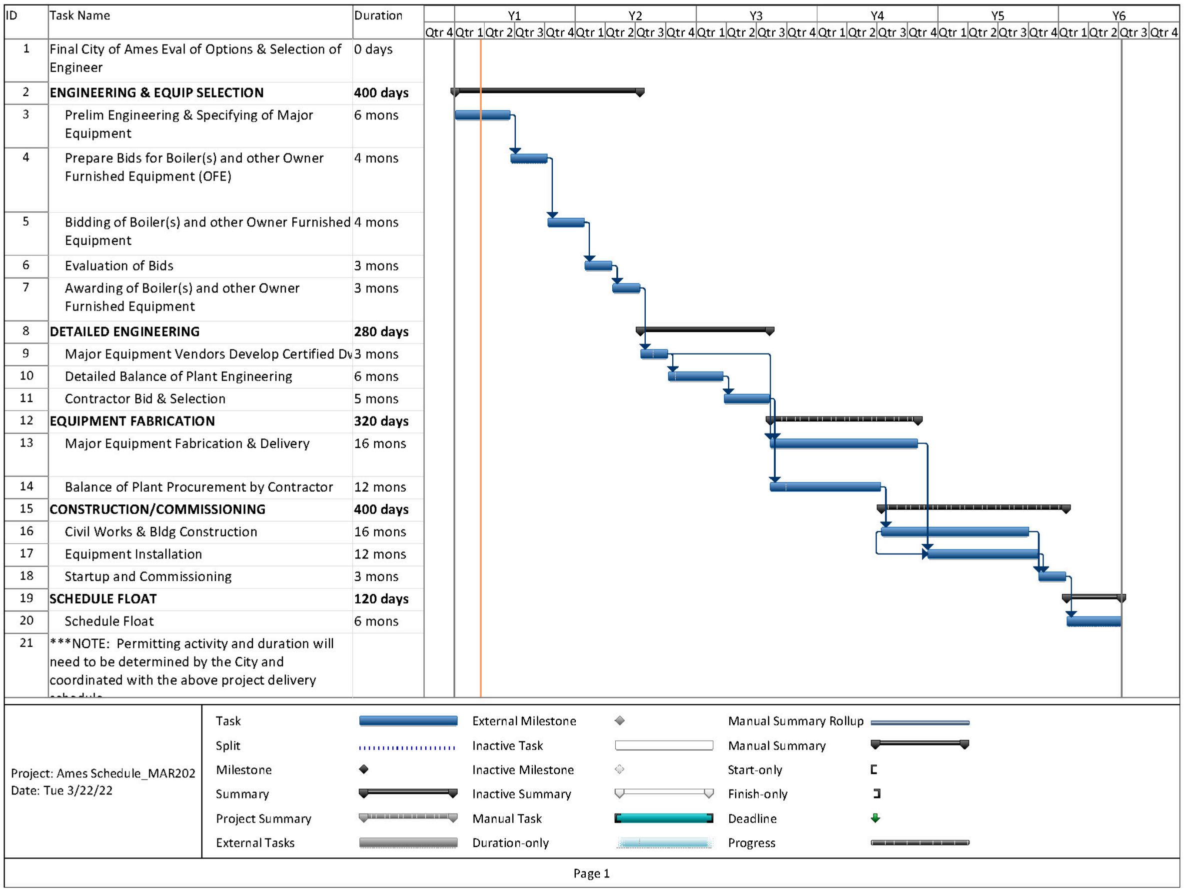

Figure 41: Estimated Timeline for Completing a Project

6.1 Considerations for Construction Inside Existing Buildings

In order to be able to utilize the existing structure for the new equipment (Option 2A), all of the existing equipment should be removed, and the remaining structural steel, piping and foundations should be inspected, and 3D scanned to create a set of baseline drawings. Then preparation of the structure in areas where the new equipment will interfere with the existing structure and/or reinforced or relocated must be accomplished prior to installing any of the new equipment. The loads from the new equipment must be supported on the existing piers and/or new piers. Structural members would likely need to be installed to receive the new equipment loads.

Construction access to the exterior walls and roof will be necessary to allow for installation of the equipment. The coal bunkers would be removed, and a replacement wall installed to enable use of the space for the new equipment. Delivery of the equipment, structural steel, piping and other large components will be delivered by train to a convenient rail siding and then by truck using local roads. Construction and laydown areas as well as trailer areas will be identified on the site for use by the contractor. Portions of the adjacent water treatment plant and/or the coal storage yard may be utilized for this purpose as well as contractor construction trailers and parking for construction workers. Careful planning will be required to arrange for the arrival of equipment to the site, storing it properly and transporting it to the erection locations in a smooth, productive workflow. A comprehensive safety program will be needed to account for the erection of components above workers, prevent fires from welding, ventilation of the workspace, weather protection, fall protection and other potential hazards during the project.

A comprehensive commissioning and startup program will be developed using the engineer's and the manufacturers' specifications along with the owner's requirements to bring the completed facility into commercial operation.

6.2 Considerations for Construction on the Coal Yard

Construction of the new facility on the coal yard site is somewhat similar to working on a previously developed site. All existing underground utilities and structures would have to be identified and relocated or removed if they encroach on the location of the new facility.

The existing coal handling equipment would be protected from damage during the construction duration. The existing RDF handling system (for applicable options) would be modified and protected to be able to be put into service for the new facility. Interconnections to the existing services such as the conveyance lines would be coordinated with operations to minimize downtime.

Laydown and storage of the equipment delivered to the site could be accommodated on the coal yard site or on nearby available space. Construction trailers would be located on the coal yard site and on nearby areas either City owned or rented property.

Delivery of equipment and material would be shipped by train to one of many nearby rail sidings for large, heavy loads and then by truck for the balance.

Careful planning will be required to arrange for the arrival of equipment to the site, store it properly and transport it to the erection locations in a smooth, productive workflow. A comprehensive safety program will be needed to account for the erection of components over working crews, prevent fires from welding, weather protection, fall protection and other potential hazards during the project.

A comprehensive commissioning and startup program will be developed using the engineer's and the manufacturers' specifications along with the City's requirements to bring the completed facility into commercial operation.

6.3 Considerations for Construction of the new Facility on a "Greenfield Site"

The Greenfield site allows for construction of the new facility to be executed with the least interactions and no required shutdowns of the existing facilities. The actual site will need to be investigated for any underground utilities, structures and interferences so they can be addressed before construction commences.

Deliveries to the site would be by rail for large loads using nearby rail spurs and the balance of the trip by truck. Laydown and storage areas, as well as trailers for storage, offices and crew change trailers should be on adjacent areas of the new building site.

Careful planning will be required to arrange for the arrival of equipment to the site, store it properly and transport it to the erection locations in a smooth, productive workflow. A comprehensive safety program will be needed to account for the erection of components over working crews, prevent fires from welding, weather protection, fall protection and other potential hazards during the project.

A comprehensive commissioning and startup program will be developed using the engineer's and the manufacturer's specifications along with the City's requirements to bring the completed facility into commercial operation.

6.4 Key Activities and Narrative for all Options

Regardless of which site arrangement is selected, the following activities will be required:

- Detailed project execution plan,
- Comprehensive project controls process to manage and forecast progress, cost and schedule,

- Change process,
- Comprehensive safety program written specifically for the project,
- Permit compliance process,
- Detailed logistics and material control plan,
- Startup and commissioning plan,
- Quality Management Process.

The schedule presented in **Figure 41** is a high-level timeline of completion for the project. Each of the options will have some variability from this indicative schedule. The following items describe some of the key City and selected engineering activities necessary for execution of the options in the study. Due to numerous factors such as material availability, concurrent construction activities in the region, technology selected, permitting of a new or existing facility, coordination with a potential industrial energy user (as applicable), and other typical factors that affect construction the actual timeline of the project will likely vary from these early planning durations.

From the options presented in this report, the City should evaluate the technical and financial merit of each. Then the permitting of the top one or two options should be discussed with regulators to gauge the ability to permit the project. The City will likely want to take site visits to operating units of the preliminarily selected technologies either prior to or during the permitting discussion process. From these activities the City would then select one option to move forward, unless further review and analysis is needed by a consultant to support the City's decision between a couple of short-listed options.

During the selection of a preferred option, the City would select an engineer to lead the design and procurement of major equipment for the project using its normal procurement process. An environmental consultant will also be needed to provide the necessary support for the air permit and other DNR related requirements. The proper preparation may require detailed boiler emissions guarantees, stack sizing etc. The exact needs would be ascertained during conversations with the Iowa DNR. Equipment procurement will be required to select the boiler and emissions processing system (scrubber, baghouse etc.). The City's engineer would prepare the boiler and emissions bid specifications.

Using the boiler and emissions processing certified drawings, the Engineer will prepare the permit drawings for submittal to the IDNR and authority having jurisdiction. Site survey and site investigations (e.g., soil analysis, soil resistivity, steel inspections etc.) would be required.

The Permit application will be submitted to the IDNR for review and approval. Reconnaissance and permit expediting may accelerate this time period; however, the unknown is the public comment and community resistance/support for the application. Through the duration of the permit review the engineering consultant will continue work on the project by preparing the civil and structural design, remainder of the Balance of Plant (BOP) drawings, equipment specifications, etc. This documentation will serve to define in detail the scope of work required to be completed by the successful construction contractor. The Contractor selection process can occur prior to receipt of permit approval. The construction contract will not be released until the construction permit is released.

Once the contractor is released, they would release the major, and long lead equipment to the manufacturers (if not already released by the City). The BOP engineering must be completed during this time. The Contractor would order BOP components and materials, staffing procedures and mobilization equipment (trailers etc.). Once mobilized the Contractor will begin construction. It is recommended that the City nominate independent inspection of the equipment during manufacturing prior to shipment as well as during installation.

Civil and building construction would occur while fabrication of major equipment is underway. This will allow the building(s) to be ready for receipt of the equipment in a proper sequencing of construction. The major equipment and ancillary systems would be installed/constructed and lead into a start-up and commissioning phase.

The new equipment will be pressure tested, pre-functionally tested, bump tested, and functionally tested with each respective system. Once all systems are tested, they will be integrated together with a formal test and commissioning phase. The contractor would turn the facility over to the City after performance testing and commercial operation of the new and/or upgraded facility would commence.

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7 ADVANTAGES AND DISADVANTAGES OF PROPOSED OPTIONS

The following section details several advantages and disadvantages of each option analyzed. The listed "pros" and "cons" of each option should not be taken as recommendations, but rather key technical, environmental, and financial considerations to compare each option to the other options considered in this study. The descriptions within the individual options are only a partial list of advantages and disadvantages and a more complete comparison table is provided in ***Appendix M***.

7.1 Option 1 – Resource Recovery and Power Plants As-is (Base Case)

One of the key reasons this study was commissioned by the City was to plot the course for the next 20 years of their RRP and PP facilities and the associated systems to process the City and surrounding area's MSW, protect the environment, and create usable energy. The existing system has worked very well for most of the last 40 years but has some aging components and affecting reliability and the associated costs with combusting RDF with natural gas.

<u>Advantages</u>

The base case has a few advantages as compared to the other options in this study and includes the following:

- There will not be any downtime for construction, which will be required for all other options being considered.
- No new major capital expenditures other than the regular annual maintenance and general capital improvement projects.
- The base case does not require any new buildings to be constructed and thus it will save on capital costs and associated soft costs for engineering and permitting of the facilities.
- The City staff will save significant time and effort with the base case as they will not be required to manage the planning, engineering, permitting and construction required for all the other options in the study.
- The other options will require new debt service and thus is an advantage of Option 1.

<u>Disadvantages</u>

The existing operations of the base case were discussed in detail with the City staff and through RRT's technical and financial analysis the following list of key disadvantages was developed.

- Re-occurring issues with the existing RDF storage bin.
- High corrosion issues at boiler (Units 7 and 8) which have hopefully been addressed with recent boiler tube coating projects but could potentially continue to be an issue. The higher boiler steam temperature conditions of the existing system contribute to the corrosion issue.
- One of the biggest disadvantages with the base case is the significant cost of natural gas to co-fire with RDF in both Units 7 and 8 as required by the operating permit's limitation of 30% RDF to 70% natural gas, by weight. At the modeled throughput and $5/dth gas, this represents approximately $11-13M annually in power costs over the cost to purchase the same power from the MISO in the other options.
- The City's electric generation is closely coupled to the price of natural gas (which has been more volatility recently) as a result of the large (70% or more) natural gas co-firing requirement under the PP Title V air permit. Therefore, the City of Ames Electric Department is not able to take advantage of the increasingly available, lower cost, renewable electric energy available in Iowa.

- The current system (Option 1) is already at its total RDF processing capacity, which will result in a much higher amount of MSW taken to the landfill over the next 20 years.

- The co-combustion of natural gas with RDF creates the most GHG emissions as compared to the other options considered.

7.2 Option 2A – Existing RRP with a New RDF Combustion Unit in the Existing PP

Option 2A utilizes the existing RRP and addresses a few existing processing system issues, but primarily this option replaces the existing co-fired boilers with a new RDF boiler for combustion of only RDF during normal operations (outside of start-up, shutdown, and backup operating modes). This option provides several advantages over the current operations, and these are listed below:

Advantages

- Some system limitations in the RRP plant will be addressed such as improved throughput and increase material separation efficiency, including a new air knife and eddy current separator.

- A cost savings compared to other new RDF options by re-use of the existing RRP building and power equipment in the existing PP.

- Significant reduction of natural gas usage as compared to Option 1. Only back-up operations (utilizing Unit 8) and start-up will require natural gas.

- The new RDF unit would not require natural gas for normal operations and therefore the operating costs will be significantly reduced as well as GHG emissions.

- The impact of changes in natural gas prices on PP operating costs would be much smaller due to the reduced reliance on natural gas.

- ST5 would serve as additional generation capacity.

Disadvantages

- Required system downtime to construct RRP modifications to improve operations as well as time to construct and tie in the new RDF boiler (Unit 9) to the existing base plant at the power plant.

- Co-firing of natural gas with Unit 8 during backup mode is still required when the new RDF boiler is unavailable. This brings with it the continued reliance on natural gas, its associated higher GHG emission rate, and higher operating costs during co-firing.

7.3 Option 2B – Modified RRP (20" RDF) with Two New RDF Combustion Units

Option 2B takes the existing RRP and modifies it to provide a coarse shred (20" minus) RDF for combustion in two new boilers at the coal yard.

Advantages

- New RRP equipment versus older equipment in Options 1 and 2A.
    - Less equipment compared to 3A and 2A and thus less O&M.
    - The newer equipment and fewer hours of operation will also reduce O&M.
    - Increased throughput, but still provides metal recovery and fines removal.

- Less overall capital expenditure as compared to Options 3A and 3B, which are primarily new construction options.
- With two redundant combustion units, Unit 8 will not be needed for back-up therefore reducing the use of natural gas and the amount of GHG emissions.
- ST5 would serve as additional generation capacity.

Disadvantages

- This option will require new RDF storage and conveyance to the boilers because the current pneumatic feed system will not accommodate the larger RDF material. The conveyance system to transfer the larger RDF material and the new PP combustion units will increase the associated capital costs in this option as compared to Options 1 and 2A.
- Option 2B will also require two new MSW boilers (similar to mass burn MSW boilers) to combust the larger RDF material. This larger material will not allow Unit 8 to be utilized as a back-up boiler for combustion of waste, thus increasing capital cost.
- There will be a significant system down-time to install the new equipment in the existing RRP.
- Additional workforce will be required at the PP to load the boiler with the larger RDF (end-loader or material handler), but this is balanced by the reduced RRP staff.

7.4 Options 3A-1 & 3A-2: New RRP and New RDF Combustion Unit(s)

Option 3A consists of two sub-options with a new facility at the existing coal yard (Option 3A-1) and a greenfield site located adjacent to an industrial user (Option 3A-2) that will take steam from the plant. Option 3A will have the greatest amount of new equipment, compared to all options, and will include a new state-of-the-art RRP.

Advantages

- S-O-A RRP with new equipment
  - Increased throughput requiring potentially fewer shifts
  - Increased RDF recovery and quality from the MSW
  - Better metal recovery (increased quantity and quality for resale) and removal of rejects
  - Both the building and RDF bin will be new and will result in less downtime during construction than options by allowing the City to utilize the existing RRP building and associated systems.
- Reduced RRP operating costs from the base case because of increased processing throughput.
- Redundancy of RDF storage bins/systems will provide greater reliability and less downtime during maintenance for either of the bins.
- Option 3A-2 also provides the additional benefit of alternative revenue from steam sales versus electrical sales.
- Improved emissions and GHG impacts on the environment.

- Natural gas usage reduction for Option 3A-1 (Unit 8 as back-up) and almost entirely reducing natural gas usage for Option 3A-2 (gas for start-up only). This will result in significant financial savings on operations and a reduced GHG impact.

- For 3A-1, ST5 would serve as additional generation capacity for the City.

Disadvantages

- Requires additional maintenance due to the increased amount of equipment.

- As a result of this new equipment, this option has the largest capital cost of the RRP evaluated systems.

- Option 3A-2 will require land purchase or lease next to an industrial location.

- Option 3A-2 is dependent on the long-term sale of steam which brings with it the associated contractual, operational, and market risks of the host industry.

- Option 3A-2 would not provide the City with incremental electric generation as all the energy produced would go to an industrial steam user.

7.5 Options 3B-1 & 3B-2: Two New MSW Mass Burn Combustion Units

Option 3B has two sub options considered with two new MSW combustors at the existing coal yard (Option 3B-1) and a greenfield site adjacent to an industrial user (Option 3B-2).

Advantages

- No RRP equipment and less overall equipment, resulting in less overall maintenance than the other options.

- Metal recovery is still achieved after combustion and the system is moderately less expensive than front-end metal recovery.

- Mass burn combustion of MSW is a widely used and accepted approach to processing waste and has a variety of suppliers.

- The existing buildings would not be altered significantly in Option 3B-1 and therefore most of the construction could occur without interrupting existing operations. For Option 3B-2 there would be no interruption to existing operations.

- For Options 3B-1 and 3B-2 the existing boilers (Units 7 and 8) could remain as capacity resources for the MISO burning natural gas only.

- The greatest level of landfill diversion by volume of all options considered (2^{nd} highest by mass).

- The new ST5 would serve as incremental capacity.

- Option 3B-2 also provides the benefit of alternative revenue from steam sales versus electrical sales.

Disadvantages

- Option 3B is a change in how the City has traditionally processed MSW.

- The unremoved fines and bulky material will wear the equipment and the boiler faster and thus require increased maintenance.

- The recovery rate and value of the metals from post-combustion processing will both be reduced with these two mass burn options.

- The mass-burn combustion emits higher NOx and CO raw emissions.

- Option 3B-2 would not provide the City with incremental generation as all the energy produced would go to an industrial steam user.

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APPENDIX A

Ames Process Options Summary

Step	Option 1	Option 2A	Option 2B	Option 3A -1	Option 3A -2	Option 3B-1	Option 3B-2
Summary Description	Resource Recovery and Power Plant As-Is (Base Case)	Existing RRP With a New RDF Unit in the Existing PP	Modified RRP (20" RDF) with Two New RDF Units at Coal Yard	New RRP and New RDF Unit at Coal Yard	New RRP and New RDF Units at Greenfield	Two New MSW WTE Units at Coal Yard	Two New MSW WTE Units at Greenfield
1 RDF/MSW Receiving and Storage	Existing RRP's Floor	Existing RRP's Floor	Modified RRP's Floor	New RRP's Floor	New RRP's Floor	New MSW Facility's Floor	New MSW Facility's Floor
2 RRP/MSW	RRP generating 4" minus RDF	RRP generating 4" minus RDF	Modified RRP generating 20" minus "RDF"	New RRP generating 4" minus RDF	New RRP generating 4" minus RDF	Direct-fired MSW (mass burn)	Direct-fired MSW (mass burn)
3a Front-end to storage conveyance	RDF pneumatic transfer to storage	RDF pneumatic transfer to storage	<20" RDF transfer via conveyor across 2nd Street	RDF pneumatic transfer to new and existing storage existing pneumatic transfer to U8 as backup	RDF transfer via pneumatic to all new storage	Raw MSW receiving and storage; End loader on Interim floor to inclined grate infeed	Raw MSW receiving and storage; End loader on Interim floor to inclined grate infeed
3b Processed RDF/MSW Storage	Existing bin	Existing bin	At inlet to boilers	New storage bin & existing bin	New storage bins	Floor/bunker	Floor/bunker
4 Conveyance From Storage to Combustor	RDF pneumatic transfer and feed to combustors Units 7 & 8	RDF pneumatic transfer and feed (as-is) to combustors (new) Unit 9 and backup Unit 8	RDF feed system: loader onto inclined grate to Units 9 &10	New RDF pneumatic transfer to Unit 9 & existing pneumatic transfer to Unit 8	RDF feed system: New RDF pneumatic transfer feeds from dual bins	MSW feed system: loader to inclined grate	MSW feed system: loader to inclined grate

Step	Option 1	Option 2A	Option 2B	Option 3A -1	Option 3A -2	Option 3B-1	Option 3B-2
5 Combustor(s) /Boilers	RDF / NG combustors: Unit 7 & Unit 8	RDF combustors: (new) Unit 9 & backup unit 8	RDF combustors: New Units 9 & 10	RDF combustors: New Unit 9, backup Unit 8	RDF combustors: New Units 9 & 10	MSW combustors: New Units 9 & 10	MSW combustors: New Units 9 & 10
6 NOx Control	No NOx control	SNCR NOx reduction	SNCR NOx reduction	SNCR NOx reduction	SNCR NOx reduction	SNCR NOx reduction	SNCR NOx reduction
7 Exhaust Scrubber	No scrubbers	Scrubber on new boiler only: 1 – SDA 2 – dry circulating 3- carbon injection	Scrubbers: 1 – SDA 2 – dry circulating 3 - carbon injection	Scrubber on new boiler only: 1 – SDA 2 – dry circulating 3 - carbon injection	Scrubbers: 1 – SDA 2 – dry circulating 3- carbon injection	Scrubbers: 1 – SDA 2 – dry circulating 3 - carbon injection	Scrubbers: 1 – SDA 2 – dry circulating 3 - carbon injection
8 PM Control	Unit 7 – Cold-side ESP Unit 8 – Hot-side ESP	Pulse-jet baghouse	Pulse-jet baghouse	Pulse-jet baghouse	Pulse-jet baghouse	Pulse-jet baghouse	Pulse-jet baghouse
9 Electric Generation	ST 7 & ST 8	Re-furbish ST 5 with bypass condenser ST8 when unit 8 operates	Re-furbish ST 5 with bypass condenser	Re-furbish ST 5 with bypass condenser ST8 when unit 8 operates	New backpressure ST with dump condenser	Re-furbish ST 5 with bypass condenser	New backpressure ST with dump condenser
10 Buildings	Existing RRP, Existing bin, Existing PP	Existing RRP, Existing bin, Existing PP	Existing RRP, New storage floors, and new PP. Pipe steam & condensate to/from existing PP	New RRP, New additional storage, new boiler in new PP. Pipe steam & condensate to/from existing PP	New RRP, New storage, New power plant. Pipe steam/condensate to/from steam host	New MSW handling facility and PP in same building. Pipe steam/condensate to/from existing PP	New MSW handling facility and PP in same building. Pipe steam/condensate to/from steam host

APPENDIX B

RDF/MSW Storage Analysis

APPENDIX B

RDF/MSW STORAGE ANALYSIS AND CONSIDERATIONS

Storage capacity is a complex factor when balancing a growing waste stream over 20 years, fixed boiler size(s), and boiler efficiency at various operating load points to determine a design criteria for RDF storage between the RRP and PP. Storage provides the buffer to "level out" the variations in tons of RDF produced by the RRP based on the quantity and composition of the incoming waste, as well as address variable operating conditions of either the RRP or PP. We have approached the WTE Options Study with the overarching goal of sustainability by avoiding landfilling waste that otherwise can be converted to energy and be reduced in quantity, as well as accommodating the City's future expected MSW (population) growth. Balancing all these factors merited some conceptual engineering and the attached storage modeling analysis was developed to better evaluate how each option would react over time to the City's desired operating considerations. The results are interesting and are to be considered when evaluating the options. RRT recommends that a detailed analysis of all these inputs be revisited when a final preferred option and equipment is selected by the City to incorporate the latest MSW growth projections, boiler part load efficiency, refining the desired storage capacity (e.g. 450 ton vs. 400 tons), contingency considerations, etc. The model could also be refined to reflect 5 days of collection vs. 7 days of collection assumed in the current storage model.

There are two distinct operating conditions RDF (MSW in the case of Option 3B) storage looks to satisfy. One condition when there is zero combustion of RDF at the PP (or MSW in the case of Option 3B) due to a total PP outage. In this case a maximum of about 4 days storage is recommended as larger values increase the risk of fire hazard due to gases created from decomposition and the possible presence of ignition sources. The second condition is a partial plant outage where the consumption of RDF is less than the production rate of RDF. This typically is the case when a primary Boiler unit is off-line. During this "rotating stock" scenario, the same mass/volume of storage will last longer, with one combustor off-line, depending on the size of the combustors. For RDF Systems, a certain amount of RDF storage is merited between the RDF leaving the RRP and the RDF that is combusted at the PP. This interim storage provides the following benefits to the System.

1. Balances the 8-12 hours/day production of RDF by the RRP with the 24 hour/day combustion of the RDF. Storage volume needed for this condition is approximately 16 hours.
2. Balances the 4- 6 days/week production of RDF with the 7 day/week combustion of the RDF. The longest weekend is a 4-day weekend such as Thanksgiving, thus the storage volume needed is approximately 4 days for this condition
3. Storage of RDF during a temporary outage of the RRP for repairs, line plugs, etc. ensuring an RDF supply is available for the combustion system. Storage volume needed is approximately 2 days.
4. MSW accumulation into the RRP greater than 4 days might be re-directed to landfill during these conditions. This landfilling could be avoided with one of the following options:
    a. Increasing provisions for MSW storage at the inlet to the RRP (front end). Please note that the current study does NOT reflect this front-end storage for Options 1, 2A or 3A.

Options 3B (MSW mass burn combustion) is the only option that provides up-front MSW storage as it is mandatory for this type of system.

b. Conducting RRP major maintenance during periods of no MSW collection (e.g. weekends).
c. Installing RRP process redundancy.

5. Storage of RDF during a relative short electric grid outage. These can be planned or unplanned. This is required occasionally for electric power system testing and electrical system disturbances. The PP would include a bypass steam condenser to enable the continued consumption of RDF/MSW during these conditions or after a steam turbine trip. In this mode no electricity would be produced but combustion of RDF would continue. Storage capacity needed is approximately 2 days.
6. Storage of RDF during a partial Power Plant outage (one of two units are offline for an extended period of 7-14 days). This is an important criterion for storage sizing. All of the evaluated options have two boiler systems. The storage duration provided by a given storage capacity is determined by the difference in RDF amount combusted during normal operation vs. the RDF combusted with a unit offline. This approximate storage amount varies in each of the options evaluated. Another important criterion is that the normal load point on the boiler(s) in the base case (lead boiler or parallel boilers) is that the boiler(s) operate between a nominal 70% and 100% over the life of the evaluation. Operation below the nominal 70% part-load is normally not desirable in RDF/MSW boilers for combustion and emissions control reasons.

   As an example, in the base case (Option 1) the air permit only allows one co-fired boiler to operate at a time. Since Unit 8 is ~25% larger than Unit 7, operation of Unit 7 becomes the controlling factor on how long a given storage capacity will last. In other words, the effectiveness of a particular storage capacity is dictated by the periods when the smaller unit is operating (larger unit offline). In the case of two identical ("twin") units designed to operate in parallel during normal operation, it is expected that one unit would continue to operate while the other is undergoing maintenance. If both units are of equal size (for commonality of parts, operation, control, reduced unit first cost) then if either unit is down, the impact is the same. Either boiler can be considered lead or lag since they are of equal size. Note that once the second unit is operational in the case of twin boilers, the combined capacity must be greater than 100% of the RDF production in all years or else the two boilers operating in parallel would never be able to consume what was accumulated in storage. The larger the size of the twin boilers the larger the first cost, land requirements, parasitic load, etc. and the lower the load point during normal operation. For example, twin boilers sized at 75% of the design load each, would yield a total installed capacity of 150%. During normal operation, each boiler would be operating at a part load of 67% (50% load/75% design) which is close to the nominal 70% minimum part load threshold desired. Boilers typically experience their best efficiency above 70% load. To optimize the boiler size selection, the type of boiler, its part-load efficiency curve, boiler physical size, boiler costing, parasitic load, and impacts on system requirements would need to be known. Once the twin boiler size is finalized with the vendor, and the part load curve is confirmed, the impact of a given storage capacity can be refined.

Storage Needs for Evaluated Options

In the attached Excel workbook, the impact of boiler rating and storage capacity is calculated for each option. Cells shown in blue font are the primary inputs in the storage calculation for each Option.

The first row of each option section is the "Annual RDF" production rate by the RRP. In the Base Case (Option 1), the throughput is truncated at the current System's existing capacity of 32,000 TPY. The row below shows the equivalent daily rate of RDF (MSW for Options 3B-1 & 3B-2). The lag unit burn rate (or twin burn rate) is listed to show the rate which is capable of being consumed when one (larger, if applicable) unit is offline. The daily rate less the burn rate of the lag unit is the accumulation to storage. The accumulation divided into the storage capacity determines the days of storage during single unit operation, assuming the bin is empty before beginning single unit operation. If there is material in the storage bin before single unit operation is commenced, the time required to fill the bin would be proportionally reduced. The two days of front-end (upstream of the RRP) is not included in the analysis, except for Options 3B-1 & 3B-2 where there is no RRP, and the only storage is front-end. A target storage capacity of at least 10 days for RDF and 4 days for MSW (3B-1,2 cases) was viewed as sufficient during single boiler operation where there is rotation of boiler feedstock. Four (4) days of non-rotating stock (no boilers operating) of RDF or MSW storage would be a target storage value over the 20-year period. More storage would accommodate longer unit outages but poses an increased danger in the potential for self-ignition due to decomposition of waste. Compaction of RDF can also be exacerbated with increased RDF storage. For MSW, where there are batteries, electronics and other materials that can serve as ignition sources, generally no more than 4 days of storage is the maximum recommended. Regardless all storage facilities would be equipped with a fire suppression system to abate any self-ignition.

In Option 1 (Base case), the throughput is at a maximum, and MSW is redirected to the landfill due to the limited capacity of 32,000 TPY through the power plant. The current storage of 200 tons can support approximately 16 days of storage (i.e. lead unit 8 outage) while maintaining the 32,000 TPD rate thru the RRP with some MSW constantly bypassed to landfill. When the RRP is operated at its full capability (same throughput as Option 2A) the days of continuous storage while operating Unit 7 drops to 9.4 days in the current year and diminishes to 4.2 days in 2044.

In Option 2A, where the new RDF boiler is larger, Unit 8 becomes the backup. Unit 9's capacity is a nominal 125 TPD (minimum). Initially storage is not an issue, since Unit 8's capacity is so large for the backup unit. However, as the available MSW (and RDF) increases with time the 200 tons of storage along with unit 8's "backup" continuous capacity of 96 TPD (peak rating can reach 115 TPD) yields approximately 7.5 days of storage at the end of the 24-year evaluation period. This means in year 2044, assuming the MSW growth and RDF yield projections are correct, and the boiler capacity is able to be maintained, that after 7.5 days the 200-ton bin would be full and the RRP would have to bypass any additional MSW to landfill. As a result, additional storage beyond the existing 200-ton RDF bin is not indicated until possibly year 19 when the storage falls below 10 days. The normal load point varies between 74% and 98% which is acceptable. Note that if Unit 9's capacity is selected for only 120 TPD, then the RDF available exceeds Unit 8's capacity in year 21. Therefore Unit 9 should be sized to handle a minimum of 125 TPD.

In Option 2B, the new twin large RDF boilers are rated at 90 TPD. At this firing rate the average boiler load during normal operation starting in 2026 (when the plant would be commercial) is 69% - 84% over the evaluation period which is acceptable (since the boiler part-load desired operating point is generally at or above a nominal 70% (which is an industry accepted operating point). With 400 tons of storage the lead unit could be offline for almost 12 days in year 2026 (but only last 6.6 days in year 2044) before MSW would need to be diverted requiring more storage possibly in later years. Reducing the size of the twin boilers improves the normal boiler load point but reduces the effective storage over the project's evaluation period. Likewise increasing the size of the boilers reduces the normal load point on the boilers to below 70% for more years, and storage is extended. Additional storage could be added in the later years of the project if the growth assumptions truly materialize. Installing two 100% boilers (@150 TPD to meet year 2044 needs) would allow one boiler to operate at 78%-100% during normal operation throughout the project life which would require less storage. This would require higher initial capital costs for the larger boilers and associated systems to support it.

In Option 3A-1, as in Option 2A, Unit 8 is the backup. With the development of a new state-of-the-art RRP additional RDF will be produced as compared to the current RRP. Unit 9 is rated at 155 TPD to yield an operating load of 74%-91% from 2026 to 2044. With the large lag unit capability of 96 TPD the current 200 tons of storage can last for 10 days in 2026, but 400 total tons of storage is needed to maintain over 10 days of storage for most of the evaluation period.

In Option 3A-2, the twin boilers are rated at 85 TPD. The boilers loading is 68% to 83% from 2026 to 2044 which is marginal. With 400 tons of storage, days of storage start as 13.2 days in 2026 and dwindle to 7.2 days in year 2044. Increasing the boiler sizing to 100 TPD improves the storage, but it also reduced the part-load of the boiler below 70% for more years which is not acceptable. Decreasing the boiler size would result in higher load points during normal operation but decrease to reduce the effective storage, requiring more storage to achieve at 10 days in the later years. Installing two 100% boilers (@150 TPD to meet year 2044 needs) would allow one boiler to operate at 78%-100% load during normal operation throughout the project life which would require very little storage to handle only the operational impacts of less than 24 hours such as startup/shutdown transitions. This would require higher initial capital costs for the larger boilers and associated systems.

In Option 3B-1 and 3B-2, the twin MSW boilers are rated at 110 TPD. All of the storage is "floor storage" (or in a pit if so designed) at the front end. More than 4 days storage during no power production periods is not recommended for MSW due to the increased fire hazard associated with it. Storage design would include water cannons to put out fires typically caused by batteries and other hazardous materials, which have not been removed from the waste stream. Approximately 400 tons of storage would provide close to 4 days of storage in year 2044. Total PP outages longer than approximately 4 days would result in MSW diversion to the landfill. The impact could be minimized by scheduling planned PP outages during time of less MSW and/or days of no collection (e.g. long weekends) to avoid landfilling.

MSW ANNUAL ESCALATION = 101.10%

RDF/MSW STORAGE ANALYSIS

OPTION 1

Lead Unit 8 continuous Rating 96 [TPD]
Lag unit 7 continuous Rating 75 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
MSW Avail		52,000	52,572	53,150	53,735	54,326	54,924	55,528	56,139	56,756	57,380	58,012	58,650	59,295	59,947	60,607	61,273	61,947	62,629	63,318	64,014	64,718	65,430	66,150
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual RDF	TPY	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Daily RDF (Annual/365)	TPD	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7
Lag unit burn rate	TPD	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Excess Accum to storage daily	TPD	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
Storage Size	tons	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
If Lead Unit is Off-line																								
Days of Continuous Outage Storage Capacity	days	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
Average load point during normal operation	%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

OPTION 2A

Lead Unit # 9 Continuous Rating 125 [TPD]
Lag unit #8 Continuous Rating 96 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual RDF	TPY	35,173	35,560	35,951	36,347	36,747	37,151	37,560	37,973	38,390	38,813	39,240	39,671	40,108	40,549	40,995	41,446	41,902	42,363	42,829	43,300	43,776	44,258	44,744
Daily RDF (Annual/365)	TPD	96	97	98	100	101	102	103	104	105	106	108	109	110	111	112	114	115	116	117	119	120	121	123
Lag unit burn rate	TPD	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Excess Accum to storage daily	TPD	0.0	1.0	2.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.5	12.7	13.9	15.1	16.3	17.6	18.8	20.1	21.3	22.6	23.9	25.3	26.6
Storage Size	tons	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
If Lead Unit is Off-line																								
Days of Continuous Outage Storage Capacity	days	n/a	200.0	100.0	50.0	40.0	33.3	28.6	25.0	22.2	20.0	17.4	15.8	14.4	13.3	12.3	11.4	10.6	10.0	9.4	8.8	8.4	7.9	7.5
Average load point during normal operation	%	77%	78%	78%	80%	81%	82%	82%	83%	84%	85%	86%	87%	88%	89%	90%	91%	92%	93%	94%	95%	96%	97%	98%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

OPTION 2B

Unit 9 Continuous Rating 90 [TPD]
Unit 10 Continuous Rating 90 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual RDF	TPY	43,139	43,614	44,093	44,578	45,069	45,565	46,066	46,572	47,085	47,603	48,126	48,656	49,191	49,732	50,279	50,832	51,391	51,957	52,528	53,106	53,690	54,281	54,878
Daily RDF (Annual/365)	TPD	118	119	121	122	123	125	126	128	129	130	132	133	135	136	138	139	141	142	144	145	147	149	150
Single unit burn rate	TPD	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Excess Accum to storage daily	TPD	28.2	29.5	30.8	32.1	33.5	34.8	36.2	37.6	39.0	40.4	41.9	43.3	44.8	46.3	47.8	49.3	50.8	52.3	53.9	55.5	57.1	58.7	60.4
Storage Size	tons	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
If 2nd Unit is Offline																								
Days of Continuous Outage Storage Capacity	days	14.2	13.6	13.0	12.4	11.9	11.5	11.0	10.6	10.3	9.9	9.6	9.2	8.9	8.6	8.4	8.1	7.9	7.6	7.4	7.2	7.0	6.8	6.6
Average load point during normal operation	%	66%	66%	67%	68%	69%	69%	70%	71%	72%	72%	73%	74%	75%	76%	77%	77%	78%	79%	80%	81%	82%	83%	84%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

OPTION 3A-1

Lead Unit 9 Continuous Rating 155 [TPD]
Lag unit 8 Continuous Rating 96 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual RDF	TPY	42,105	42,568	43,036	43,509	43,988	44,472	44,961	45,456	45,956	46,461	46,972	47,489	48,011	48,539	49,073	49,613	50,159	50,711	51,268	51,832	52,403	52,979	53,562
Daily RDF (Annual/365)	TPD	115	117	118	119	121	122	123	125	126	127	129	130	132	133	134	136	137	139	140	142	144	145	147
Lag unit burn rate	TPD	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Excess Accum to storage daily	TPD	19.4	20.6	21.9	23.2	24.5	25.8	27.2	28.5	29.9	31.3	32.7	34.1	35.5	37.0	38.4	39.9	41.4	42.9	44.5	46.0	47.6	49.1	50.7
Storage Size	tons	200	200	200	200	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
If Lead Unit is Off-line																								
Days of Continuous Outage Storage Capacity	Days	10.3	9.7	9.1	8.6	16.3	15.5	14.7	14.0	13.4	12.8	12.2	11.7	11.3	10.8	10.4	10.0	9.7	9.3	9.0	8.7	8.4	8.1	7.9
Average load point during normal operation	%	74%	75%	76%	77%	78%	79%	79%	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%	91%	92%	93%	94%	95%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

OPTION 3A-2

Unit 9 Continuous Rating 85 [TPD]
Unit 10 Continuous Rating 85 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual RDF	TPY	42,105	42,568	43,036	43,509	43,988	44,472	44,961	45,456	45,956	46,461	46,972	47,489	48,011	48,539	49,073	49,613	50,159	50,711	51,268	51,832	52,403	52,979	53,562
Daily RDF (Annual/365)	TPD	115	117	118	119	121	122	123	125	126	127	129	130	132	133	134	136	137	139	140	142	144	145	147
Single unit burn rate	TPD	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Excess Accum to storage daily	TPD	30.4	31.6	32.9	34.2	35.5	36.8	38.2	39.5	40.9	42.3	43.7	45.1	46.5	48.0	49.4	50.9	52.4	53.9	55.5	57.0	58.6	60.1	61.7
Storage Size	tons	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
If 2nd Unit is Offline																								
Days of Continuous Outage Storage Capacity	Days	13.2	12.6	12.2	11.7	11.3	10.9	10.5	10.1	9.8	9.5	9.2	8.9	8.6	8.3	8.1	7.9	7.6	7.4	7.2	7.0	6.8	6.7	6.5
Average load point during normal operation	%	68%	69%	69%	70%	71%	72%	72%	73%	74%	75%	76%	77%	77%	78%	79%	80%	81%	82%	83%	84%	84%	85%	86%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Option 3B-1

Unit 9 Continuous Rating 105 [TPD]
Unit 10 Continuous Rating 105 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual MSW	TPY	51,208	51,772	52,341	52,917	53,499	54,087	54,682	55,284	55,892	56,507	57,128	57,757	58,392	59,034	59,684	60,340	61,004	61,675	62,354	63,039	63,733	64,434	65,143
Daily MSW (Annual/365)	TPD	140	142	143	145	147	148	150	151	153	155	157	158	160	162	164	165	167	169	171	173	175	177	178
Single unit burn rate	TPD	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
Excess Accum to storage daily	TPD	35.3	36.8	38.4	40.0	41.6	43.2	44.8	46.5	48.1	49.8	51.5	53.2	55.0	56.7	58.5	60.3	62.1	64.0	65.8	67.7	69.6	71.5	73.5
Storage Size	tons	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
If 2nd Unit is Offline																								
Days of Continuous Outage Storage Capacity	Days	11.3	10.9	10.4	10.0	9.6	9.3	8.9	8.6	8.3	8.0	7.8	7.5	7.3	7.0	6.8	6.6	6.4	6.3	6.1	5.9	5.7	5.6	5.4
Average load point during normal operation	%	67%	68%	68%	69%	70%	71%	71%	72%	73%	74%	75%	75%	76%	77%	78%	79%	80%	80%	81%	82%	83%	84%	85%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Option 3B-2

Unit 9 Continuous Rating 100 [TPD]
Unit 10 Continuous Rating 100 [TPD]

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
YEAR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Annual MSW	TPY	51,208	51,772	52,341	52,917	53,499	54,087	54,682	55,284	55,892	56,507	57,128	57,757	58,392	59,034	59,684	60,340	61,004	61,675	62,354	63,039	63,733	64,434	65,143
Daily MSW (Annual/365)	TPD	140	142	143	145	147	148	150	151	153	155	157	158	160	162	164	165	167	169	171	173	175	177	178
Single unit burn rate	TPD	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Excess Accum to storage daily	TPD	40.3	41.8	43.4	45.0	46.6	48.2	49.8	51.5	53.1	54.8	56.5	58.2	60.0	61.7	63.5	65.3	67.1	69.0	70.8	72.7	74.6	76.5	78.5
Storage Size	tons	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
If 2nd Unit is Offline																								
Days of Continuous Outage Storage Capacity	Days	9.9	9.6	9.2	8.9	8.6	8.3	8.0	7.8	7.5	7.3	7.1	6.9	6.7	6.5	6.3	6.1	6.0	5.8	5.6	5.5	5.4	5.2	5.1
Average load point during normal operation	%	70%	71%	72%	72%	73%	74%	75%	76%	77%	77%	78%	79%	80%	81%	82%	83%	84%	84%	85%	86%	87%	88%	89%
Avg lag unit load point during lead unit outage	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

APPENDIX C

Preliminary Conceptual Facility Layouts

OPTION 1 (As - Is)

Resource Recovery and Power Plant As-Is (Base Case)

RRT DESIGN & CONSTRUCTION
A Service of Enviro-Services & Constructors, Inc.

CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA

OVERALL SITE PLAN
OPTION 1

REV	DESCRIPTION	DATE BY CHK
A	ISSUED FOR FINAL REPORT	4/7/22 LH JS

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1 Huntington Quadrangle, 3S01 ph: 631-756-1060
Melville, N.Y. 11747 fax: 631-756-1064

	BY	DATE
DRAWN	LH	6/29/21
CHECKED	JS	6/29/21
DESIGNED	JS	6/29/21
APPROVED		
APPROVED		

PROJ. No: 507-006
SCALE: 1" = 100'-0"
DWG. NO: SK-1
REV: A
CAD FILE:
SHEET SIZE: D-24x36

OPTION 2A

Existing RRP With A New RDF Unit in the Existing Power Plant

RRT DESIGN & CONSTRUCTION
A Service of Enviro-Services & Constructors, Inc.

CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA

CONCEPTUAL LAYOUT
OPTION 2A

REV	DESCRIPTION	DATE	BY	CHK
A	ISSUED FOR FINAL REPORT	4/7/22	LH	JS

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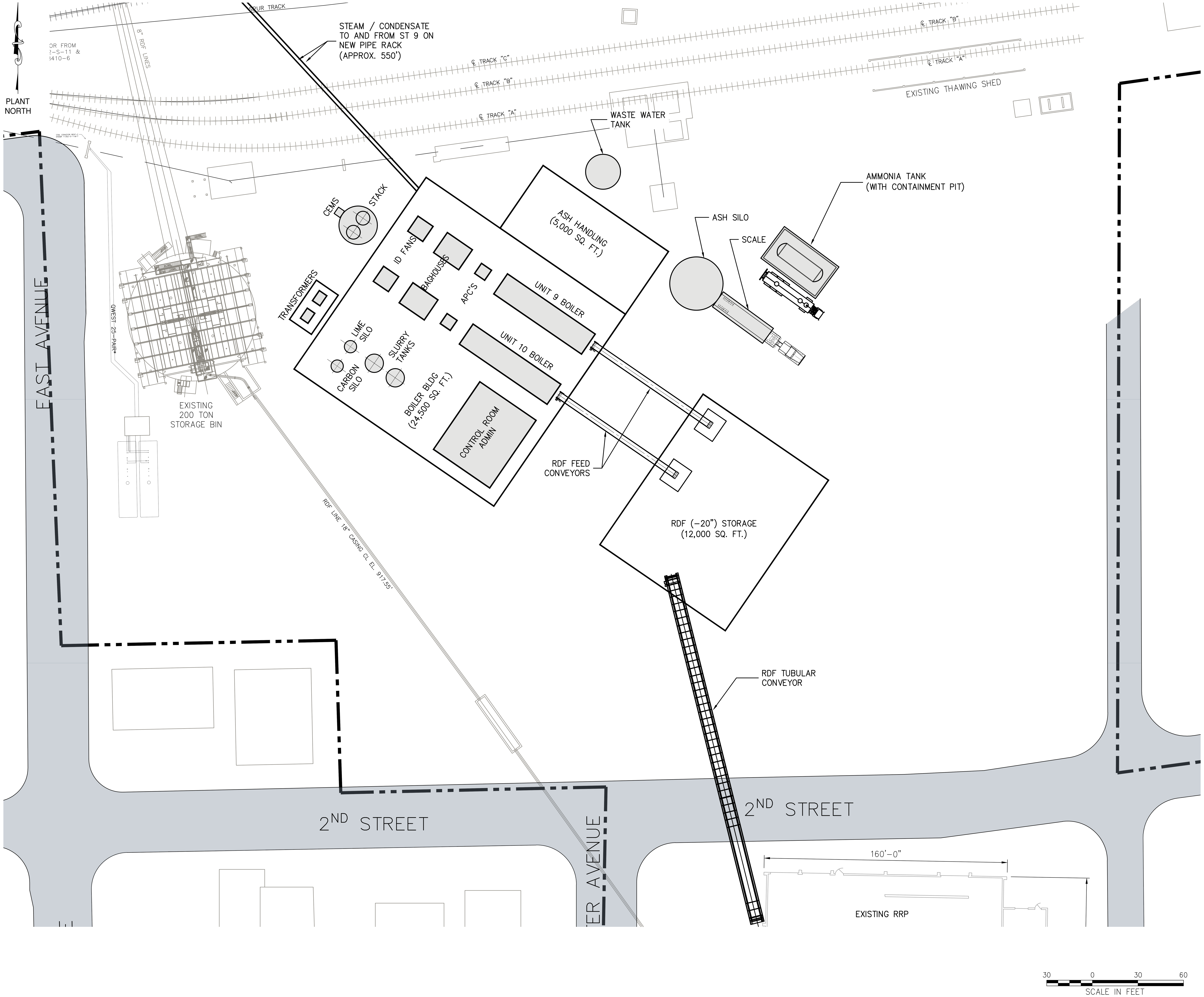
APPROVED		

PROJ. No: 507-006 | SCALE: 1/16" = 1'-0"
DWG. NO: SK-2A | A
CAD FILE:
SHEET SIZE: D-24x36 | REV



OPTION 2B

Modified RRP (20" RDF) With Two New RDF Units at Coal Yard

REV	DESCRIPTION	DATE	BY	CHK
A	ISSUED FOR FINAL REPORT	4/7/22	LH	JS

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CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA

CONCEPTUAL LAYOUT
OPTION 2B

	BY	DATE
DRAWN	LH	6/29/21
CHECKED	JS	6/29/21
DESIGNED	JS	6/29/21
APPROVED		
APPROVED		

PROJ. No: 507-006 SCALE: 1" = 30'-0"
DWG. NO: SK-2B REV: A
CAD FILE:
SHEET SIZE: D-24x36

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Melville, N.Y. 11747
ph: 631-756-1060
fax: 631-756-1064


PLANT NORTH
SPUR TRACK
STEAM / CONDENSATE TO AND FROM ST 9 ON NEW PIPE RACK (APPROX. 550')
℄ TRACK "C"
℄ TRACK "B"
℄ TRACK "A"
EXISTING THAWING SHED
WASTE WATER TANK
TRANSFORMERS
NEW RDF FEED LINE 130'-0"
BOILER
LIME SILO
ASH HANDLING (5,000 SQ. FT.)
SLURRY TANKS
BAGHOUSE
APC
STACK
ID FAN
BOILER BLDG (20,00 SQ.FT.)
CONTROL ROOM ADMIN
ASH SILO
SCALE
AMMONIA TANK (WITH CONTAINMENT PIT)
TRUCK SCALES
SCALE HOUSE
EXISTING 200 TON STORAGE BIN
EAST AVENUE
NEW RDF FEED LINE 210'-0"
NEW 200 TON STORAGE BIN (7,000 SQ.FT.)
RDF LINE 18" CASING CL EL 917.55'
NEW RDF FEED LINES
NEW S.O.A. RRP TIPPING, STORAGE AND PROCESSING BUILDING (35,000 SQ.FT.)
2ND STREET
2ND STREET
160'-0"
30 0 30 60
SCALE IN FEET
AREA OF WORK
KEY PLAN
SCALE: NONE
OPTION 3A - 1
New RRP and New RDF Unit at Coal Yard
RRT DESIGN & CONSTRUCTION
A Service of Enviro-Services & Constructors, Inc.
CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA
CONCEPTUAL LAYOUT
OPTION 3A-1
A ISSUED FOR FINAL REPORT 4/7/22 LH JS
REV DESCRIPTION DATE BY CHK
DRAWN LH 6/29/21
CHECKED JS 6/29/21
DESIGNED JS 6/29/21
APPROVED
PROJ. No: 507-006
SCALE: 1" = 30'-0"
DWG. NO: SK-3A-1
REV A
SHEET SIZE: D-24x36
RRT Design & Construction
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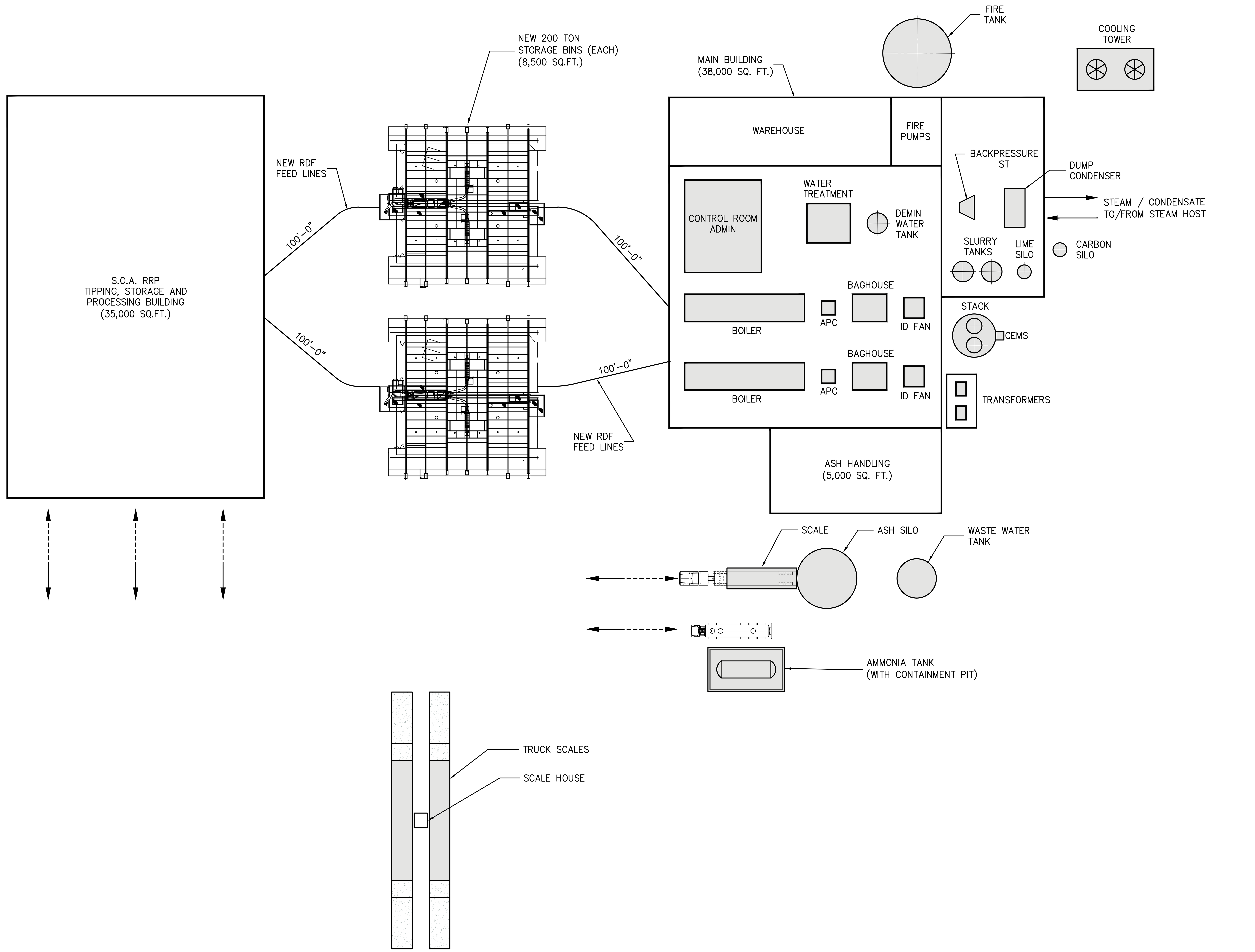

NOTE:

1. AREA ASSUMPTION FOR THIS SITE IS APPROXIMATELY 10.0 ACRES.

OPTION 3A - 2

New RRP and New RDF Units at Greenfield

RRT DESIGN & CONSTRUCTION
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CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA

CONCEPTUAL LAYOUT
OPTION 3A-2

REV	DESCRIPTION	DATE	BY	CHK
A	ISSUED FOR FINAL REPORT	4/7/22	LH	JS

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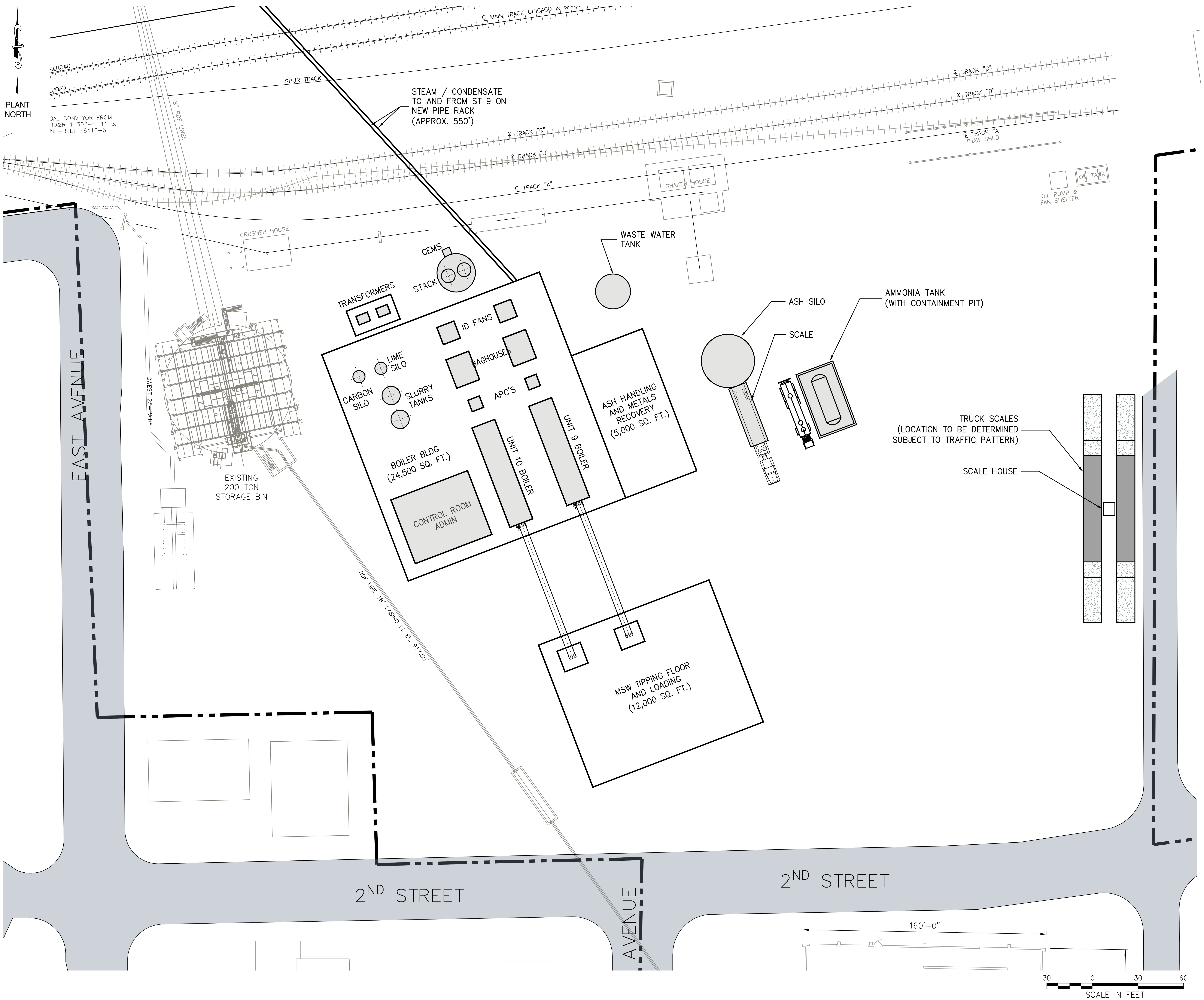
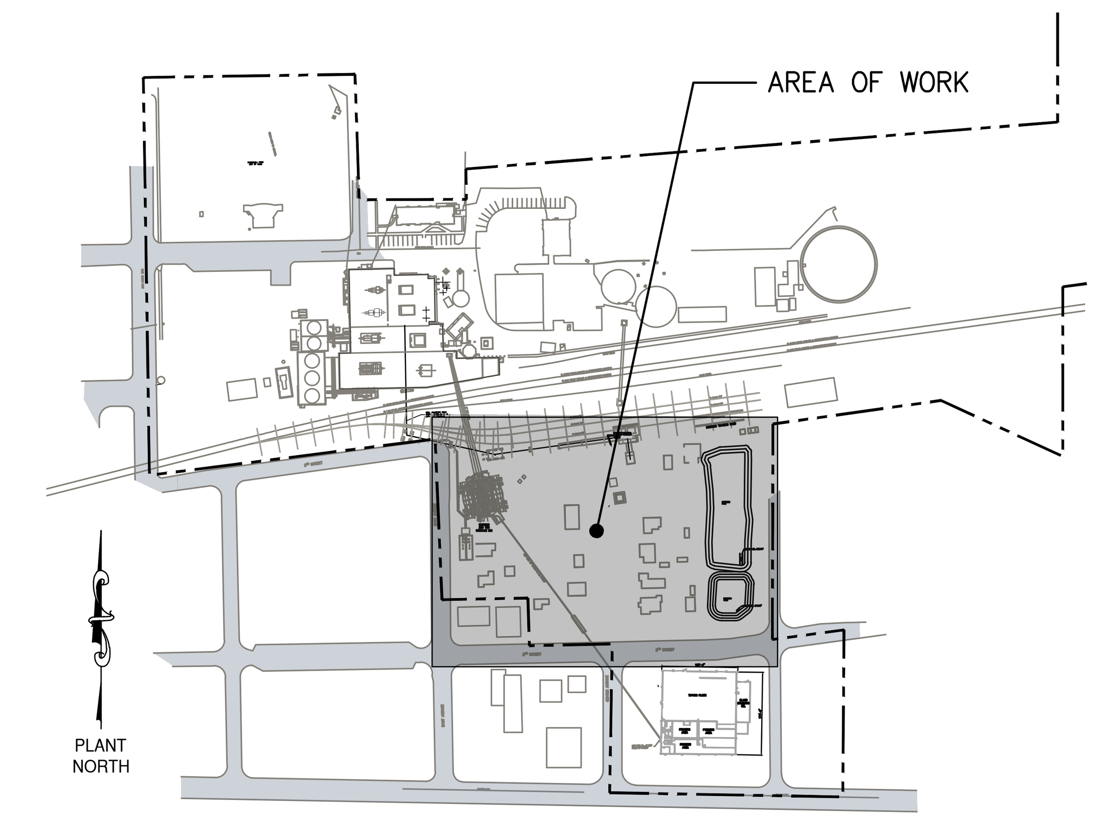
	BY	DATE
DRAWN	LH	6/29/21
CHECKED	JS	6/29/22
DESIGNED	JS	6/29/21
APPROVED		
APPROVED		

PROJ. No: 507-006 SCALE: 1" = 30'-0"
DWG. NO: SK-3A-2 REV A
CAD FILE:
SHEET SIZE: D–24x36





KEY PLAN
SCALE: NONE

OPTION 3B - 1

Two New MSW WTE Units at Coal Yard

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CITY OF AMES
RESOURCE RECOVERY FACILITY
AMES, IA

CONCEPTUAL LAYOUT
OPTION 3B-1

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fax: 631-756-1064

	BY	DATE
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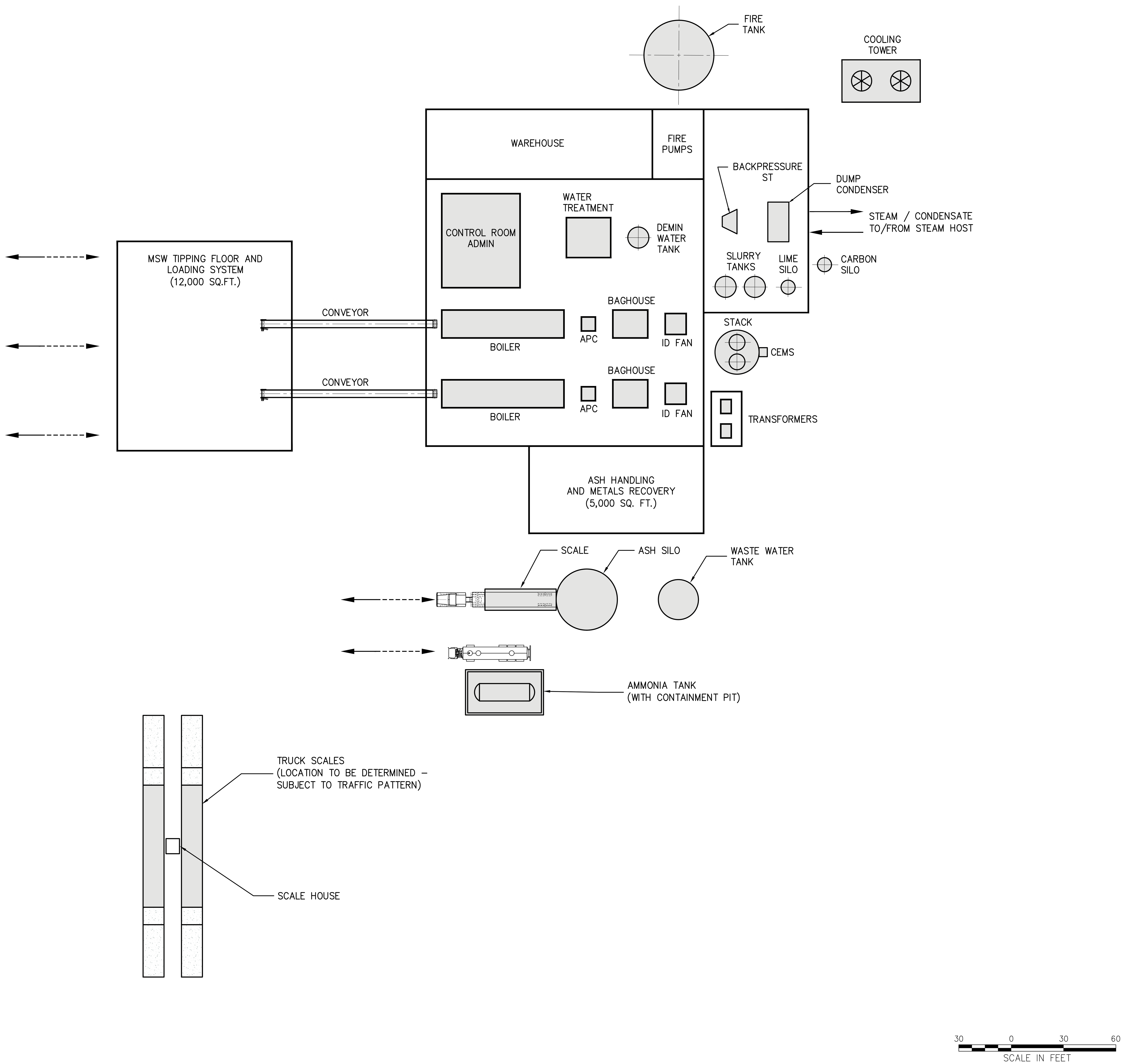
CHECKED	JS	6/29/21
DESIGNED	JS	6/29/21
APPROVED		
APPROVED		

PROJ. No: 507-006
SCALE: 1" = 30'-0"
DWG. NO: SK-3B-1
REV: A
CAD FILE:
SHEET SIZE: D-24x36

NOTE:

1. AREA ASSUMPTION FOR THIS SITE IS APPROXIMATELY 9.0 ACRES.



OPTION 3B - 2

Two New MSW WTE Units at Greenfield

REV	DESCRIPTION	DATE / BY / CHK
A	ISSUED FOR FINAL REPORT	4/7/22 LH JS

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CONCEPTUAL LAYOUT
OPTION 3B-2

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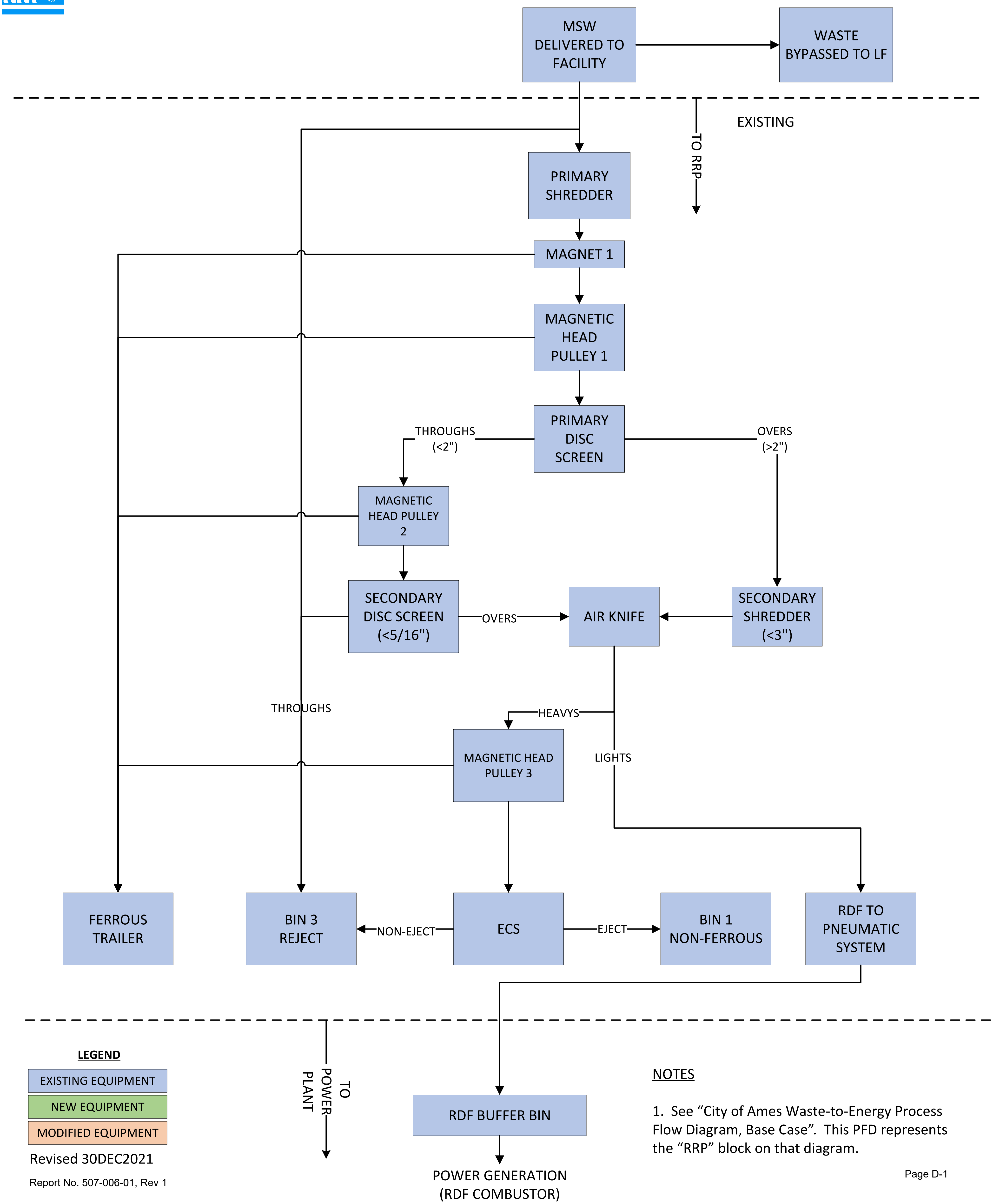
	BY	DATE
DRAWN	LH	6/29/21
CHECKED	JS	6/29/21
DESIGNED	JS	6/29/21
APPROVED		
APPROVED		

PROJ. No: 507-006
SCALE: 1" = 30'-0"
DWG. NO: SK-3B-2
REV: A
CAD FILE:
SHEET SIZE: D–24x36

APPENDIX D
RRP Process Flow Diagrams

RRP PROCESS FLOW DIAGRAM, OPTION 1



LEGEND

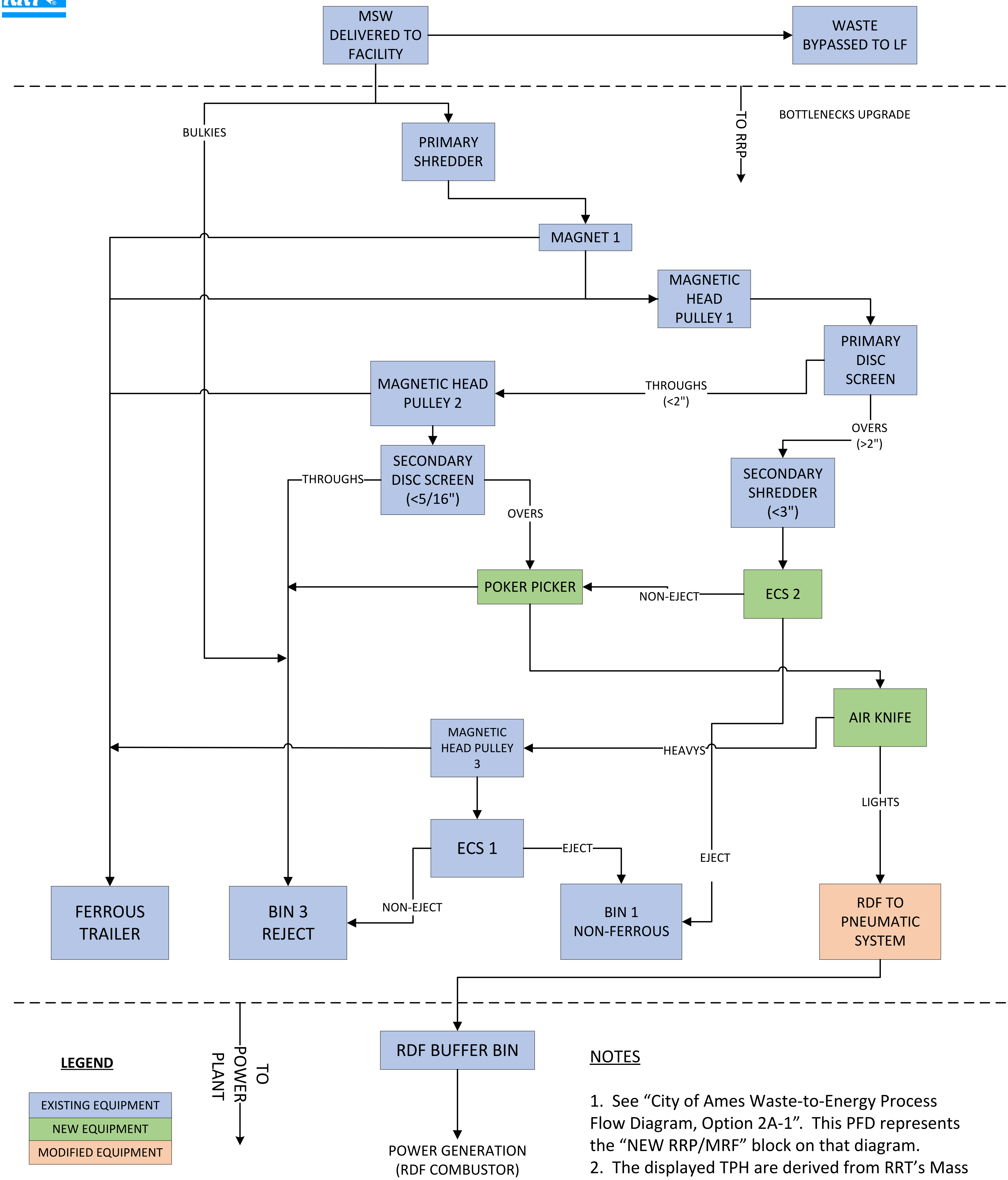
- EXISTING EQUIPMENT
- NEW EQUIPMENT
- MODIFIED EQUIPMENT

Revised 30DEC2021

NOTES

1. See “City of Ames Waste-to-Energy Process Flow Diagram, Base Case”. This PFD represents the “RRP” block on that diagram.

RRP PROCESS FLOW DIAGRAM, OPTION 2A



LEGEND

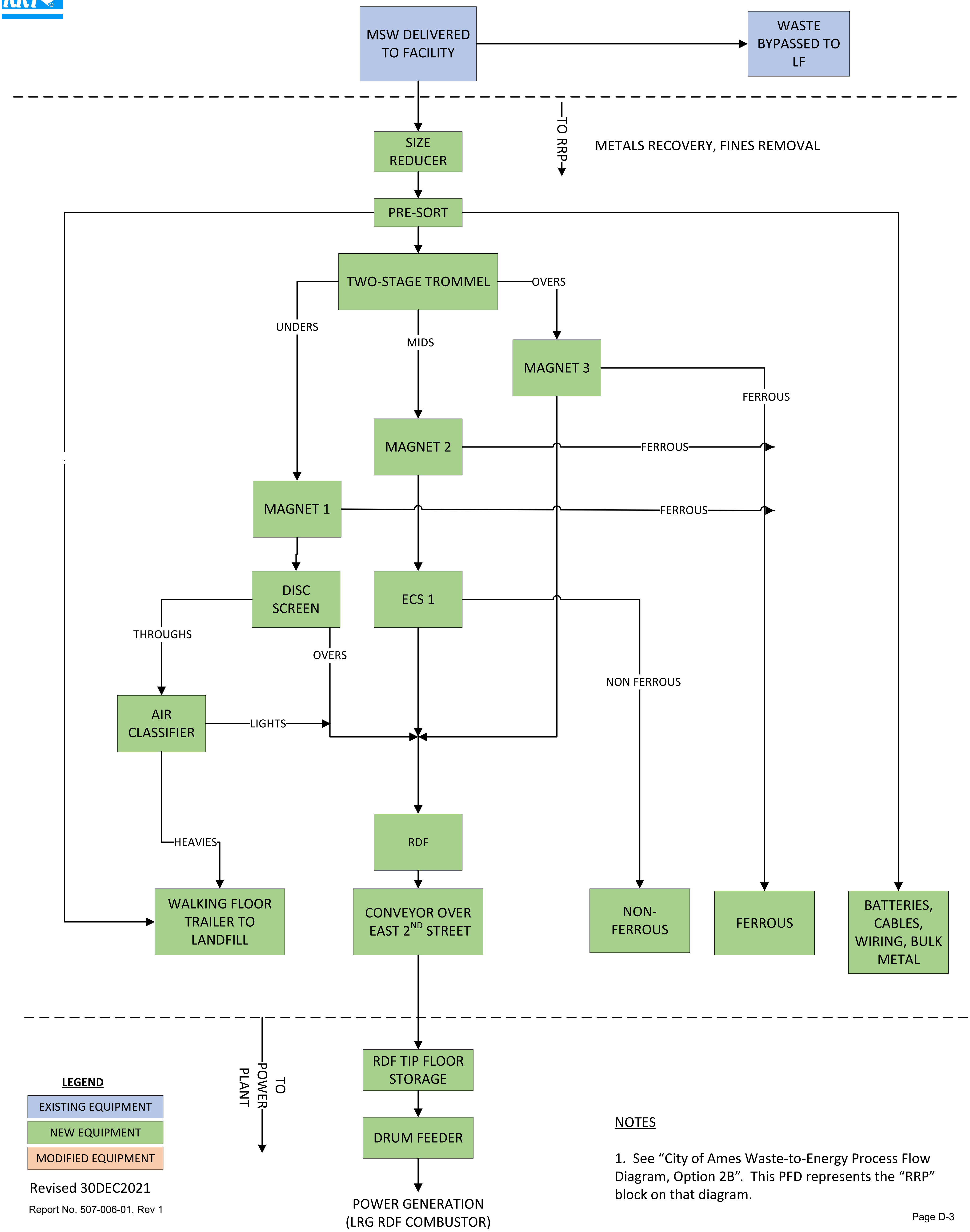
EXISTING EQUIPMENT
NEW EQUIPMENT
MODIFIED EQUIPMENT

Revised 02MAR2022

NOTES

1. See "City of Ames Waste-to-Energy Process Flow Diagram, Option 2A-1". This PFD represents the "NEW RRP/MRF" block on that diagram.
2. The displayed TPH are derived from RRT's Mass Balance dated 10/26/2021.
3. Option 2A includes RDF storage in new and existing buffer bin.

RRP PROCESS FLOW DIAGRAM, OPTION 2B

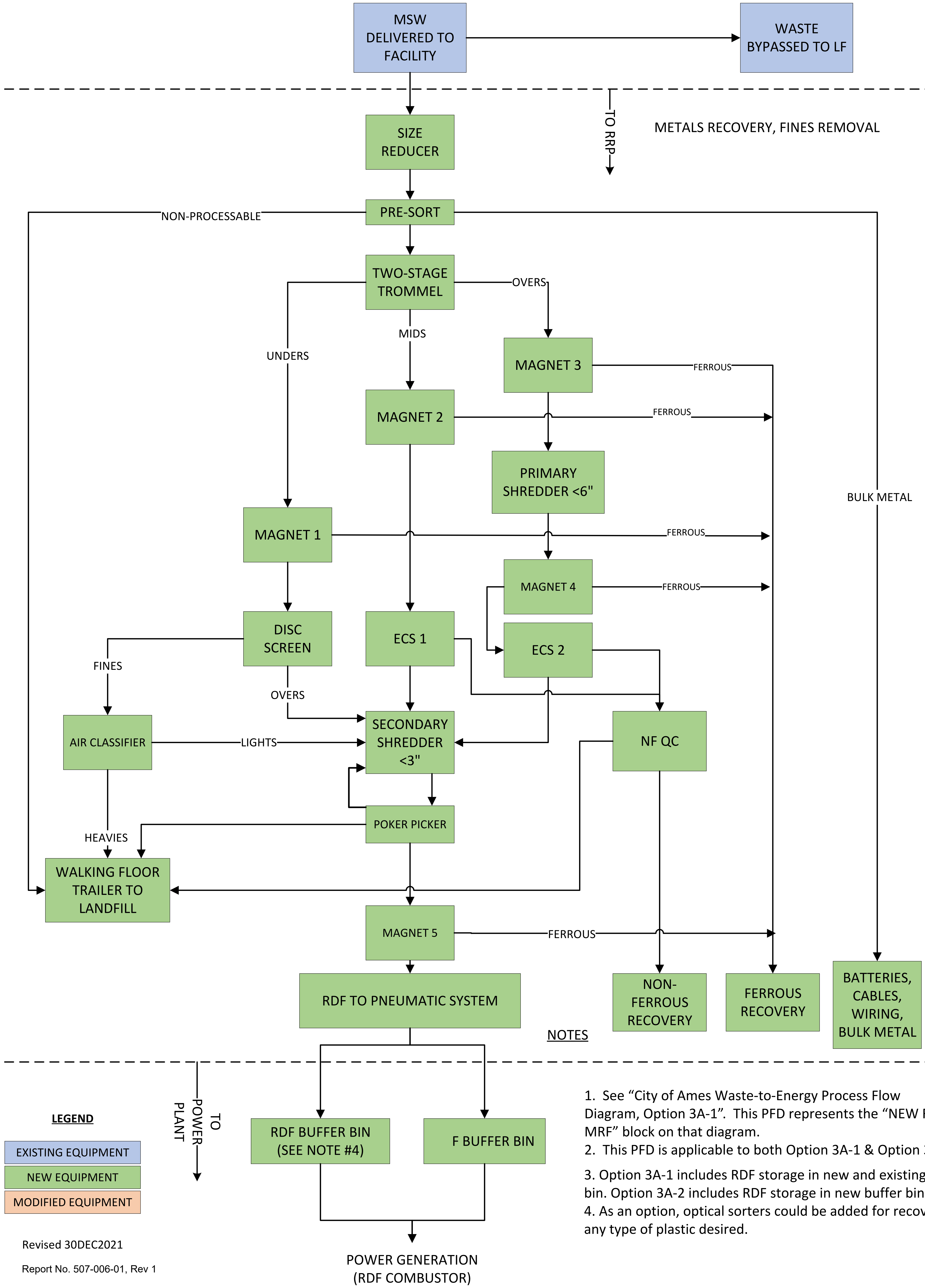


Revised 30DEC2021

NOTES

1. See "City of Ames Waste-to-Energy Process Flow Diagram, Option 2B". This PFD represents the "RRP" block on that diagram.

RRP PROCESS FLOW DIAGRAM, OPTION 3A



LEGEND

- EXISTING EQUIPMENT
- NEW EQUIPMENT
- MODIFIED EQUIPMENT

NOTES

1. See "City of Ames Waste-to-Energy Process Flow Diagram, Option 3A-1". This PFD represents the "NEW RRP/ MRF" block on that diagram.
2. This PFD is applicable to both Option 3A-1 & Option 3-A2
3. Option 3A-1 includes RDF storage in new and existing buffer bin. Option 3A-2 includes RDF storage in new buffer bin.
4. As an option, optical sorters could be added for recovery of any type of plastic desired.

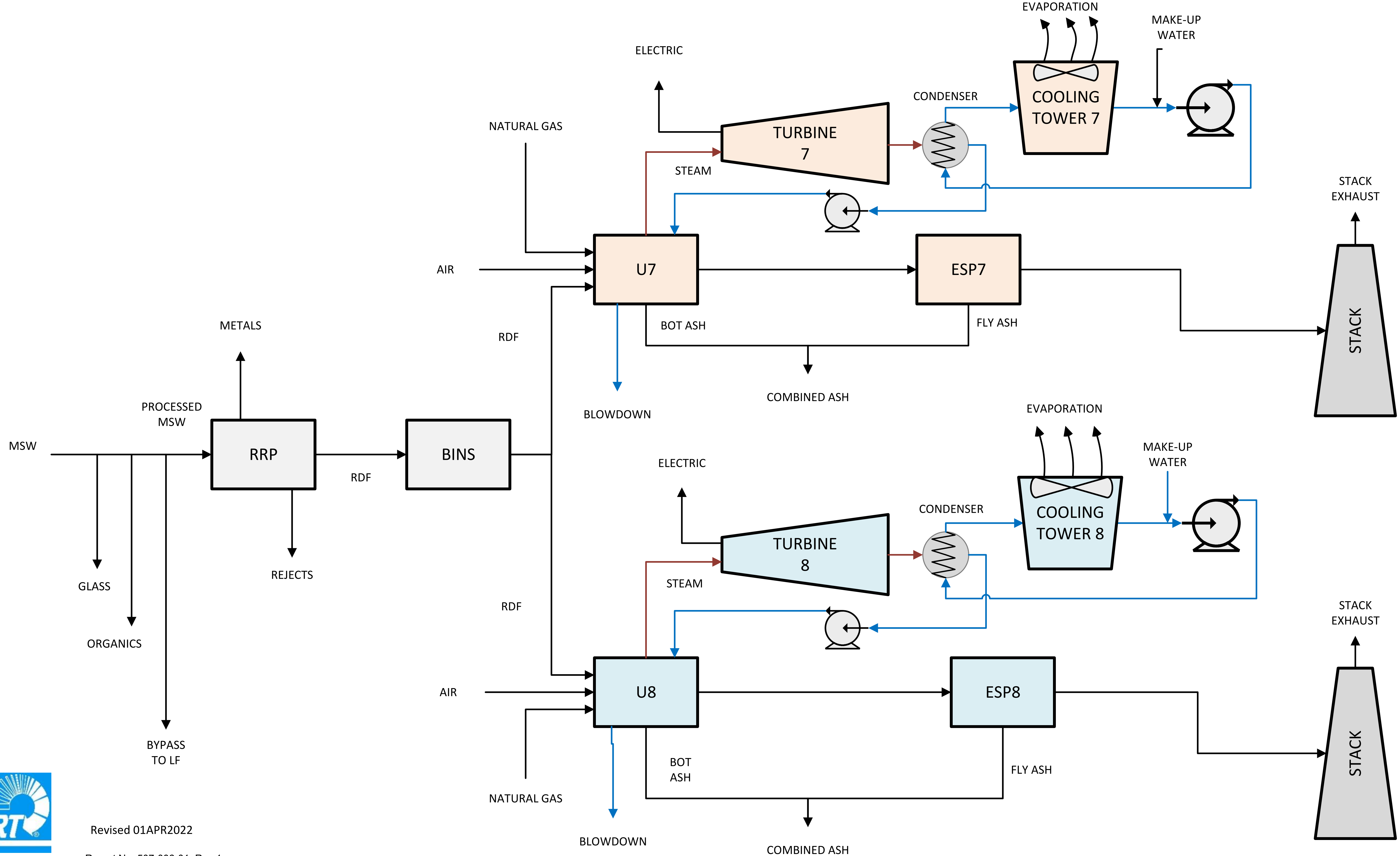
Revised 30DEC2021

Report No. 507-006-01, Rev 1

APPENDIX E

Overall Process Flow Diagrams

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, BASE CASE

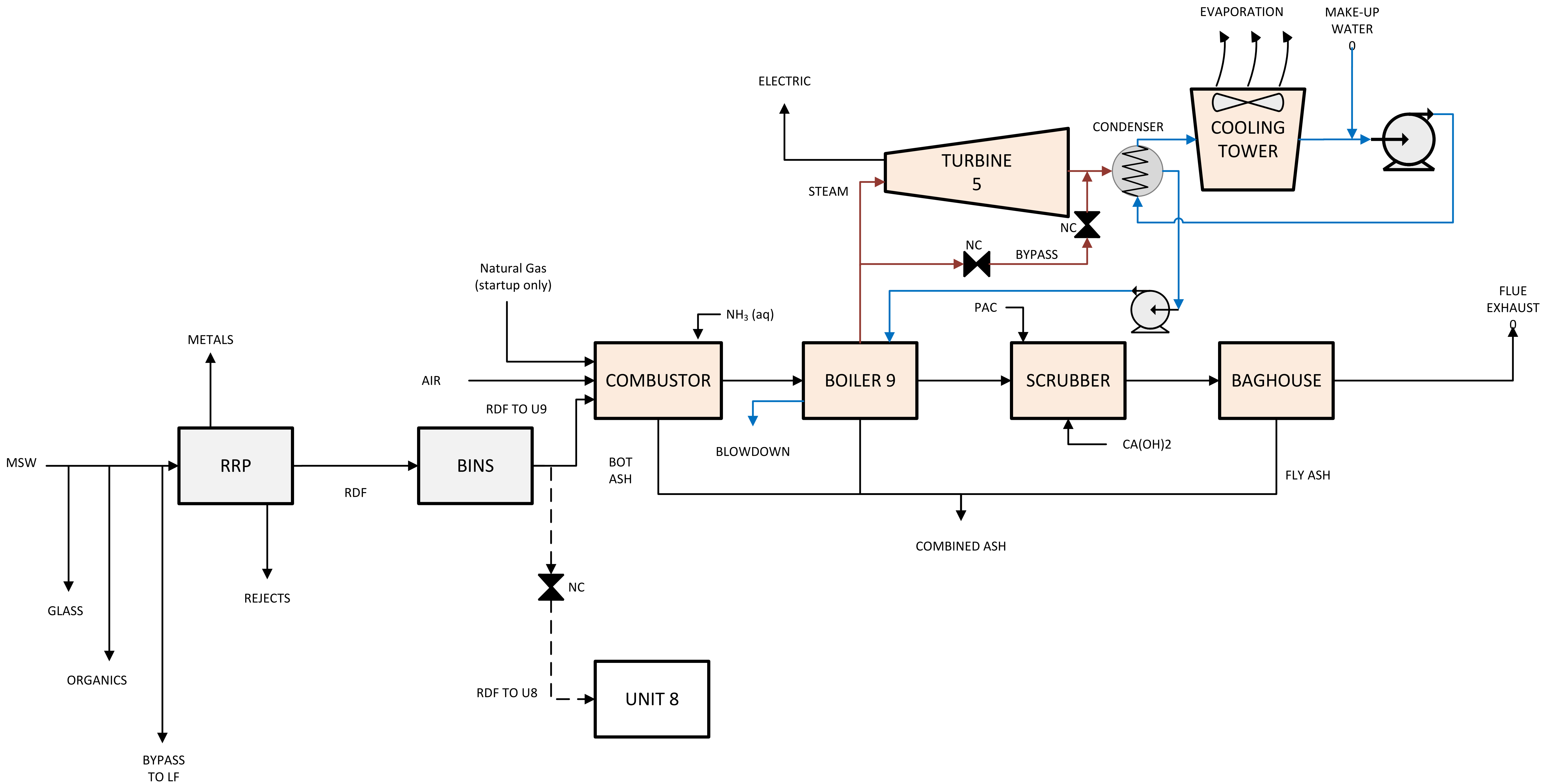


Revised 01APR2022

Report No. 507-006-01, Rev 1

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 2A

RDF (-4"), NEW BOILER WHERE UNIT 5/6 IS LOCATED, REFURBISHED STEAM TURBINE 5, UNIT 8 AS BACKUP

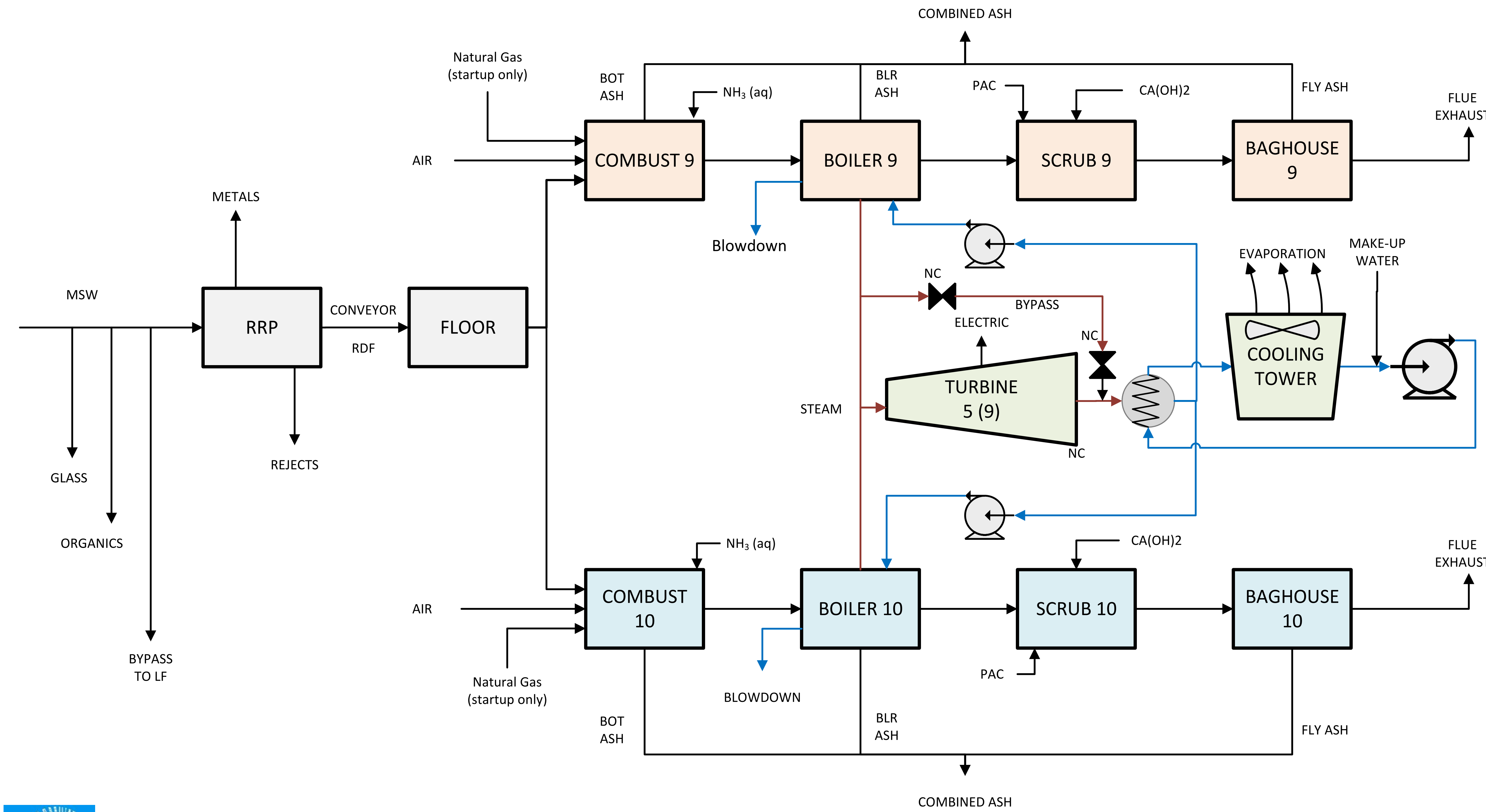


Revised 01APR2022

Report No. 507-006-01, Rev 1

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 2B

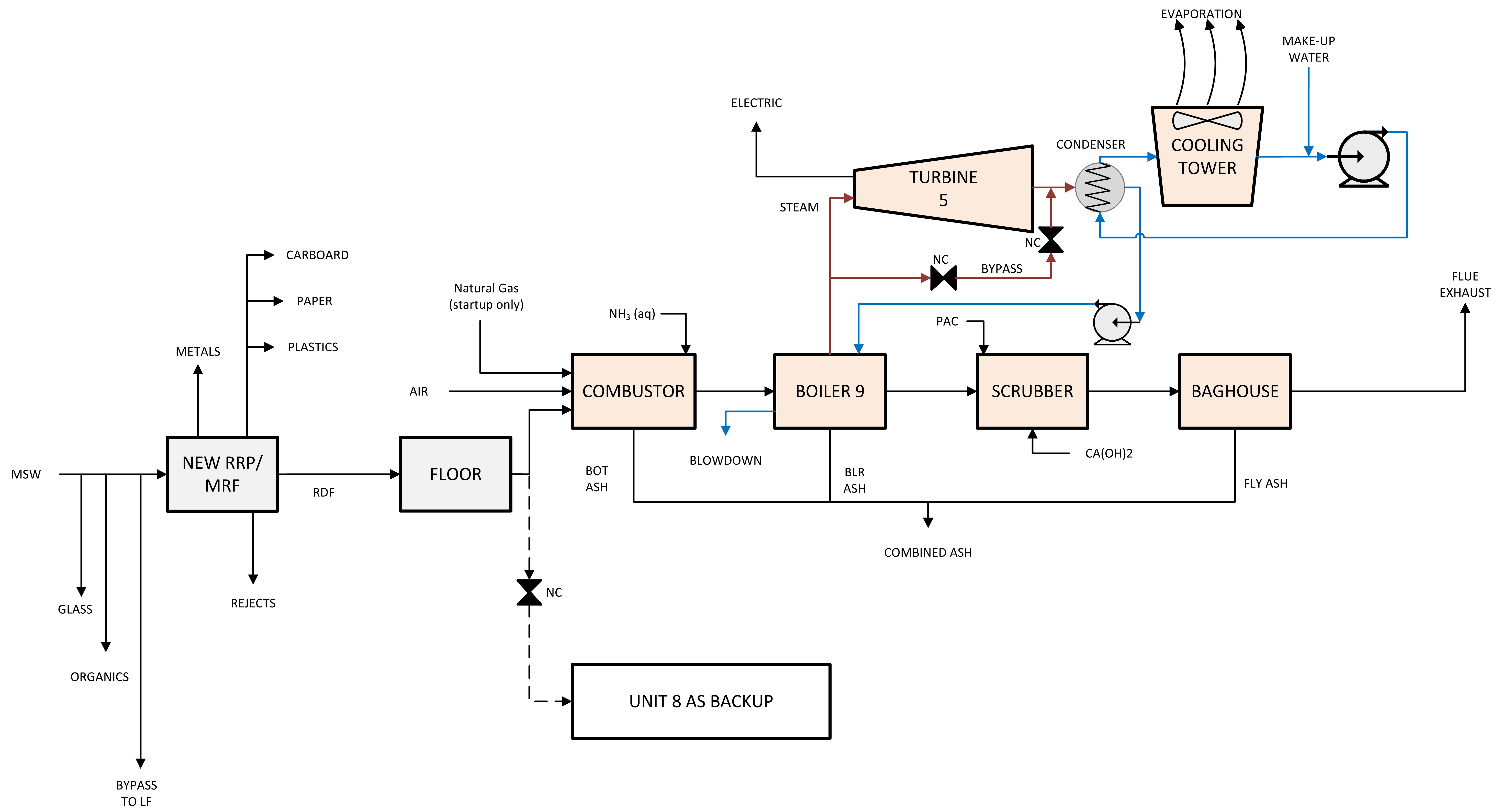
LARGE RDF, TWO (2) NEW BOILERS ON COAL YARD, REFURBISHED STEAM TURBINE 5



Revised 01APR2022

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 3A-1

STATE OF THE ART RDF (-3"). REFURBISHED STEAM TURBINE 5 UNIT 8 AS BACKUP

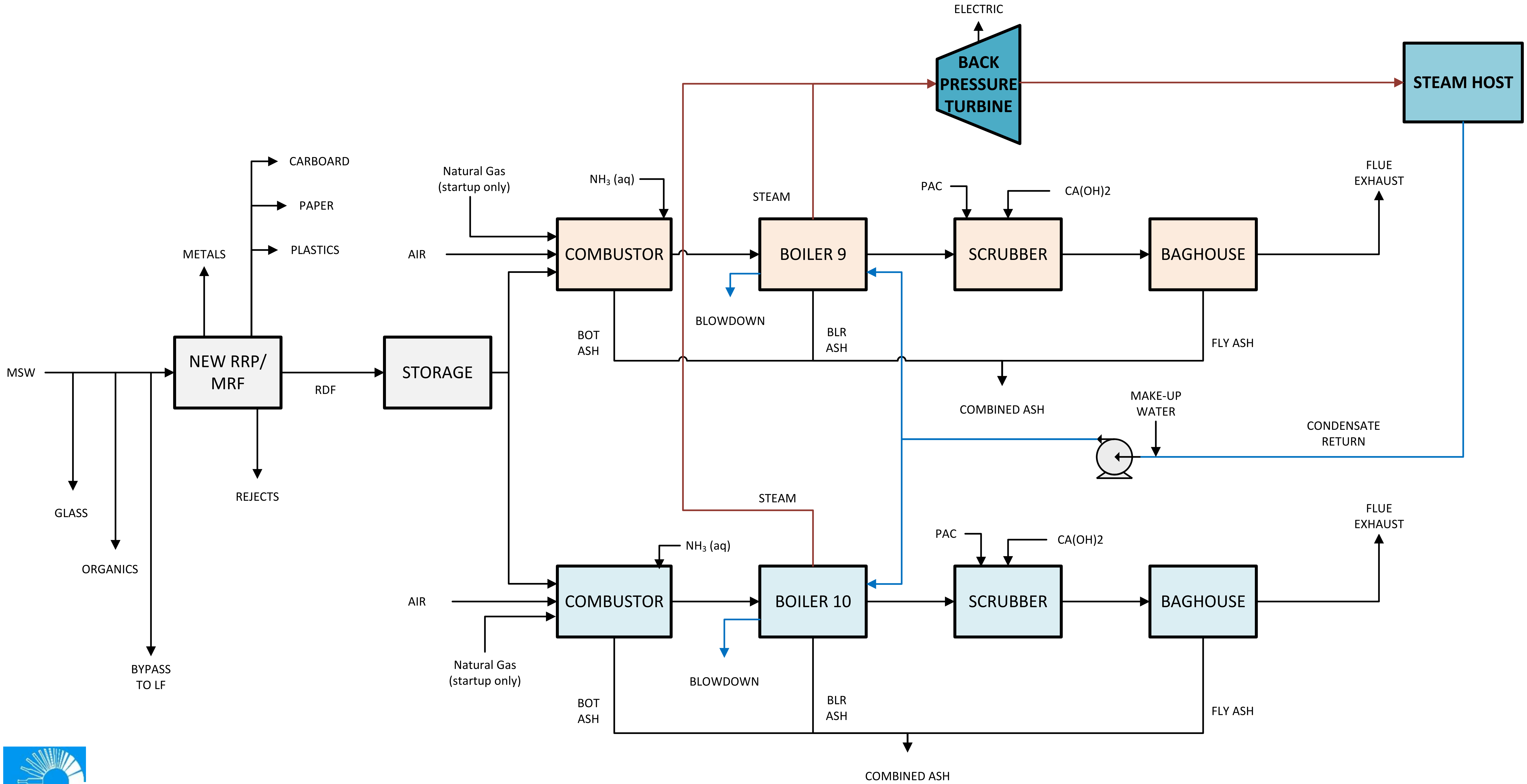


Revised 01APR2022

Report No. 507-006-01, Rev 1

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 3A-2

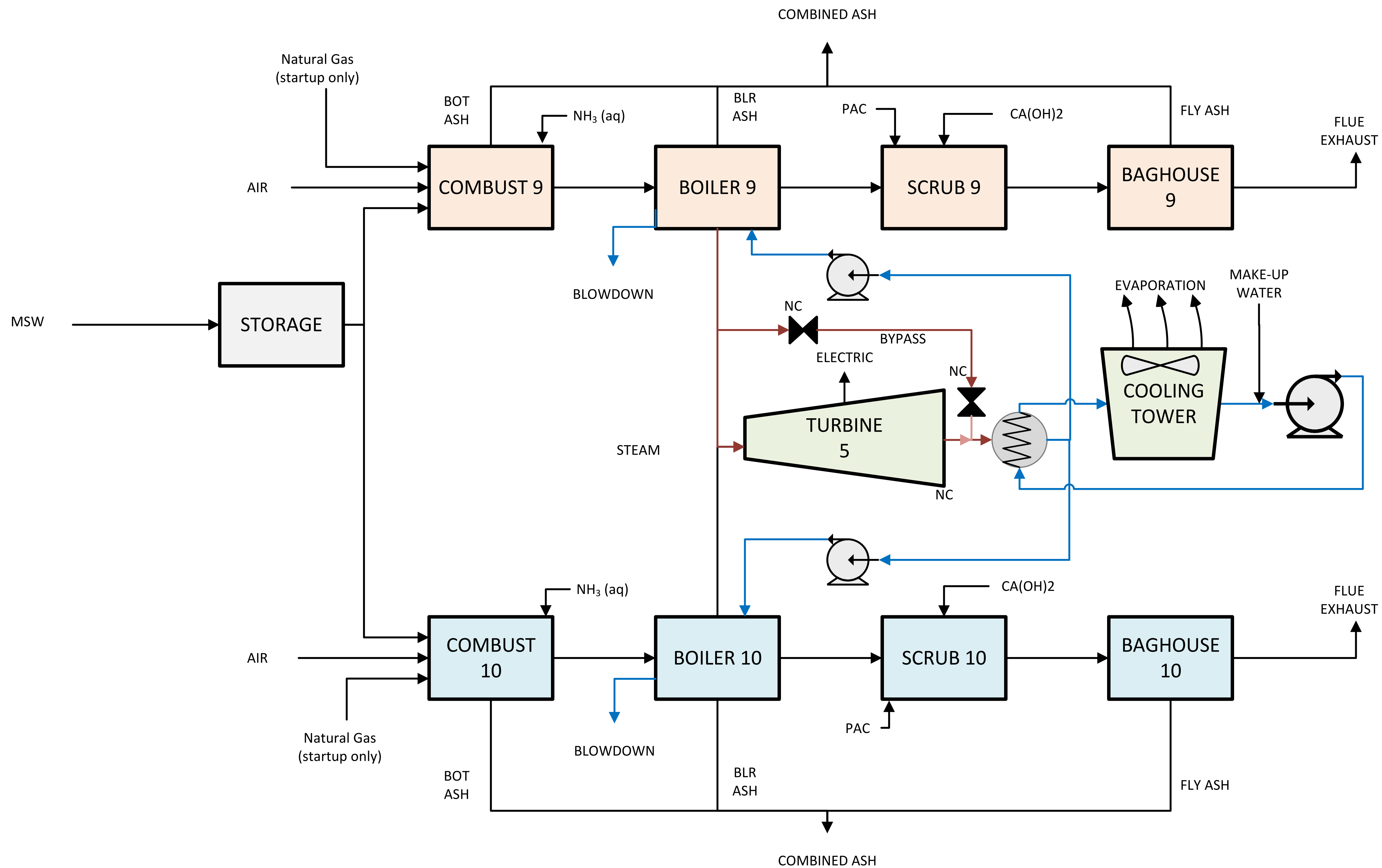
STATE OF THE ART RDF (-3"), NEW INDUSTRIAL SITE, DUAL BOILERS, STEAM HOST (MINIMAL POWER GENERATION)



Revised 01APR2022

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 3B-1

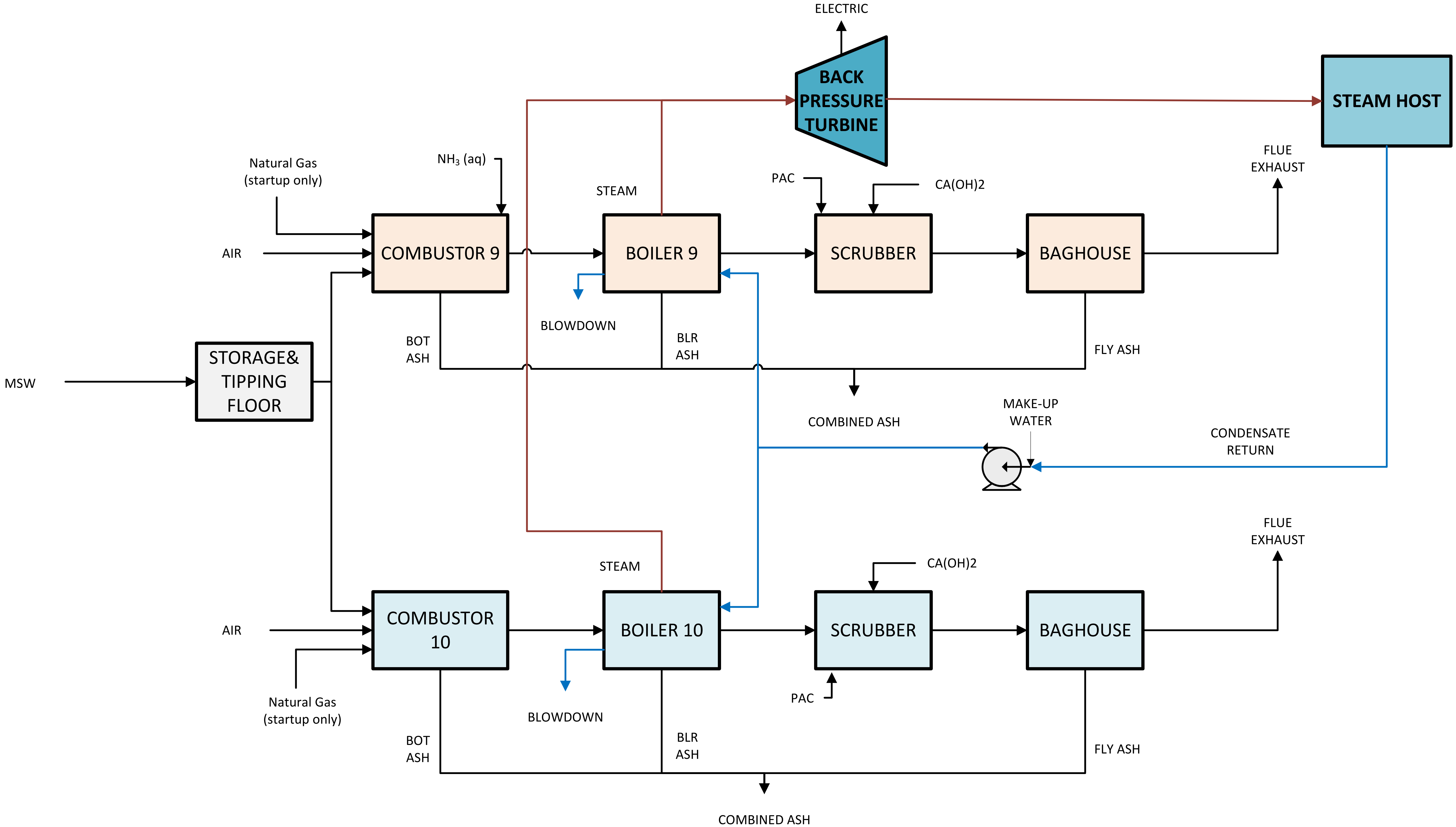
STATE OF THE ART MSW, COAL YARD, DUAL BOILERS, REFURBISHED STEAM TURBINE 5



Revised 01APR2022

CITY OF AMES WASTE-TO-ENERGY PROCESS FLOW DIAGRAM, OPTION 3B-2

STATE OF THE ART MSW, NEW SITE, DUAL BOILERS, STEAM HOST (MINIMAL POWER GENERATION)



Revised 01APR2022

APPENDIX F

Mass and Heat Balance Data Tables

DESIGN ANNUAL WASTE FLOW	
Option 1	
Current Operation	
3-4" Minus RDF	
Current Total MSW CY2022 (TPY)	52,000
Projected Growth in Waste Volume to 2044	27%
Projected Future Total MSW (TPY)	66,150
Percent Glass Recovery Rate	0.43%
Glass Recovered (TPY)	286
Percent Organics Recovery Rate	0.06%
Organics Recovered in CY 2044 (TPY)	63
Waste bypassed to landfill over RRP capacity (TPY)	16,796
Total Waste input into RRP LIMIT (TPY)	49,005
Bulky Waste By-Passed RRP to landfill (TPY)	1,715
Process Rejects Percentage	27.6%
Rejects Hauled to landfill (TPY)	13,525
Waste Processed at RRP LIMIT (TPY)	32,000
Pre-Comb % Ferrous Metals Recovery	3.4%
Pre-Comb. Ferrous Metals Recovery (TPY)	1,666
Pre-Comb. % Non-Ferrous Metals Recovery	0.20%
Pre-comb. Non-Fer. Metals Recovered (TPY)	98
Net Percent RDF Fuel Recovery	65.3%
Total Waste to Landfill (TPY)	32,036
RDF to WtE PP (TPY)	32,000

RRP / MRF DESIGN MASS BALANCE CALCULATIONS	
Option 1	
Current Operation	
3-4" Minus RDF	
Total Waste Processed (TPY)	49,005
RRP Operating Data	
Operating Hours per week	80
Operating Hours per year	3,536
Waste Processing Rate (tons per operating hour)	14
Waste Processing Rate (tons per operating day)	190
Percent RDF Fuel Recovery	65.3%
Rejects (tons per operating hour)	4.9
Rejects (tons per operating day)	66
RDF to WtE PP (Tons per Operating Hour)	9.1
RDF to WtE (Tons per Operating Day)	124
RDF/MSW to WtE (tons per year)	32,000
Incoming Waste Storage	
RRP Tipping Floor Capacity (tons)	400
Days of Equiv RRP Throughput Storage	2.1
MSW Density (lb/cf)	12
Est. Storage Volume Required (ft3)	66,700

COMBUSTION DESIGN MASS BALANCES W/ULTIMATE ANALYSIS		
Option 1		
Current Operation (RDF Component Only)		
3-4" Minus RDF		
Total RDF Fuel (TPY)	**32,000**	
Number of Units Needed to Combust RDF	1	
Combustor	**Primary U8**	**Secondary U7**
Combustor Annual Availability (%)	90%	10%
Operating Days per Year	329	37
RDF Fuel Flow per Unit (TPD)	89	75
Nominal Boiler Size (TPD)	96	75
Waste Elemental Composition	Wt%	
C	36.7%	
O	21.7%	
H	5.1%	
N	0.6%	
S	0.2%	
Cl	1.0%	
Ash	8.5%	
H2O	26.2%	
TOTAL	100.0%	
Calculated HHV (Btu/lb) *	6,827	
Combustion Air Flow (lb/hr)	44,793	37,713
Stack Gas Flow (lb/hr)	52,181	43,934
Boiler Steam Conditions:		
Pressure (psia)	1250	915
Temperature (F)	950	905
*DuLong empirical equation: HHV = (14545*C + 62028*H + 4050*S - 7753.5*O)/100		

STEAM AND POWER CALCULATIONS			
Option 1			
DESCRIPTION	**[UNITS]**	**Lead Unit 8**	**Lag Unit 7**
RDF / MSW Fuel Flow per Unit	[TPD]	89	75
RDF / MSW Fuel Flow per Unit	[tons/hr]	3.7	3.1
Annual Operation	[% year]	90%	10%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	6,827	6,827
Hourly RDF Heat Input	[MMBTU/hr]	51	43
Maximum RDF Mass Ratio (RDF/Total) permitted	[%]	30%	30%
RDF Mass Consumption Operating Margin	[%]	1.6%	1.6%
Min Natural Gas Required by Weight	[tonsNG/hr]	9.4	7.9
Natural Gas Thermal Content -HHV	[BTU/lbm]	22,468	22,468
Min Natural Gas Required by Weight	[MMBTU/hr]	420	354
Min Natural Gas Required by Heat Input	[MMBTU/hr]	512	431
Total Boiler input fuel (RDF/MSW + NG)	[MMBTU/hr]	563	474
Boiler efficiency	[%]	78%	78%
Heat transferred to steam	[MMBTU/hr]	439	369.8
Boiler Exit Steam Pressure Condition	psia	1265	915
Boiler Exit Steam Temperature Condition	degF	950	905
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1,468.5	1,454.6
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28.1	28.1
Condensate return %	[%]	97%	97%
Condensate Enthalpy	BTU/lbm	78.0	78.0
Net steam enthalpy per pound	BTU/lb steam	1,390.5	1,376.6
Design Boiler Production	[lbs/hr]	630,000	360,000
WITH CONDENSING STEAM TURBINE		**ST8**	**ST7**
Steam Turbine Backpressure	[inches HgA]	2.0	2.0
Steam Turbine Exit Temperature	[degF]	101.0	101.0
Quality of Steam existing ST	[%]	91%	91%
Steam Turbine Exhaust Enthalpy	[BTU/lbm]	1,018.4	1,018.4
Condensate Return Temperature	degF	100	100
Steam Turbine conversion rate to generator terminals	[BTU/kWh]	11,161	11,552
Power Output	[MW]	56.4	31.2

DESIGN ANNUAL WASTE FLOW	
Option 2A	
Enhanced Current RRP New RDF Combustor (#9)	
3-4" Minus RDF	
Current Total MSW CY2022 (TPY)	52,000
Projected Growth in Waste Volume to 2044	27%
Projected Future Total MSW (TPY)	66,150
Percent Glass Recovery Rate	0.43%
Glass Recovered (TPY)	286
Percent Organics Recovery Rate	0.06%
Organics Recovered in CY 2044 (TPY)	63
Waste bypassed to landfill over RRP capacity (TPY)	0.0
Total Waste input into RRP (TPY)	65,801
Bulky Waste By-Passed RRP to landfill (TPY)	2,303
Process Rejects Percentage	23.7%
Rejects Hauled to landfill (TPY)	15,595
Waste Processed at RRP (TPY)	44,745
Pre-Comb % Ferrous Metals Recovery	3.34%
Pre-Comb. Ferrous Metals Recovery (TPY)	2,198
Pre-Comb. % Non-Ferrous Metals Recovery	1.46%
Pre-comb. Non-Fer. Metals Recovered (TPY)	961
Net Percent RDF Fuel Recovery	68.0%
Total Waste to Landfill (TPY)	17,898
RDF to WtE PP (TPY)	44,745

RRP / MRF DESIGN MASS BALANCE CALCULATIONS	
Option 2A	
Enhanced Current RRP New RDF Combustor (#9)	
3-4" Minus RDF	
Total Waste Processed (TPY)	65,801
RRP Operating Data	
Operating Hours per week	80
Operating Hours per year	3,536
Waste Processing Rate (tons per operating hour)	20
Waste Processing Rate (tons per operating day)	272
Percent RDF Fuel Recovery *	68.0%
Rejects (tons per operating hour)	6.4
Rejects (tons per operating day)	87.0
RDF/MSW to WtE (tons per operating hour)	13.6
RDF/MSW to WtE (tons per operating day)	185
RDF/MSW to WtE (tons per year)	48,000
Incoming Waste Storage	
RRP Tipping Floor Capacity (tons)	400
Days of Equiv RRP Throughput Storage	1.5
MSW Density (lb/cf)	12
Est. Storage Volume Required (ft3)	66,700

COMBUSTION DESIGN MASS BALANCES W/ULTIMATE ANALYSIS		
Option 2A		
Enhanced Current RRP; New RDF-only Combustor; Unit 8 Back-up		
3-4" Minus RDF		
Total RDF Fuel (TPY)	44,745	
Number of Units Needed to Combust RDF	1	
Combustor	New U9	Backup U8
Combustor Annual Availability (%)	90.00%	10.00%
Operating Days per Year	329	37
RDF Fuel Flow per Unit (TPD)	126	96
Nominal Boiler Size (TPD)	125	96
Waste Elemental Composition	Wt%	
C	36.7%	
O	21.7%	
H	5.1%	
N	0.6%	
S	0.2%	
Cl	1.0%	
Ash	8.5%	
H2O	26.2%	
TOTAL	100.0%	
Calculated HHV (Btu/lb) *	6,827	
Combustion Air Flow (lb/hr)	73,649	48,273
Stack Gas Flow (lb/hr)	83,890	56,235
Boiler Steam Conditions:		
Pressure (psia)	615	1250
Temperature (F)	750	950

*DuLong empirical equation: HHV = (14545*C + 62028*H + 4050*S - 7753.5*O)/100

STEAM AND POWER CALCULATIONS			
Option 2A			
DESCRIPTION	[UNITS]	New U9	Backup U8
RDF Fuel Flow per Unit	[TPD]	126	96
RDF Fuel Flow per Unit	[tons/hr]	5.2	4.0
Annual Operation	[% year]	90%	10%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	6827	6827
Hourly RDF Heat Input	[MMBTU/hr]	71.4	54.6
Maximum RDF Mass Ratio (RDF/Total) permitted	[%]	n/a	30%
RDF Mass Consumption Operating Margin	[%]	n/a	1.6%
Min Natural Gas Required by Weight	[tonsNG/hr]	n/a	10.1
Natural Gas Thermal Content -HHV	[BTU/lbm]	n/a	22,468
Min Natural Gas Required by Weight	[MMBTU/hr]	n/a	453.2
Min Natural Gas Required by Heat Input	[MMBTU/hr]	n/a	552.2
Total Boiler input fuel (RDF + NG)	[MMBTU/hr]	71	607
Boiler efficiency	[%]	80%	78%
Heat transferred to steam	[MMBTU/hr]	57	473
Boiler Exit Steam Pressure Condition	psia	615	1265
Boiler Exit Steam Temperature Condition	degF	750	950
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1379.6	1,468.5
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28.1	28.1
Condensate return %	[%]	97%	97%
Condensate Enthalpy	BTU/lbm	78	78
Net steam enthalpy per pound	BTU/lb steam	1302	1,391
Design Boiler Production	[lbs/hr]	43,900	630,000
WITH CONDENSING STEAM TURBINE		ST9	ST8
Steam Turbine Backpressure	[inches HgA]	2.0	2.0
Steam Turbine Exit Temperature	[degF]	101.0	101.0
Quality of Steam existing ST	[%]	0.9	0.9
Steam Turbine Exhaust Enthalpy	[BTU/lbm]	1,018.4	1,018.4
Condensate Return Temperature	degF	99.8	99.8
Steam Turbine conversion rate to generator terminals	[BTU/kWh]	13,390	11,161
Power Output	[MW]	3.3	56.4

DESIGN ANNUAL WASTE FLOW	
Option 2B	
Modified RRP - 20" RDF New RDF Combustors	
20" Minus RDF	
Current Total MSW CY2022 (TPY)	52,000
Projected Growth in Waste Volume to 2044	27%
Projected Future Total MSW (TPY)	66,150
Percent Glass Recovery Rate	0.43%
Glass Recovered (TPY)	286
Percent Organics Recovery Rate	0.06%
Organics Recovered in CY 2044 (TPY)	63
Waste bypassed to landfill over RRP capacity (TPY)	0.0
Total Waste input into RRP (TPY)	65,801
Bulky Waste By-Passed RRP to landfill (TPY)	2,303
Process Rejects Percentage	7.26%
Rejects Hauled to landfill (TPY)	4,777
Waste Processed at RRP (TPY)	54,878
Pre-Comb % Ferrous Metals Recovery	4.4%
Pre-Comb. Ferrous Metals Recovery (TPY)	2,915
Pre-Comb. % Non-Ferrous Metals Recovery	1.41%
Pre-comb. Non-Fer. Metals Recovered (TPY)	928
Percent RDF Fuel Recovery	83.4%
Total Waste to Landfill (TPY)	4,777
RDF to WtE PP (TPY)	54,878

RRP / MRF DESIGN MASS BALANCE CALCULATIONS	
Option 2B	
Modified RRP - 20" RDF Two New RDF Combustors	
20" Minus RDF	
Total Waste Processed (TPY)	65,801
RRP Operating Data	
Operating Hours per week	50
Operating Hours per year	2,210
Waste Processing Rate (tons per operating hour)	25
Waste Processing Rate (tons per operating day)	250
Percent RDF Fuel Recovery *	83.4%
Rejects (tons per operating hour)	4.2
Rejects (tons per operating day)	42
RDF/MSW to WtE (tons per operating hour)	21
RDF/MSW to WtE (tons per operating day)	209
RDF/MSW to WtE (tons per year)	54,000
Incoming Waste Storage	
RRP Tipping Floor Capacity (tons)	400
Days of Equiv RRP Throughput Storage	1.9
MSW Density (lb/cf)	14
Est. Storage Volume Required (ft3)	57,100

COMBUSTION DESIGN MASS BALANCES W/ULTIMATE ANALYSIS		
Option 2B		
Modified RRP - 20" RDF; Two New RDF Combustors		
20" Minus RDF		
Total RDF / MSW Fuel (TPY)	54,878	
Number of Units Needed to Combust Large RDF	2	
Combustor	New U9	New U10
Combustor Annual Availability (%)	90.0%	90.0%
Operating Days per Year	329	329
RDF Fuel Flow per Unit (TPD)	84	84
Nominal Boiler Size (TPD)	90	90
Waste Elemental Composition	Wt%	
C	35.0%	
O	22.0%	
H	4.6%	
N	0.6%	
S	0.2%	
Cl	1.0%	
Ash	12.6%	
H2O	24.0%	
TOTAL	100.0%	
Calculated HHV (Btu/lb) *	6,246	
Combustion Air Flow (lb/hr)	61,488	61,488
Stack Gas Flow (lb/hr)	68,013	68,013
Boiler Steam Conditions:		
Pressure (psia)	615	
Temperature (F)	750	

*DuLong empirical equation: HHV = (14545*C + 62028*H + 4050*S - 7753.5*O)/100

STEAM AND POWER CALCULATIONS			
Option 2B			
DESCRIPTION	[UNITS]	New U9	New U10
RDF / MSW Fuel Flow per Unit	[TPD]	84	84
RDF / MSW Fuel Flow per Unit	[tons/hr]	3.5	3.5
Annual Operation	[% year]	90%	90%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	6,246	6,246
Hourly RDF Heat Input	[MMBTU/hr]	43	43
Total Boiler input fuel (RDF/MSW + NG)	[MMBTU/hr]	43	43
Boiler efficiency	[%]	72%	72%
Heat transferred to steam	[MMBTU/hr]	31	31.3
Boiler Exit Steam Pressure Condition	psia	615	615
Boiler Exit Steam Temperature Condition	degF	750	750
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1379.6	1,379.6
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28.1	28.1
Condensate return %	[%]	97%	97%
Condensate Enthalpy	BTU/lbm	78	78
Net steam enthalpy per pound	BTU/lb steam	1,302	1,302
Design Boiler Production	[lbs/hr]	24,050	24,050
WITH CONDENSING STEAM TURBINE		ST9	
Steam Turbine Backpressure	[inches HgA]	2.0	
Steam Turbine Exit Temperature	[degF]	101.0	
Quality of Steam existing ST	[%]	0.9	
Steam Turbine Exhaust Enthalpy	[BTU/lbm]	1,018.4	
Condensate Return Temperature	degF	99.8	
Steam Turbine conversion rate to generator terminals	[BTU/kWh]	13,390	
Power Output	[MW]	3.6	

DESIGN ANNUAL WASTE FLOW	
Option 3A-1&2	
New S-O-A RRP; New RDF Combustor; Unit 8 Back-up	
3-4" Minus RDF	
Current Total MSW CY2022 (TPY)	52,000
Projected Growth in Waste Volume to 2044	27%
Projected Future Total MSW (TPY)	66,150
Percent Glass Recovery Rate	0.43%
Glass Recovered (TPY)	286
Percent Organics Recovery Rate	0.06%
Organics Recovered in CY 2044 (TPY)	63
Waste bypassed to landfill over RRP capacity (TPY)	0.0
Total Waste input into RRP (TPY)	65,801
Bulky Waste By-Passed RRP to landfill (TPY)	2,303
Process Rejects Percentage	11.6%
Waste Processed at RRP (TPY)	51,252
Pre-Comb % Ferrous Metals Recovery	5.46%
Pre-Comb. Ferrous Metals Recovery (TPY)	3,593
Pre-Comb. % Non-Ferrous Metals Recovery	1.55%
Pre-comb. Non-Fer. Metals Recovered (TPY)	1,020
Percent RDF Fuel Recovery	77.9%
RDF to WtE PP (TPY)	51,252
Total Waste to landfill (TPY)	9,936

RRP / MRF DESIGN MASS BALANCE CALCULATIONS	
Option 3A-1&2	
New S-O-A RRP; New RDF Combustor; Unit 8 Back-up	
3-4" Minus RDF	
Total Waste Processed (TPY)	65,801
RRP Operating Data	
Operating Hours per week	50
Operating Hours per year	2,210
Waste Processing Rate (tons per operating hour)	25
Waste Processing Rate (tons per operating day)	250
Percent RDF Fuel Recovery	77.9%
Rejects (tons per operating hour)	5.5
Rejects (tons per operating day)	55
RDF to WtE (tons per operating hour)	19
RDF to WtE (tons per operating day)	195
RDF/MSW to WtE (tons per year)	51,000
Incoming Waste Storage	
RRP Tipping Floor Capacity (tons)	1,000
Days of Equiv RRP Throughput Storage	4.7
MSW Density (lb/cf)	14
Est. Storage Volume Required (ft3)	142,900

COMBUSTION DESIGN MASS BALANCES W/ULTIMATE ANALYSIS		
Option 3A-1		
New S-O-A RRP; New RDF Combustor; Unit 8 Back-up		
3-4" Minus RDF		
Total RDF / MSW Fuel (TPY)	51,252	
Number of Units Needed to Combust RDF / MSW	1	
Combustor	New U9	Backup U8
Combustor Annual Availability (%)	90.00%	10.00%
Operating Days per Year	329	37
RDF/MSW Fuel Flow per Unit (TPD)	145	96
Nominal Boiler Size (TPD)	150	96
Waste Elemental Composition	Wt%	
C	36.7%	
O	21.7%	
H	5.1%	
N	0.6%	
S	0.2%	
Cl	1.0%	
Ash	8.5%	
H2O	26.2%	
TOTAL	100.0%	
Calculated HHV (Btu/lb) *	6,827	
Combustion Air Flow (lb/hr)	85,271	
Stack Gas Flow (lb/hr)	97,128	
Boiler Steam Conditions:		
Pressure (psia)	615	
Temperature (F)	750.0	

*DuLong empirical equation: HHV = (14545*C + 62028*H + 4050*S - 7753.5*O)/100

STEAM AND POWER CALCULATIONS			
Option 3A-1			
DESCRIPTION	[UNITS]	New U9	Backup U8
RDF / MSW Fuel Flow per Unit	[TPD]	145	96
RDF / MSW Fuel Flow per Unit	[tons/hr]	6	4
Annual Operation	[% year]	90.0%	10.0%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	6,827	6,827
Hourly RDF Heat Input	[MMBTU/hr]	83	55
Maximum RDF Mass Ratio (RDF/Total) permitted	[%]	n/a	30%
RDF Mass Consumption Operating Margin	[%]	n/a	1.6%
Min Natural Gas Required by Weight	[tonsNG/hr]	n/a	9.4
Natural Gas Thermal Content -HHV	[BTU/lbm]	n/a	22,468
Min Natural Gas Required by Weight	[MMBTU/hr]	n/a	420
Min Natural Gas Required by Heat Input	[MMBTU/hr]	n/a	552
Total Boiler input fuel (RDF/MSW + NG)	[MMBTU/hr]	83	607
Boiler efficiency	[%]	80%	78%
Heat transferred to steam	[MMBTU/hr]	66	473.3
Boiler Exit Steam Pressure Condition	psia	615	1,265
Boiler Exit Steam Temperature Condition	degF	750	950
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1,379.6	1,468.5
Make-up water temperature	degF	60	60.0
Make-up water enthalpy	[BTU/lbm]	28	28.1
Condensate return %	[%]	97%	97%
Condensate Enthalpy	BTU/lbm	78	78
Net steam enthalpy per pound	BTU/lb steam	1,302	1,391
Design Boiler Production	[lbs/hr]	50,830	341,000
WITH CONDENSING STEAM TURBINE GENERATOR		ST9	ST8
Steam Turbine Backpressure	[inches HgA]	2.0	2.0
Steam Turbine Exit Temperature	[degF]	101.0	101.0
Quality of Steam existing ST	[%]	91%	91%
Steam Turbine Exhaust Enthalpy	[BTU/lbm]	1,018.4	1,018.4
Condensate Return Temperature	degF	100	100
Steam Turbine conversion rate to generator terminals	[BTU/kWh]	13,390	11,161
Power Output	[MW]	5.2	30.6

STEAM AND POWER CALCULATIONS			
Option 3A-2			
3-4" Minus RDF			
DESCRIPTION	[UNITS]	New U9	New U10
RDF / MSW Fuel Flow per Unit	[TPD]	78.0	78.0
RDF / MSW Fuel Flow per Unit	[tons/hr]	3.3	3.3
Annual Operation	[% year]	90%	90%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	7,884	7,884
Hourly RDF Heat Input	[MMBTU/hr]	44	44
Boiler efficiency	[%]	80%	80%
Heat transferred to steam	[MMBTU/hr]	36	36
Boiler Exit Steam Pressure Condition	psia	615	615
Boiler Exit Steam Temperature Condition	degF	750	750
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1,380	1,380
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28	28
Condensate return %	[%]	85%	85%
Condensate Enthalpy	BTU/lbm	78	78
Net steam enthalpy per pound	BTU/lb steam	1,302	1,302
Design Boiler Production	[lbs/hr]	27,280	27,280
WITH BACKPRESSURE STEAM TURBINE GENERATOR		ST10	
Steam Turbine Backpressure	[psia]	165	
ST Exhaust Steam Temperature	[degF]	535	
Exhaust Steam Enthalpy	[BTU/lbm]	1,292	
Exhaust steam quality	[%]	100%	
Back Pressure Turbine Conversion Rate at Gen Terminals	[lbs/kWh]	33	
Back Pressure ST Power output	[MW]	1,650	
Turbine exhaust flow	[lbs/hr]	54,560	
Degrees of superheat of Exhaust flow	[degF]	169	
Desuperheater water flow from BFP	[lbs/hr]	3,044	
Export Steam flow w/50F superheat	[lbs/hr]	57,604	
Net Enthalpy sold	[BTU/lbm]	1,160	

DESIGN ANNUAL WASTE FLOW	
Option 3B-1&2	
MSW Pre-Sort New MSW Combustors	
MSW	
Current Total MSW CY2022 (TPY)	52,000
Projected Growth in Waste Volume to 2044	27%
Projected Future Total MSW (TPY)	66,150
Percent Glass Recovery Rate	0.43%
Glass Recovered (TPY)	286
Percent Organics Recovery Rate	0.06%
Organics Recovered in CY 2044 (TPY)	63
Total Waste input into RRP (TPY)	65,801
Percent Processed	99%
Bulky Waste By-Passed RRP to landfill (TPY)	658
Waste Processed (TPY)	65,143
Percent MSW as Fuel Recovery	99%
Processed MSW to WtE PP (TPY)	65,143
Total Waste to landfill (TPY)	658
Post Comb. Ferrous Metals Recovery (TPY)	2,289
Post Comb. Non-Ferrous Metals Recovered (TPY)	108

RRP / MRF DESIGN MASS BALANCE CALCULATIONS	
Option 3B-1&2	
MSW Pre-Sort New MSW Combustors	
MSW	
Total Waste Processed (TPY)	65,801
RRP Operating Data	
Operating Hours per week	50
Operating Hours per year	2,210
Waste Processing Rate (tons per operating hour)	25
Waste Processing Rate (tons per operating day)	250
Percent RDF Fuel Recovery	99.0%
Rejects (tons per operating hour)	0.3
Rejects (tons per operating day)	3
MSW Fuel to WtE (Tons per Operating Hour)	24.8
MSW Fuel to WtE (Tons per Operating Day)	248
MSW to WtE (tons per year)	64,000
Incoming Waste Storage	
MSW Tipping Floor Capacity (tons)	1,000
Days of Equiv RRP Throughput Storage	5
MSW Density (lb/cf)	14
Est. Storage Volume Required (ft3)	142,900

COMBUSTION DESIGN MASS BALANCES W/ULTIMATE ANALYSIS		
Option 3B-1&2		
MSW Pre-Sort; Two New MSW Combustors; Steam Export		
MSW		
Total MSW Fuel (TPY)	**65,143**	
Number of Units Needed to Combust MSW	2	
Combustor	**New U9**	**New U10**
Combustor Annual Availability (%)	90%	90%
Operating Days per Year	329	329
RDF/MSW Fuel Flow per Unit (TPD)	99	99
Nominal Boiler Size (TPD)	100	100
Waste Elemental Composition	Wt%	
C	29.0%	29.0%
O	21.0%	21.0%
H	3.9%	3.9%
N	1.3%	1.3%
S	0.3%	0.3%
Cl	1.0%	1.0%
Ash	19.6%	19.6%
H2O	24.0%	24.0%
TOTAL	100.0%	100.0%
Calculated HHV (Btu/lb) *	5,019	5019
Boiler Steam Conditions:		
Pressure (psia)	615	
Temperature (F)	750	
*DuLong empirical equation: HHV = (14545*C + 62028*H + 4050*S - 7753.5*O)/100		

STEAM AND POWER CALCULATIONS			
Option 3B-1			
DESCRIPTION	**[UNITS]**	**New U9**	**New U10**
RDF / MSW Fuel Flow per Unit	[TPD]	99.2	99.2
RDF / MSW Fuel Flow per Unit	[tons/hr]	4.1	4.1
Annual Operation	[% year]	90%	90%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	5,019	5,019
Hourly Heat Input	[MMBTU/hr]	41	41
Boiler efficiency	[%]	70%	70%
Heat transferred to steam	[MMBTU/hr]	29	29
Boiler Exit Steam Pressure Condition	psia	615	615
Boiler Exit Steam Temperature Condition	degF	750	750
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1,379.6	1,379.6
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28.1	28.1
Condensate return %	[%]	97%	97%
Condensate Enthalpy	BTU/lbm	78.0	78.0
Net steam enthalpy per pound	BTU/lb steam	1,301.6	1,301.6
Design Boiler Production	[lbs/hr]	21,040	21,040
WITH CONDENSING STEAM TURBINE GENERATOR		**ST9**	
Steam Turbine Backpressure	[inches HgA]	2.0	
Steam Turbine Exit Temperature	[degF]	101.0	
Quality of Steam existing ST	[%]	0.9	
Steam Turbine Exhaust Enthalpy	[BTU/lbm]	1,018.4	
Condensate Return Temperature	degF	99.8	
Steam Turbine conversion rate to generator terminals	[BTU/kWh]	13,390	
Power Output	[MW]	4.3	
Cooling Tower heat rejection	[BTU/hr]	53.9	

STEAM AND POWER CALCULATIONS			
Option 3B-2			
DESCRIPTION	**[UNITS]**	**New U9**	**New U10**
RDF / MSW Fuel Flow per Unit	[TPD]	99	99
RDF / MSW Fuel Flow per Unit	[tons/hr]	4.1	4.1
Annual Operation	[% year]	90%	90%
Calculated RDF/MSW Heat Content	[BTU/lb-HHV]	5,019	5,019
Hourly Heat Input	[MMBTU/hr]	41	41
Boiler efficiency	[%]	70%	70%
Heat transferred to steam	[MMBTU/hr]	29.03	29.03
Boiler Exit Steam Pressure Condition	psia	615	615
Boiler Exit Steam Temperature Condition	degF	750	750
Enthalpy of Boiler Steam Exit Condition (ST inlet)	BTU/lbm	1,379.6	1,379.6
Make-up water temperature	degF	60	60
Make-up water enthalpy	[BTU/lbm]	28.1	28.1
Condensate return %	[%]	85%	85%
Condensate Enthalpy	BTU/lbm	78.0	78.0
Net steam enthalpy per pound	BTU/lb steam	1,301.6	1,301.6
Design Boiler Production	[lbs/hr]	22,300	22,300
WITH BACKPRESSURE STEAM TURBINE GENERATOR		**ST10**	
Steam Turbine Backpressure	[psia]	165	
ST Exhaust Steam Temperature	[degF]	535	
Exhaust Steam Enthalpy	[BTU/lbm]	1,292	
Exhaust steam quality	[%]	1	
Back Pressure Turbine Conversion Rate at Gen Terminals	[lbs/kWh]	33	
Back Pressure ST Power output	[MW]	1	
Turbine exhaust flow	[lbs/hr]	44,600	
Degrees of supereheat of Exhaust flow	[degF]	169	
Desuperheater water flow from BFP	[lbs/hr]	2,489	
Export Steam flow w/50F superheat	[lbs/hr]	47,089	
Net Enthalpy sold	[BTU/lbm]	1,160	

APPENDIX G

Details Regarding Combustor Systems

APPENDIX G

COMBUSTION SYSTEMS TECHNOLOGY

F.1 Small RDF Combustion System Options (2A, 3A-1, 3A-2)

A variety of combustor design options could be used for the combustion of 3”-4” RDF, including bubbling fluidized beds, suspension-fired traveling grates, and inclined reciprocating grates. The major suppliers of these combustor designs are summarized in Table G - 1 and details on all of these combustor types are described below.

Table G - 1: Waste Combustion Options Overview

Supplier	Combustor Type	Waste Feedstock	Scope of Supply	Excess Air*	Combustion Emissions*
Metso: Outotec	Bubbling Fluidized Bed	3”-4” RDF	Chute to Stack	30-50%	Very Good
Detroit Stoker RotoGrate	Suspension Fired	3”-4” RDF	Combustor	40-60%	Acceptable
Martin	Reverse-Recip. Inclined Grate	MSW RDF	Combustor	60-90%	Good
Hitachi Zosen	Forward-Recip. Inclined Grate	MSW RDF	Chute to Stack	60-90%	Good
Detroit Stoker	Forward-Recip. Inclined Grate	MSW RDF	Combustor	60-90%	Good
B&W Volund	Articulating Inclined Grate	MSW RDF	Chute to Stack	60-90%	Good
Keppel Seghers	Forward-Recip. Inclined Grate	MSW RDF	Chute to Stack	60-90%	Good
Ruths	Forward-Recip. Inclined Grate	MSW RDF	Combustor & Boiler	60-90%	Good
Eco Waste Emercon	Stepped Grate	MSW RDF	Chute to Stack	60-90%	Acceptable
EnerSol	Vibratory Grate	MSW RDF	Chute to Stack	50-70%	Good

F.1.1 Suspension Firing

Historically, the most common combustor design for RDF utilizes suspension firing where the RDF is sprayed into the combustion chamber. This system is used in Units 7 and 8. The RDF ignites and is consumed. Larger materials that are not consumed fall onto the horizontal traveling grate below to continue combusting. The RDF size requirement for suspension-fired systems is typically 6” minus, which can usually be achieved in a single shredding step. Larger RDF is not suitable because of the reduced surface area and larger weight per particle. Back in the 1970’s and 1980’s, several large boiler suppliers adapted designs from other solid fuel systems to combust RDF, and a number of large facilities were built in the U.S., a few of which still operate today. These systems were much larger than that needed for the City of Ames, with unit capacities on the order of 1,000 TPD. The overall costs to produce and combust the RDF in these facilities has been determined to be much higher than mass-burn systems and it is generally accepted in the industry that mass-burn is the preferred approach to recovering energy from waste as compared to suspension-fired RDF systems. For this reason, no new suspension fired RDF facilities have been constructed since the early 1980’s.

Detroit Stoker is one remaining supplier of suspension-fired systems for the combustion of RDF. Their RotoGrate stoker, shown in Figure G - 1, below, employs a spreader stoker and traveling grate designed for a wide range of solid fuels, including 6" minus RDF. The RotoGrate stoker is typically fed by a series of conveyors that distribute the RDF to multiple injectors, where an air knife projects the RDF into the combustion chamber and distributes it across the traveling grate. Interruption of the RDF feed to any one injector causes immediate loss of heat release and steam generation by the combustor. This is a common challenge to maintaining combustion control in suspension-fired RDF combustion systems. The forward-moving grate provides continuous ash discharge, which is well suited for high-ash fuels such as RDF. The RotoGrate also employs a unique, hinged bar design that opens as it moves through the lower portion of the catenary to discharge siftings and improve primary air flow and distribution though the grate. The RotoGrate combustor employs multiple levels of high-pressure secondary air injection to achieve thorough mixing of the combustion air with volatiles for efficient combustion. The staged secondary air also aids in reducing NOx formation.

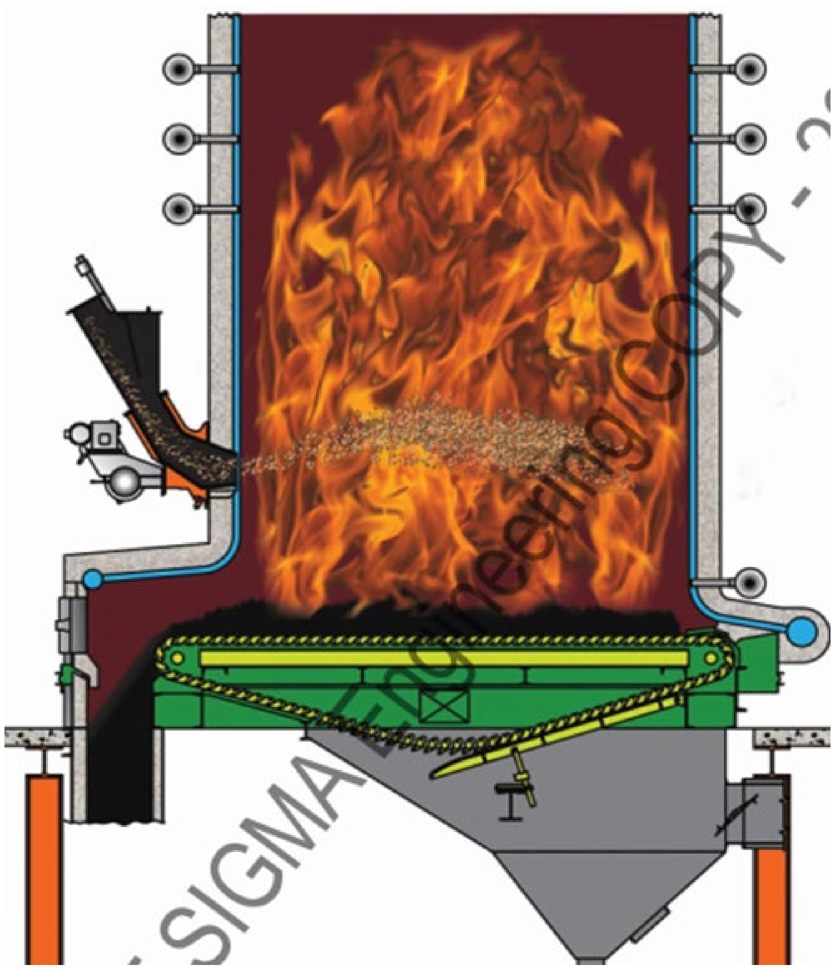


Figure G - 1: Detroit Stoker RotoGrate for Suspension-Fired Combustion of 6" Minus RDF

F.1.2 Bubbling Fluidized Bed

Bubbling fluidized bed combustion systems have been successfully applied to RDF applications for many years but require a finer RDF size of 3” to 4” minus, similar to the RDF currently produced by the City of Ames. A leading supplier of bubbling fluidized bed combustion systems is Metso:Outotec. A schematic of their combustor is shown below in Figure G – 2.

In a Fluidized Bed Combustor (FBC), a gas (air in RDF consumption) is passed through a bed of solid granular material at velocities that are high enough to suspend the solids and cause the suspended material to behave as though it were a fluid. This process has many important advantages including high gas/solids mixing and turbulency, excellent heat transfer between bed particles and fluidizing gas and between the bed and heat transfer surfaces; resulting in stable consistent process control. The FBC provides long resident times, stable temperatures for good combustion, including the amount of burnout of CO and efficient capture of SO2 by limestone injected into the bed. FBC is particularly well suited for burning fuels with high moisture and ash content like biomass and waste fuels.

In the Metso:Outotec system, waste is fed to the combustor by a metering bin located above the combustor. The metered RDF flows by gravity to the inlet of an air-swept spreader that disperses the RDF across the bubbling bed of the combustor. The City’s current pneumatic system for transporting and feeding RDF could feed the metering bin, or alternately, replace the metering bin and feed the RDF directly to the bubbling bed combustor. Metso:Outotec has some experience with this type of direct pneumatic feed to their bubbling bed combustion systems.

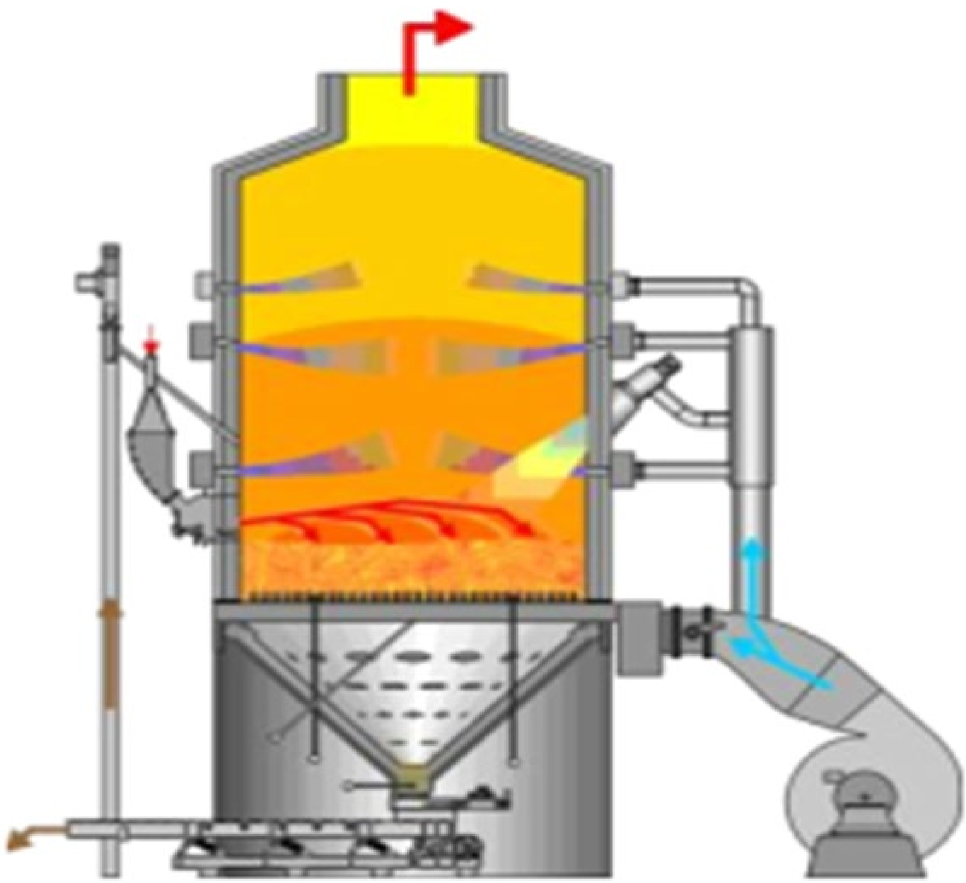


Figure G – 2: Metso:Outotec Bubbling Fluidized Bed Combustor for 3” to 4” Minus RDF

RDF entering the hot, bubbling bed dries and combusts at a relatively low temperature and is a well-mixed system that promotes efficient combustion and prevents localized high temperature areas where melting of the ash could occur. This controlled combustion conditions require less excess air when compared to suspension fired systems and results in lower CO and NOx emissions from the combustor. Non-combustible inorganics in the RDF are removed from the bubbling bed automatically by Outotec's proprietary bed material cleaning system that recovers the bed material sand for recycling back to the combustor and rejects ash and other inerts.

Metso:Outotec has commercial experience processing RDF in their bubbling fluidized bed combustion systems, including French Island and the City of Tacoma in the U.S., three Italian facilities in Ravenna, Bergamo, and Massafra, and several new facilities in the UK. However, these systems are typically much larger than 200 TPD. The size range needed for Ames is on the very low end of the equipment product line, resulting in a very high costs per ton of RDF.

F.1.3 Inclined Reciprocating Grate System

Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. While inclined reciprocating grates are designed to combust unprocessed MSW, they could also be used for the combustion of RDF. However, the mechanical design of these systems is thought to be overkill for a processed RDF feedstock, particularly one that is sized to 3" to 4", as is currently produced by the City of Ames RRP. However, this technology is more suitable to the larger RDF (20"-) evaluated in Option 2B.

F.2 Large RDF Combustion System (Options 2B, 3B-1, 3B-2)

The 20" minus RDF in Option 2B is too large and heterogenous of a material to be combusted in suspension-fired or bubbling bed combustors that can be used for the finer RDF in Options 2A and 3A. To combust the large 20" minus RDF, a mass-burn grate system designed for unprocessed MSW would have to be used.

Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. These systems are offered by a number of proven suppliers. Inclined reciprocating grates are designed to combust unprocessed MSW and would be well suited for the combustion of the large 20" minus RDF.

One of the world's most established suppliers of mass-burn combustion systems is Martin GmbH of Germany, who have supplied nearly 1000 units in over 500 plants around the world since 1960. The Martin system employs an inclined, reverse-acting, reciprocating grate where the grate bars move counter to the downward movement of the waste by gravity, providing enhanced stoking of the burning bed of waste. Figure F - 3 provides a schematic of the Martin system showing the waste feed hopper and chute (1), hydraulic ram feeder (2), reverse-acting grate (3), ash discharger (4), furnace (5), combustion air fan (6), grate siftings removal (7) and secondary air supply (8).

Figure F - 3: Martin Mass-Burn Combustion System

As the waste moves down the grate, it first dries from radiation of the flames and primary air flowing up through the grate. Combustible material in the waste then volatilizes and combusts in the main combustion zone. Secondary air is injected through nozzles in both the front and rear walls above the grate to ensure complete combustion of the burning gases. The combustion of the waste is substantially completed in the top two thirds of the grate. In the bottom third, additional air flow through the grate ensures good burnout and cooling of the ash residue. At the end of the grate, the ash residue falls into a water filled ash discharger that quenches the ash and discharges it to a metal pan conveyor.

A more detailed general arrangement drawing of the Martin mass-burn combustion system is shown below in Figure G - 4. One disadvantage of the Martin system, caused by the somewhat steep angle of the reverse-reciprocating grate, is the resulting elevation of the feed chute entrance, which would be about 55 feet above grade. This makes it more challenging to design a conveyor waste feed system, which is thought to be the most economical approach for the City of Ames.

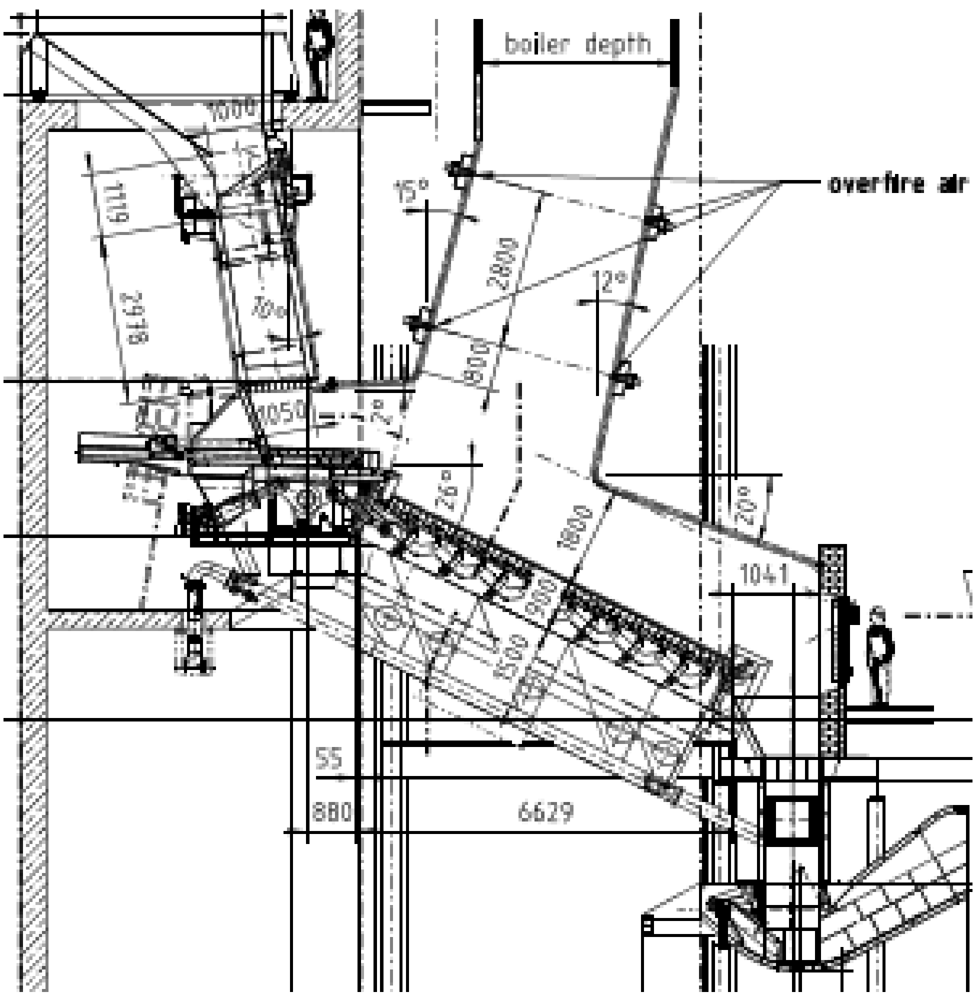


Figure G - 4: Martin Reverse-Reciprocating Grate System

There are a number of other major suppliers of mass-burn combustion systems, including Hitachi Zosen INOVA (Figure G - 5), Detroit Stoker (Figure G - 6), B&W Volund and Keppel Seghers. As with Martin, these suppliers offer mass-burn combustion systems using inclined, reciprocating grates, but with forward moving grate bars. Although the equipment is somewhat different between the suppliers, the processes are essentially the same for the combustion of MSW or RDF.

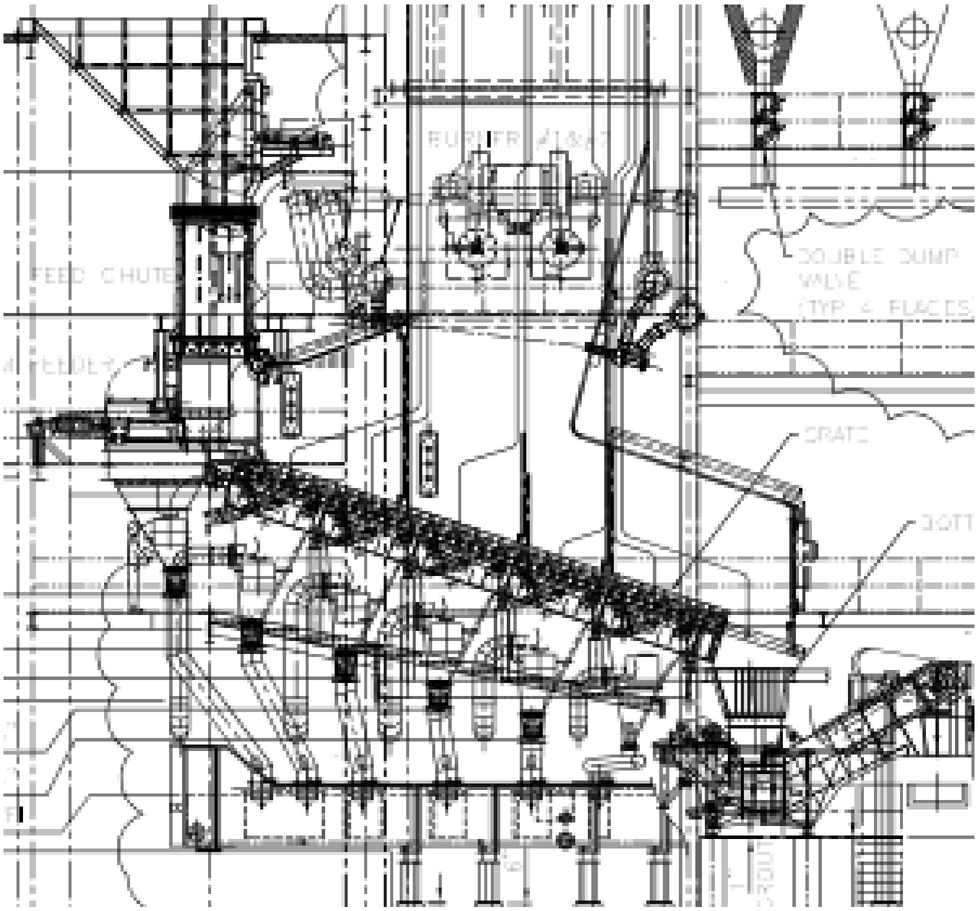


Figure G - 5: Hitachi Zosen INOVA Forward-Reciprocating Grate System

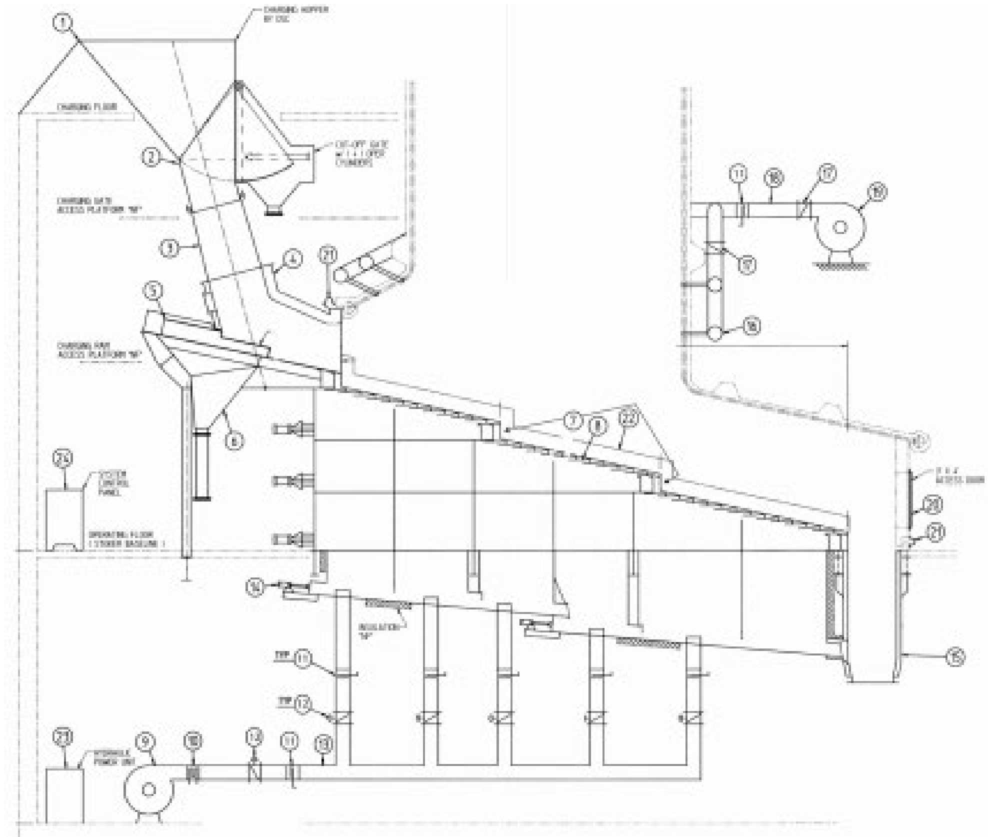


Figure G - 6: Detroit Stoker Forward-Reciprocating Grate System

Another lesser-known European supplier of mass-burn combustion systems is Ruths S.p.A. of Genova, Italy. They offer both inclined and horizontal reciprocating grates for the combustion of MSW, which could also be used for the combustion of large 20” minus RDF. Figure G - 7, below, shows a general arrangement drawing of their inclined grate system. They are a proven supplier specializing in smaller capacity units with reference plants throughout Europe and parts of Asia. The option of a horizontal grate system would reduce construction costs and further lower the elevation of the feed chute for a conveyor feed system when compared to the inclined, reciprocating grate systems.

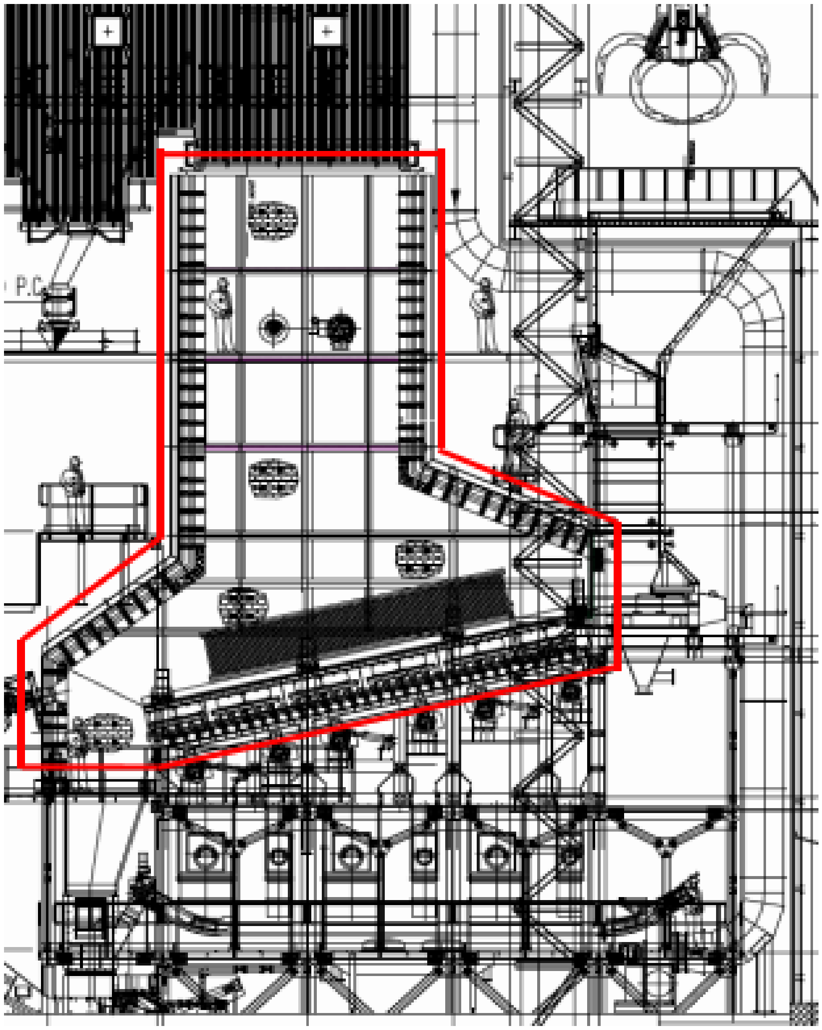


Figure G - 7: Ruths Inclined Reciprocating Grate Combustor

Another unique option for the combustion of MSW or RDF is a horizontal vibratory hearth system offered by a U.S. company called EnerSol. The vibratory hearth provides excellent waste stoking and mixing with the primary combustion air coming through the hearth. This improved stoking enables the EnerSol system to operate with a lower excess air requirement of 30% to 50% when compared to conventional reciprocating grate systems of 60% to 90%. The lower excess air requirement will result in a higher boiler efficiency, smaller boiler and emissions control systems, and lower emissions.

The horizontal orientation of the hearth enables the combustion system to be fed by either a charging conveyor for RDF or a hydraulic ram for MSW. EnerSol also has experience with direct feed from a trailer or container, which could reduce the cost of RDF storage. The horizontal orientation of the EnerSol hearth would result in a lower elevation for the feed chute relative to the inclined grate systems. EnerSol also has experience with direct feed from a trailer or container, which could reduce the cost of RDF storage.

The primary negative of EnerSol is that they have limited commercial experience with their vibratory hearth system. Figure G - 8, below, shows their only commercial installation in Australia for the combustion of municipal and medical wastes, which operated successfully for a number of years before being shut down for market reasons.

Figure G - 8: EnerSol Vibratory Hearth Combustion System

F.3 MSW Combustion System (Option 3B)

Similar to Option 2B, a mass-burn combustion system designed for unprocessed MSW would be used to combust the MSW in Option 3B. Inclined reciprocating grate systems are by far the most common combustion system used throughout the world for the combustion of municipal solid waste. These systems are offered by a number of proven suppliers including Martin, Hitachi Zosen INOVA, Detroit Stoker, B&W Volund, Keppel Seghers and Ruths. All of these suppliers offer inclined, reciprocating grate systems and although the equipment is somewhat different between the suppliers, the processes are essentially the same for the combustion of unprocessed MSW or large RDF. These systems were briefly described in section 2B, Refer back to the figures above for examples of these designs.

APPENDIX H
Details Regarding Boiler Designs

APPENDIX H

BOILER OPTIONS TECHNOLOGY

H.1. Small RDF Boiler Design Options (2A, 3A-1, 3A-2)

For small RDF (3”-4”) to the best technology is the bubbling fluidized bed combustion system. With a bubbling fluidized bed system, separate boiler modules can be used for the convection and economizer sections. For the smaller units being evaluated for the City of Ames, this allows for these modules to be shop fabricated and thus reducing field construction costs. Figure H-1, below, shows the typical boiler arrangement for a bubbling fluidized bed combustion system.

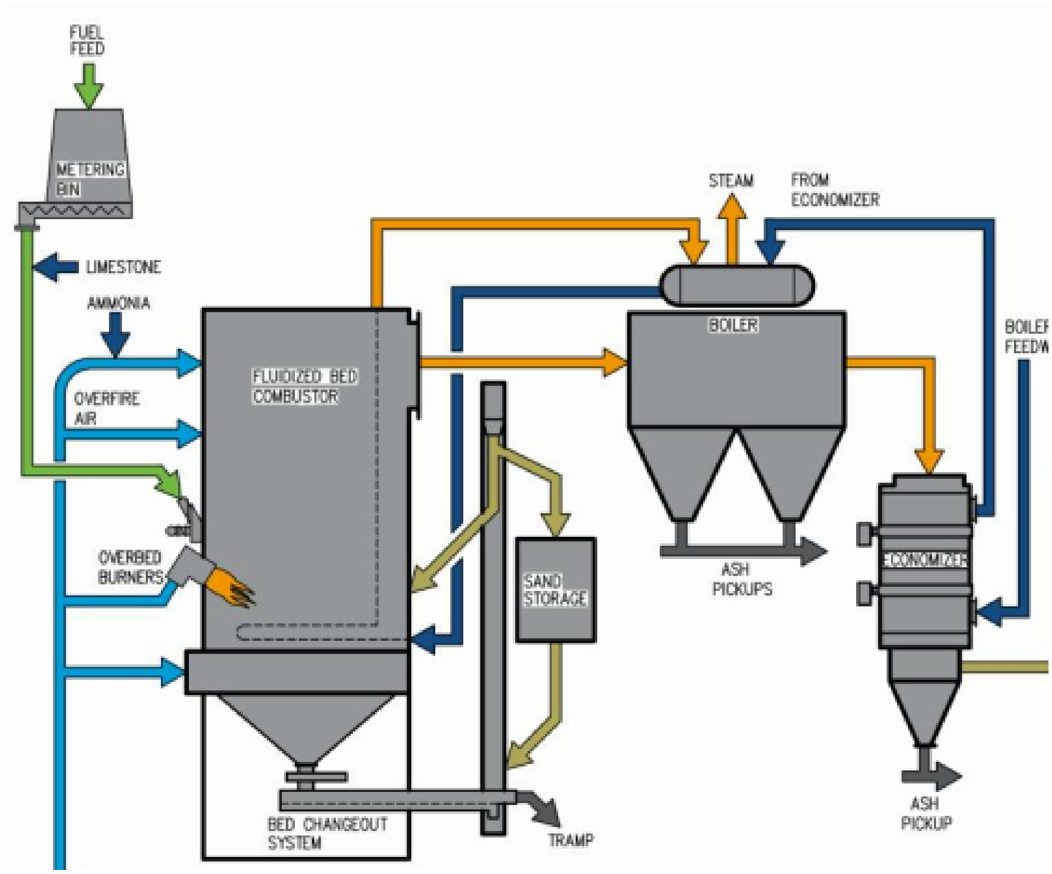


Figure H - 1: Typical Bubbling Fluidized Bed Combustor Boiler

The detailed design of the boiler will consider the high fouling and corrosion potential of the RDF feedstock, driven by the high chorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features, along with operation and maintenance approaches, have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Protective alloys will also be used in select areas to prevent high corrosion rates.

Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. On-line cleaning of the boiler tubes is typically done by either steam sootblowers or mechanical rappers, with cleaning being done several times per day. Sootblowers are more common in larger boilers but can cause operational problems in smaller units since their steam usage can cause significant swings to the plant's steam balance when they are activated. Mechanical rappers would likely be the preferred choice in the smaller units being considered by the City of Ames. On-line explosive cleaning systems are another type of boiler cleaning method that has emerged in recent years with several commercial suppliers entering the market. They typically have a higher installed capital cost and their overall effectiveness are still being evaluated by waste-to-energy operators.

H.2. Large RDF Boiler Designs

H.2.1 Option 2B Boiler Design

Mass-burn, inclined reciprocating grate combustors typically use a boiler design with multiple vertical radiant waterwall passes, followed by a horizontal convection section for steam superheat and additional steam generation. The flue gas would then go to an economizer section before exiting the boiler. This boiler design is typically field-fabricated for larger mass-burn units.

Some suppliers, such as Ruths, which specializes in smaller mass-burn units, offer a modular design approach to maximize shop fabrication and reduce field construction cost and time. Figure G - 2, below, shows a schematic of their boiler design where the evaporator bundles (blue), superheater bundles (red), and economizer bundles (green) would all be shop-fabricated and delivered to the field for placement.

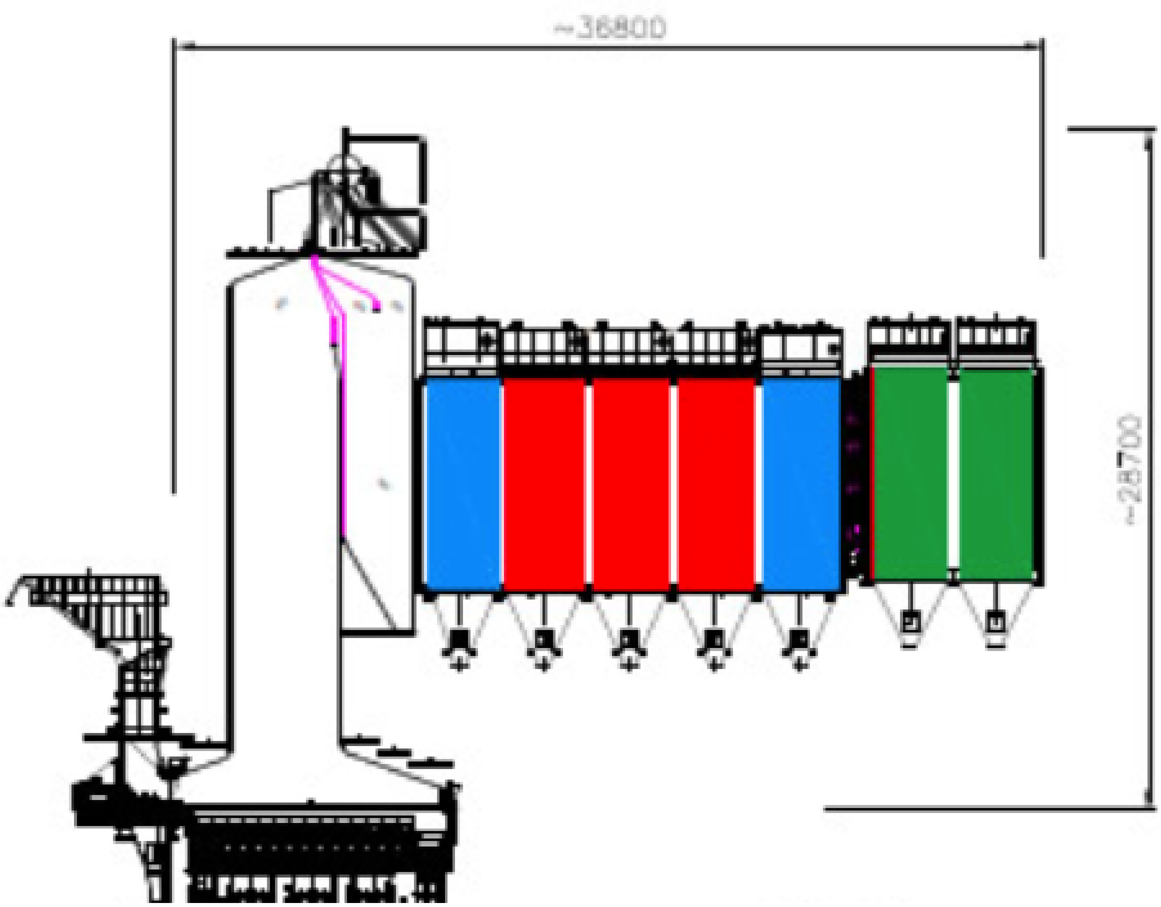


Figure G - 2 Ruths Modular Boiler Design

As with Option 2A, the detailed design of the boiler will consider the high fouling and corrosion potential of the RDF feedstock, driven by the high chlorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Protective alloys will also be used in select areas to prevent high corrosion rates. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Different methods of on-line cleaning are discussed in Section G.1 above.

H.2.2 Option 3A Boiler Design

Similar to Option 2A, the boiler design for a bubbling fluidized bed combustion system would have separate modules for the convection and economizer sections. For the smaller units being evaluated for the City of Ames, this allows for these modules to be shop fabricated and thus reduce field construction costs . This boiler design is described in Option 2A.

As with the previous options, the detailed design of the boiler will consider the high fouling and corrosion potential of the RDF feedstock, driven by the high chorine content of MSW and RDF. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Protective alloys will also be used in select areas to prevent high corrosion rates. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Different methods of on-line cleaning are discussed in Section G.1 above.

H.2.3 Option 3B Boiler Design

As with Option 2B, the recommended boiler for smaller mass-burn units would employ a modular design approach to maximize shop fabrication and reduce field construction cost and time.

As with the other options, the detailed design of the boiler will consider the high fouling and corrosion potential of the RDF feedstock, driven by the high chlorine content of MSW. Management of boiler fouling and corrosion has always been a significant challenge in the waste-to-energy industry and boiler design features along with operation and maintenance approaches have been developed to control fouling and minimize corrosion to ensure reliable operation. Flue gas and steam conditions will be set to control maximum boiler tube wall temperatures in the steam superheat section where the highest corrosion potential exists. Protective alloys will also be used in select areas to prevent high corrosion rates. Boiler tube arrangements and spacing will be designed to minimize fouling and allow for effective on-line cleaning. Different methods of on-line cleaning are discussed in Section G.1 above.

APPENDIX I

Details Regarding Emission Controls

APPENDIX I

EMISSION CONTROL TECHNOLOGY

I.1 Emissions Control

The EPA considers the Best Available Control Technology (BACT) for waste combustion systems as the combination of a dry scrubber, baghouse, Selective Non-Catalytic Reduction (SNCR) and Powder Activated Carbon (PAC) injection. These systems are proven to be very reliable at controlling emissions well below the EPA Maximum Achievable Control Technology (MACT) limits for particulates, SO2, HCl, trace metals and dioxins. CO and NOx are combustion-related emissions that are not controlled by the scrubber/baghouse system. CO is controlled by combustion control methods and will easily meet the EPA MACT standard in modern waste combustion systems. NOx is also partially controlled by combustion control methods that may be adequate to meet the EPA standard, but often a SNCR system is added to the combustor design to further control NOx emissions and reliably meet the EPA limits. Mercury is somewhat unique relative to other trace metals in that it is a very volatile metal and largely present in the vapor phase in scrubber/baghouse system. Significant amounts of mercury are adsorbed in the scrubber and baghouse therefore the injection of powder activated carbon (PAC) is added prior to the scrubber to enhance the removal of mercury. PAC injection also enhances the control of dioxins, further reducing these emissions relative to the EPA limits.

Scrubbers: Historically, the most common type of scrubber used is a Spray Dry Absorber (SDA) design where a calcium hydroxide slurry is atomized into an open vessel and contacted with the flue gas exiting the boiler. SO_2 and HCl in the flue gas are absorbed onto the atomized droplets and react with the $Ca(OH)_2$ to form $CaSO_4$ and $CaCl_2$. In parallel, the atomized droplets dry as they move through the scrubber leaving a mixture of $CaSO_4$, $CaCl_2$ and $Ca(OH)_2$ salts, called scrubber residue, which are removed from the flue gas in the downstream baghouse along with fly ash from the boiler.

In recent years, a new type of scrubber design has emerged called a Circulating Dry Scrubber (CDS) shown in Figure I - 1. The CDS employs the injection of dry $Ca(OH)_2$ into an open vessel along with recirculated fly ash / scrubber residue from the baghouse. The CDS vessel contains a large amount of fluidized $Ca(OH)_2$, scrubber residue and fly ash, which provides excellent mixing and contact with the flue gas for the effective adsorption of SO_2 and HCl. The scrubber / baghouse is typically augmented with the injection of powder activated carbon (PAC) into the flue gas at the entrance of the scrubber for additional control of both mercury and dioxins.

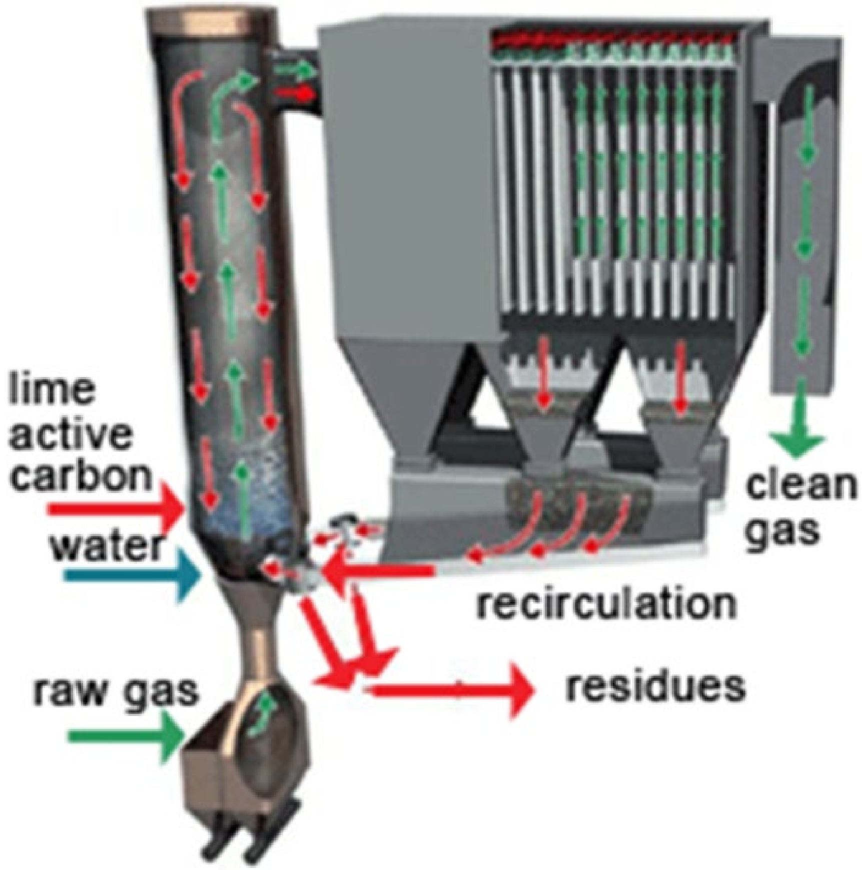


Figure I - 1: Circulating Dry Scrubber (CDS) Design

Baghouse: The workhorse of this emissions control system is the baghouse, also known as a fabric filter, which in addition to removing particulate from the flue gas, also aids in the removal of SO_2 and HCl, as well as mercury and dioxins. As the name implies, baghouses are large devices containing hundreds of long, thin bags that filter the particulate out of the flue gas (see Figure I - 2, below). The most common type of baghouse used in waste-to-energy applications is the pulse-jet baghouse. In this design, the flue gas flows from the outside to the inside of the bags. A particulate cake forms on the outside of the bags which aids in the removal of fine particulates, as well as providing additional adsorption of SO_2, HCl, mercury and dioxins. The bags are cleaned by pulses of high-pressure air that cause the bags to flex and shed the collected filter cake. The baghouse is also divided into multiple cells, typically four (4) to ten (10) cells, to allow for one cell to be isolated for maintenance while the other cells remain in service.

There are a number of suppliers of CDS/baghouse systems both in the U.S. and Europe that could provide this system to the City of Ames. Alternately, some combustor/boiler suppliers would supply the CDS/baghouse system as part of their scope of supply.

The scrubber/baghouse system has been proven and reliable for meeting the EPA emission standards for particulates, SO2, HCl, trace metals and dioxins. Mercury is somewhat unique relative to other trace metals in that it is a very volatile metal and largely present in the vapor phase at the boiler outlet and through the scrubber/baghouse system. Significant amounts of mercury are adsorbed by the Ca(OH)2 in the scrubber, as well as by excess Ca(OH)2 and fly ash unburned carbon in the baghouse. This level of mercury control is often adequate to meet the Federal mercury emission limits. However, many states look to further lower mercury emissions requiring additional control. This enhanced mercury control is achieved by pneumatically injecting of PAC into the flue gas at the inlet to the scrubber. PAC injection also enhances the control of dioxins, further reducing these emissions relative to the EPA limits.

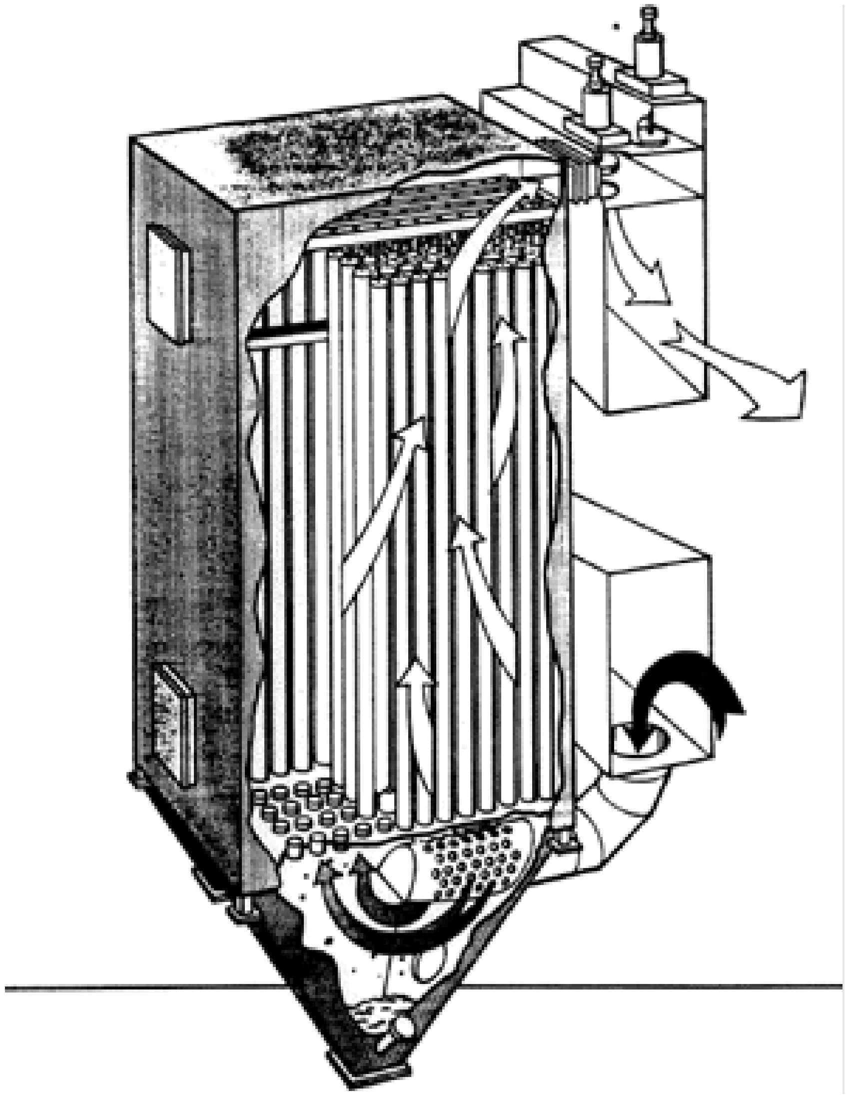


Figure I - 2: Pulse-Jet Baghouse Design

CO and NOx are combustion-related emissions that are not controlled by the scrubber/baghouse system. CO is controlled by combustion control methods and would easily meet the EPA standard of 100 ppm in a bubbling fluidized bed combustor. NOx is also partially controlled by combustion control methods that may be adequate to meet the EPA standard of 205 ppm.

SNCR: If there is a need for further NOx control, a Selective Non-Catalytic Reduction (SNCR) system is included in the combustor design. In SNCR, aqueous ammonia or urea is injected into the upper furnace of the combustor at a flue gas temperature range of 1600 to 1800 F. In this temperature range, NOx reacts with NH_3 to produce N2 and H_2O. SNCR systems can typically achieve 40–60% reductions in NOx exiting the combustor.

APPENDIX J

Bond Evaluation Process Description

APPENDIX J

DEBT SERVICE MODEL METHODOLOGY
(PREPARED BY CAPITAL MARKET ADVISORS)

The following is a list of the assumptions used to model the Debt Service Schedules required to pay back the funds borrowed (via bond issuance) to finance the capital needs for each of the non-Base Case options in the Financial Model. This list can be found in the Financial Model in the tab titled "*Assumptions – Debt Models*". Each assumption listed is followed by a brief explanation of how the assumption was made.

Assumptions:

- Closing (Funds Received) Date: 9/15/2024
- Sale Date: 9/1/2024
  - The standard market practice is to sell bonds about two weeks prior to closing to give each party involved in the financing time to settle the paperwork.
- Principal Repayment: Annual payments beginning 6/15/2025 and ending 6/15/2044.
  - The first maturity mimics the City's Electric Revenue Bonds – 2015B (most recent electric bonds). Those bonds were structured to have the first principal maturity paying in June of the following fiscal year.
  - The final maturity date is the final year of the Financial Models (2044).
  - The annual payment frequency is standard bond issuance practice.
- Interest Payment: Semi-annual payments beginning 6/15/2025 and ending 6/15/2044
  - First payment mimics the Ames 2015B Bonds.
  - Final payment is the same as the last principal payment.
  - Semi-annual payment frequency is standard bond issuance practice.
- Optional Redemption (Call) Date: 6/15/2034 (10 years after issuance) at par
  - 10-years mimics 2015B and is a standard practice.
  - Calling at par price is also standard.
- Debt Service Reserve Fund (DSRF): Lesser of Max Annual Debt Service or 10% of Total Par
  - Mimics 2015B Bonds and is standard practice. The larger the funding of the DSRF, the better it looks to investors.
  - DSRF is used as a securitization to pay back bond holders. If unused (almost always), it is used to pay the final principal maturity (shown in models).
- Debt Service Solution: Fiscal Year Level
  - The methodology chosen is every fiscal year the total debt service is the same. Other options exist such as having debt service escalate to mimic an assumed increase in electric revenues.
- Uses of Funds:
  - Deposit to Construction Fund
    - The amount needed to complete each capital project as estimated by RRT.
  - Deposit to DSRF (as discussed above)
  - Costs of Issuance
    - Amount needed to pay everyone involved in the financing (bond counsel, rating agency, municipal advisor, etc.).
  - Underwriter's Discount
    - The spread taken by the purchaser of the bonds.

- Rounding Amount
    - All bonds are sold in denominations of $5,000 but the money received may be in smaller denominations. The rounding amount is a dollar amount between 0 and 4,999.99 that gets the uses to match the sources of funds.
- Sources of Funds:
    - Par Amount
        - The amount of bonds sold and the principal amount that must repaid.
    - Reoffering Premium
        - The amount over the par amount that investors provide to lower the yield the City pays on the bonds (increases the price they pay for the City's bonds). The resulting yield typically matches the market interest rate available for other similar municipal bonds at the time of the bond sale. It keeps the coupon rate high so that the bonds are easier to resell to investors.
- Coupons: Large 5% coupons until the call date, drop to 2.125% then start slowly escalating
    - Made to mimic 2015B Bonds which closely resembles how most bonds sell currently.
- Yields: Start small and increase every year, matches closely to the same slope as the US Treasury yield curve (there's more risk in a company defaulting in 30 years than in 2 years so the bonds maturing in 2 years are more expensive to buy (lower yields)).
    - The yields are created by taking the prevailing 'Aaa' MMD (Municipal Market Data) General Obligation Yields (on 2/24/2022), adding the spread between the yields the City received on the 2015B Bonds and the 'Aaa' MMD scale the day of sale, and then adding 160 basis points (bps), which is ~10 bps for every month between these projections and the projected sale date.
        - It is assumed interest rates will be rising for the foreseeable future since they're currently hovering above all-time lows and inflation is rapidly increasing which will likely cause the Fed to begin increasing rates.

APPENDIX K

Capital Cost Estimating Methodology and Cost Summary Table

APPENDIX K – CAPITAL COSTS ESTIMATING METHODOLOGY AND ESTIMATE TABLE

Overview

The capital cost estimates are based on the anticipated scope of work associated with the design and construction costs for each option. The anticipated scope of work for each option was developed based on conceptual process flows, schematics, preliminary plant and major equipment sizing, similar projects, vendor budgetary pricing as well as assumptions that help communicate the entire scope of each option's work.

The values for the cost estimates were prepared with the intent to be conservative and representative of the high side of the probable cost for construction such that comparisons to the current operations would add greater confidence if the critical decision were made to move away from the current operations and embark on a new solid waste management and energy production model compared to the current system that has served the City effectively for 50 years. The estimates also reflect some areas for system enhancement, operational improvement, and better environmental performance. When the results of the modeling reveal too close of a difference in comparison to the current operations (or between multiple options), then more refinement would be warranted. However, the financial model reveals the differences are not close and therefore the costs as presented reflect a proper cost estimate for consideration and planning at this programming level of evaluation, estimating and engineering.

Estimating Methodology

The estimating methodology used by RRT is based on standard estimating practices. For a project of this magnitude to be successful, the budget must be developed and controlled from inception through completion in concert with the approach and use. We draw from our historical cost database developed from the construction RRT has managed and executed over the past 30 years. While actively performing work all over the United States and in Canada, we are continuously contracting for commodity materials, specialty process equipment, and subcontracting services, and have a strong understanding of the current market conditions, demands, and the associated market prices. RRT can leverage this knowledge to bring further accuracy to our cost efforts.

The basis of the capital cost estimates is considered a Class 4 estimate per AACE (Association for the Advancement of Cost Engineering) Guidelines. It is generally prepared based on limited information and subsequently has wide accuracy ranges. This level of estimate is typical for use with project screening, determination of feasibility, concept evaluation, and preliminary budget approval. Engineering is from 1% to 15% complete, and comprised of very basis definition: plant capacity, block schematics, indicated layout, process flow diagrams (PFDs) for main process systems, and preliminary engineered process and major equipment list.

The estimate is based on the actual cost of similar projects for each Option utilizing the same or very similar equipment adjusted for escalation, location, prepared order of magnitude estimates, manufacturer's quotes and proposals, and historical data for similar type of work.

Expected Accuracy Range
Any opinion of construction costs prepared by RRT is supplied for the general guidance of the Client only. Since RRT has no control over competitive bidding or market conditions, RRT does not guarantee the accuracy of such opinions as compared to contract bids or actual costs to Client.

Typical accuracy ranges for Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances.

Based on RRT's inclusion of an appropriate contingency and the methodology applied, we estimate the construction costs to be within +/- 25% accuracy.

Escalation
The construction industry historically has always been affected by supply chain and shipping disruptions, labor shortages, fuel prices, and tariffs on raw material imports. Just-in-time inventory management methods and "build-to-suit" materials, equipment and machinery are the industries practices. The larger the project, the more acute these issues can be even with bulk commodity materials. Notwithstanding Covid-19 times, these are serious considerations.

These factors, combined with rising labor costs and high inflation, have led to significant cost increases and volatility in construction which must be accounted for. Engineering News Record reports over 13% increase in building construction costs for 2021 and 7% increase in infrastructure construction costs. It is crucial for successful project screening and concept evaluation to account for and allocate risk in pricing in the current economic times as well as the limited information in the engineering and particulars of each option.

Given our estimating methodology applied to each option is the same, we believe on a relative basis the stated capital costs provide a relative difference suitable for effective comparisons. Once one (or two options) are selected by the City, then a Class 3 estimate can be prepared to form the basis for budget authorization, appropriation, and/or funding. Typically, engineering is then progressed to a level of 10% to 40% complete and would include at a minimum the following: process flow diagrams, utility flow diagrams, preliminary piping and instrument diagrams, plot plan, developed site layout drawings, equipment general arrangements and essentially complete engineered process and utility equipment lists.

Contracting Approach

The approach used for procurement/implementation of the work for any option being evaluated could be a single EPC contractor or could be a traditional design-bid-build with a separate procurement for the equipment system. Given the many procurement methods, it is beyond the scope of this study to recommend the method for any option. It is notable that the procurement method will determine risk allocations and therefore the cost for implementation will be affected significantly. The estimate as prepared is based on a shared allocation of risks between the City and the contractors and a reasonable number of subcontract tiers.

Labor, Material, Equipment & Subcontract Pricing Methodology

The cost estimate basis is from RRT's historical cost database developed from numerous similar projects that RRT has built over the past 30 years and pricing we received from multiple vendors and subcontractors for the Cost Estimate. RRT requested and received vendor pricing and technical estimating data from many of the industry leaders for the necessary processing equipment and technology needed for the Options. Whenever possible, this included multiple companies covering the major equipment packages so we get a clear view of the costs across difference sources. Quotes were solicited through meetings, conference calls and extensive correspondence. Some of the vendors also actively participated in the selection process and provided input for equipment sizing, layout and flexibility so the cost estimates could be built with confidence, within the limitations of engineering at this time is very much conceptual. The pool of vendors included companies not only from the US, but also from Europe. In many cases, these vendors currently or have worked with RRT on other projects; this strengthens the accuracy of the estimates and the design approach by pooling the experiences on similar projects.

In some cases, particularly for the components associated with the combustion train, we had difficulty in obtaining vendor pricing due to their reluctance to expend their time and efforts for a "study" for the size range of this study. However, for each option we were able to rely on historical projects for similar type and size projects such as the front-end processing plant at Perham, MN or the addition of a 3rd Unit (200 TPD) at Rochester, MN (Olmsted County) and Covanta Durham York, ON. When using historical costs we applied adjustments to cover cost escalations over the passage of time, differences in the scopes of work and applicability to Ames and feedback discussions we held with the plant owners and others on whether the reported costs were representative of the probable costs. In these cases, we considered adjustments to cover contractor claims, work that needed to be added after the project was "completed" and work need to cover the level of reliability and redundancy needed for Ames to meet the stated goals.

Engineering Input

RRT assembled its team of engineers and construction professionals from the recycling, solid waste processing, waste-to-energy, and power plant industries to evaluate the needs and considerations of each option. The estimating process included a site visit, review of existing drawings and process flow diagrams, review and analysis of existing operating and extensive interviews and regular meetings with City staff both on the solid waste side and power plant side. RRT also solicited input from industry leaders and technology providers considering not only technical and financial factors but also environmental, commercial viability, constructability and operating performance. RRT also contacted plant operators to gather critical input data based on their experience as well as actual costing for the financial model. It was the objective throughout to secure data and information that was substantiated from one or more sources and was adjusted when needed for specific use in this Ames project by applying the process flow diagrams, plant sizing and construction approaches for each specific option.

Exclusions Approach

Certain items were not considered in the capital cost estimates and they were excluded for each option; below is a list of the key items:

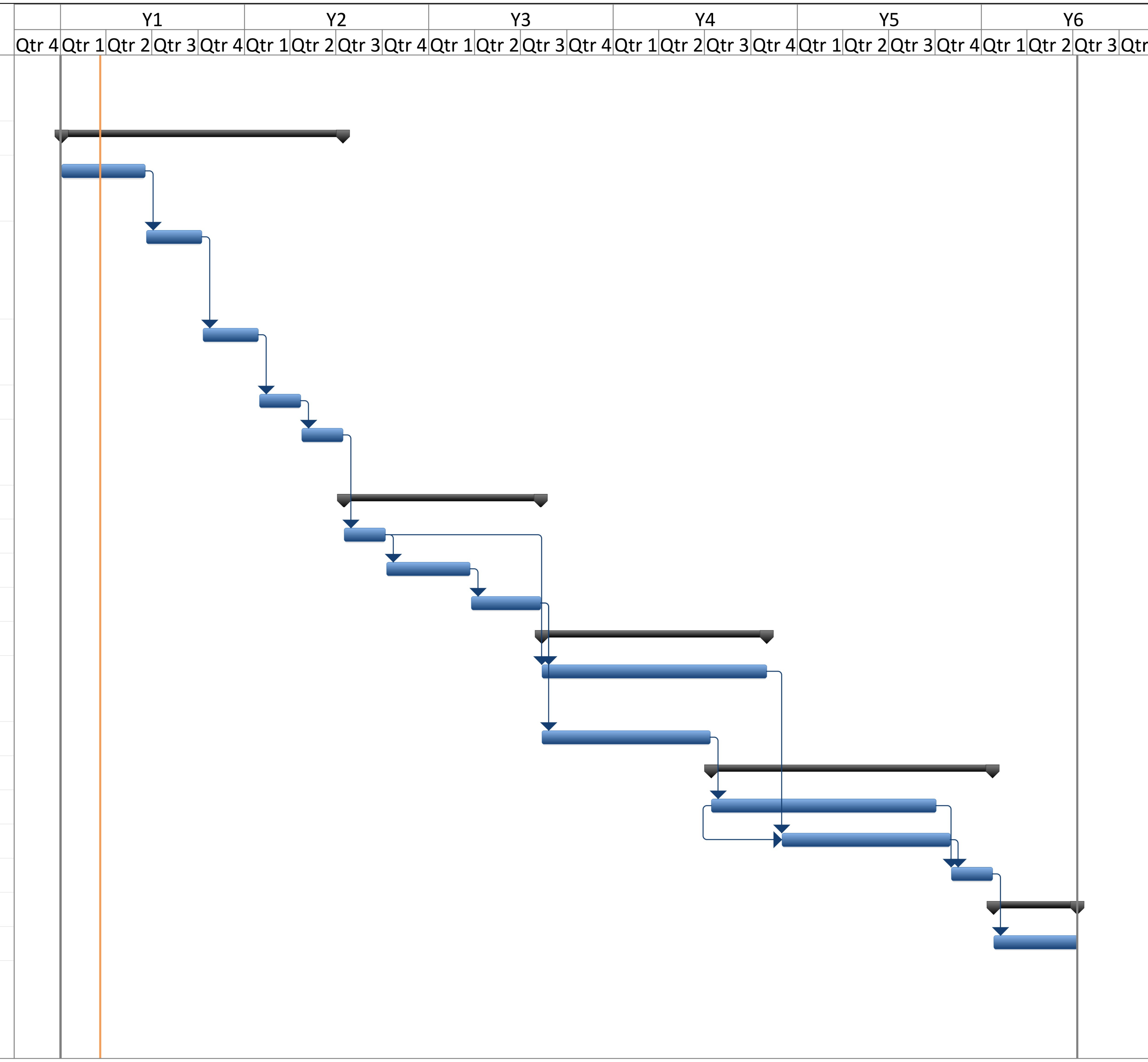
- Sales tax
- Off-site utilities
- Permitting
- City staff development costs
- Site remediation (as required)

CITY OF AMES - WTE OPTIONS CAPITAL COST ESTIMATE SUMMARY						
	(in millions of US Dollars - Feb 2022)					
	Option 2A	**Option 2B**	**Option 3A-1**	**Option 3A-2**	**Option 3B-1**	**Option 3B-2**
	4"RDF	20" RDF	4"RDF	4"RDF	MSW	MSW
DESCRIPTION	5/6 building	Coal Yard	Coal Yard	Industrial Site	Coal Yard	Industrial Site
RRP Equipment Capital Costs	$0.95	$5.65	$5.75	$5.75	$0.32	$0.32
RDF Storage Costs	$0.32	$-	$3.21	$2.59	$-	$-
RRP Building & Equip Installation Costs	$0.59	$2.00	$8.14	$8.69	$-	$-
PP Major Equipment	$66.708	$79.73	$68.16	$108.22	$80.21	$82.26
PP Installation, parts, materials & labor	$14.429	$31.35	$23.03	$35.04	$31.35	$42.18
Metal Ash Recovery (MSW options only)	$-	$-	$-	$-	$3.30	$3.30
Pipe Rack	$-	$2.70	$2.70	$0.26	$2.70	$0.26
Land Acquisition	$-	$-	$-	$1.00	$-	$0.90
Subtotal	**$82.99**	**$121.42**	**$111.00**	**$161.56**	**$117.88**	**$129.22**
Pre-Construction Services, Engineering	$5.07	$7.24	$7.16	$9.99	$6.30	$8.19
Constr. Mgmt., 3rd Party Testing, Commissioning	$13.78	$19.75	$19.64	$28.23	$20.42	$23.54
Subtotal	$101.83	$148.41	$137.79	$199.77	$144.59	$160.95
Contingency (15% equip, 25% labor)	$13.98	$20.41	$20.09	$28.97	$21.04	$23.91
TOTAL 2022	**$115.82**	**$168.82**	**$157.88**	**$228.74**	**$165.63**	**$184.86**

APPENDIX L

Project Schedule

ID	Task Name	Duration
1	Final City of Ames Eval of Options & Selection of Engineer	0 days
2	**ENGINEERING & EQUIP SELECTION**	**400 days**
3	Prelim Engineering & Specifying of Major Equipment	6 mons
4	Prepare Bids for Boiler(s) and other Owner Furnished Equipment (OFE)	4 mons
5	Bidding of Boiler(s) and other Owner Furnished Equipment	4 mons
6	Evaluation of Bids	3 mons
7	Awarding of Boiler(s) and other Owner Furnished Equipment	3 mons
8	**DETAILED ENGINEERING**	**280 days**
9	Major Equipment Vendors Develop Certified Dv	3 mons
10	Detailed Balance of Plant Engineering	6 mons
11	Contractor Bid & Selection	5 mons
12	**EQUIPMENT FABRICATION**	**320 days**
13	Major Equipment Fabrication & Delivery	16 mons
14	Balance of Plant Procurement by Contractor	12 mons
15	**CONSTRUCTION/COMMISSIONING**	**400 days**
16	Civil Works & Bldg Construction	16 mons
17	Equipment Installation	12 mons
18	Startup and Commissioning	3 mons
19	**SCHEDULE FLOAT**	**120 days**
20	Schedule Float	6 mons
21	***NOTE: Permitting activity and duration will need to be determined by the City and coordinated with the above project delivery schedule	



Project: Ames Schedule_MAR202
Date: Mon 3/21/22

Task		External Milestone		Manual Summary Rollup	
Split		Inactive Task		Manual Summary	
Milestone		Inactive Milestone		Start-only	
Summary		Inactive Summary		Finish-only	
Project Summary		Manual Task		Deadline	
External Tasks		Duration-only		Progress	

APPENDIX M
Advantages and Disadvantages Table

1	Advantages	Disadvantages
RRP	No downtime for construction	
Storage	No downtime for construction	Improvements needed to RDF bin. Limited storage capacity for RDF. Compaction issues and heavy reliance on storage continue.
Boiler/Combustor		Corrosion issues, higher boiler operating temperatures.
Power		Continued use of natural Gas for co-firing RDF. Lost opportunity to purchase regional renewable power.
Financial	No new capital expenditures	At $5.00/dth gas under Ames' contracts, $18M+ annual operating cost for required co-firing natural gas with RDF.
Site Considerations	Same RRP & PP buildings being reused	
Environmental		Higher GHG emissions of CO_2 due to the required combustion of natural gas with RDF in both Units 7 and 8. Higher "baseline" emission with continued use of older air pollution control technology.

2A	Advantages	Disadvantages
RRP	Increased throughput. Increased separation efficiency and RDF recovery by replacing air knife. Additional eddy current separator for improved non-ferrous metal recovery.	Reuses most of the old equipment -> potential for greater maintenance.
Storage	Increased throughput consumption may reduce reliance on existing storage.	No increase in storage capacity for MSW or RDF.
Boiler/Combustor	Increased capacity throughput, reducing need to bypass to landfill during normal operation. Continued use of pneumatic conveyance and potentially direct feed to the bubbling fluidized bed combustors. Higher boiler efficiency and energy recovery due to lower excess air requirement of bubbling fluidized bed combustor for RDF. More reliable equipment (new).	
Power	Additional generation capacity for the City (ST5) of 5-6 MW. Use of existing power plant, operations staff and HV infrastructure. ~25-35MW of gas-fired generation replaced with MISO purchases at lower cost.	Less local generation on-line and synchronized for City voltage stability.
Financial	Relatively low RRP capital expenditure. Significantly lower cost of replacement electricity from MISO to replace gas-fired portion of generation. Reduced exposure to natural gas price volatility for City power needs.	Still some gas required for co-firing operating cost in Unit 8 as backup. High boiler unit cost.
Site Considerations	RRP & PP buildings being reused. Extensive use of existing PP infrastructure. Re-purpose existing plant floor where retired Units 5 &6 are located. All power gen continues under "one roof".	

2A	Advantages	Disadvantages
Environmental	Removal of SO_2, HCl, mercury and dioxins by the PAC, scrubber/baghouse system. Significantly lower greenhouse gases (less gas consumption), than Base Case. Lower NOx and CO emissions resulting from the excellent mixing, temperature control and lower excess air requirement of bubbling fluidized bed combustor. Stabilization of heavy metals in the ash due to alkalinity control from the addition of $Ca(OH)_2$ through the scrubber. Reduced NOx by 75% due to newer emissions controls (ammonia injection).	GHG CO_2 emissions continue from NG combustion when Unit 8 is operated as back-up, but at a substantially reduced level. Continued higher NOx emissions in Unit 8 as backup.

2B	Advantages	Disadvantages
RRP	New RRP equipment. Rough shred, while metals and fines are recovered. Increased throughput. Less equipment compared to other RDF options-> and thus less O&M.	Long downtimes to demo existing equipment and add new equipment. Existing conveyance lines cannot be used due to RDF size.
Storage	Increased RDF storage at PP tipping floor.	Existing bin abandoned in place to be dismantle (extra cost).
Boiler/Combustor	Multiple potential providers for MSW WTE boiler manufacturers to accept large RDF.	Lower boiler efficiency and energy recovery due to higher excess air requirement of mass-burn (rough shred) combustor.
Power	Additional generation capacity for City with ST5 (5-6 MW). Utilization of existing turbine hall and HV interconnection.	Less generation on-line and synchronized for COA voltage stability new building required on coal yard.
Financial	Reduced exposure to volatility of natural gas prices for baseload generation. Significantly lower cost of replacement power from MISO. Potential for less FTEs, maintenance and costs. Less capital expenditure for RRP compared to 3A and 3B	Additional manpower/loader for RDF tipping floor management at PP. Higher unit capital cost of mass-burn for two new boilers due to sizing is at smaller end of industry range.
Site Considerations	RRP building being reused. Re-purpose of coal yard property.	Additional footprint needed at PP to store RDF.
Environmental	Removal of SO2, HCl, mercury and dioxins by the scrubber/baghouse system.Stabilization of heavy metals in the ash due to alkalinity control from the addition of Ca(OH)2 through the scrubber. No greenhouse gas (CO2) from combustion of natural gas co-firing for waste consumption	Higher NOx and CO emissions from mass-burn combustion systems.

3A-1	Advantages	Disadvantages
RRP	S-O-A RRP, new equipment. Increased throughput with same FTEs. Reduces wear on equipment and costs Increased RDF recovery and quality. Better metals recovery rates, better rejects removal rates. New building -> no downtime while construction occurs. New building -> old RRP can be repurposed once construction is over.	More equipment compared to 2B and 3B -> more maintenance.
Storage	Increased RDF and MSW storage to delay need to fire Unit 8 as backup. Existing RDF bin can be used as additional & redundant RDF storage.	Costs of additional RDF storage bin and material transfer system
Boiler/Combustor	Higher boiler efficiency and energy recovery due to lower excess air requirement of bubbling fluidized bed combustor for RDF.	Limited suppliers of RDF combustors.
Power	Additional generation capacity for City from with ST5 (5-6 MW). Utilization of existing turbine hall and HV interconnect.	Less generation on-line in City for voltage support. New RRP building required on coal yard.
Financial	Reduced exposure to natural gas price volatility for baseload generation. Significantly lower cost of replacement power from MISO. Reduced maintenance cost of new equipment	Highest capital expenditure for the RRP.
Site Considerations	Near existing infrastructure (PP).	New RRP building, new RDF storage bin footprint and PP on coal yard.
Environmental	Removal of SO_2, HCl, mercury and dioxins by the PAC, scrubber/baghouse system. Significantly lower greenhouse gases (less gas consumption), than Base Case. Lower NOx and CO emissions resulting from the excellent mixing, temperature control and lower excess air requirement of bubbling fluidized bed combustor. Stabilization of heavy metals in the ash due to alkalinity control from the addition of $Ca(OH)_2$ through the scrubber. Reduced NOx by 75% due to newer emissions controls (ammonia injection).	Continued GHG CO_2 emissions from NG combustion with use of Unit 8 as back-up

3A-2	Advantages	Disadvantages
	S-O-A RRP, new equipment. Increased throughput, with same number of FTEs. Increased RDF recovery and quality. Better metals recovery rates, better rejects removal rates. New building -> no downtime while construction occurs. New building -> old RRP can be repurposed once construction is over.	More equipment compared to 2B and 3B -> potentially more maintenance.
Storage	Increased RDF and MSW storage.	
Boiler/Combustor	Higher boiler efficiency and energy recovery due to lower excess air requirement of bubbling fluidized bed combustor for RDF.	Limited suppliers of RDF combustors.
Power	Thermal sales.	Tied to host viability long term, contract risk. No incremental generation for COA. Staffing increase to man existing (Units 7&8) for capacity and new PP (Units 9&10).
Financial		Highest capital expenditure for the RRP. Host credit/market risk.
Site Considerations	New greenfield site	New land area required (~10 acres) (purchase? lease?). Potential delays in siting and approval due to citizen concern or re-zoning. New building and new RDF storage bin footprint. staffing inefficiencies as a result from segregated location from existing 7 & 8 capacity resources.
Environmental	Removal of SO2, HCl, mercury and dioxins by the scrubber/baghouse system. Lower NOx and CO emissions that results from the bubbling bed combustion of RDF with excellent air mixing and temperature control. Stabilization of heavy metals in the ash due to alkalinity control from the addition of Ca(OH)2 through the scrubber.	

3B-1	Advantages	Disadvantages
RRP	No RRP Equipment -> Less maintenance and O&M compared to 2A, 2B, 3A. No Building - > no downtime while construction occurs. No Building -> old RRP can be repurposed once construction is over. Metal recovery post -combustion -> recovering metals at lower cost compared to a new RRP. Less material diverted from direct processing.	No fines/rejects removal-> more wear of equipment & maintenance on boilers. Metal recovery post-combustion -> lower metal recovery % and market value compared to an RRP.
Storage	Increased MSW storage compared to Option 1. Same/adjacent building to PP.	Industry max MSW storage recommendation of ~4 days results in bypassing to landfill sooner compared to RDF options.
Boiler/Combustor	S-O-A MSW Combustion Boiler. Multiple potential providers of MSW boilers.	Lower boiler efficiency and energy recovery due to higher excess air requirement of mass-burn combustor.
Power	Additional generation capacity with Units 9 & 10 with ST5 (5-6 MW).	Less generation on-line for COA voltage support. -New PP building required on coal yard.
Financial	Less equipment -> less maintenance. Less equipment-> lower capital cost.	Higher capital cost of mass-burn inclined reciprocating grate combustion system.
Site Considerations	Less equipment -> smaller footprint.	
Environmental	Removal of SO_2, HCl, mercury and dioxins by the scrubber/baghouse system. Stabilization of heavy metals in the ash due to alkalinity control from the addition of $Ca(OH)_2$ through the scrubber.	Higher NOx and CO emissions from mass-burn combustion systems vs. RDF.

3B-2	Advantages	Disadvantages
RRP	No RRP Equipment -> Less maintenance and O&M compared to 2A, 2B, 3A. No Building - > no downtime while construction occurs. No Building -> old RRP can be repurposed once construction is over. Metal recovery post -combustion -> recovering metals at lower cost compared to a new RRP. Less material diverted from direct processing.	No fines/rejects removal-> more wear of equipment & maintenance on boilers. Metal recovery post-combustion -> lower metal recovery % and market value compared to an RRP.
Storage	Increased MSW storage compared to Option 1Same/adjacent building to PP.	MSW storage can typically only be stored for 3 days so less overall storage compared to some of the other options.
Boiler/Combustor	S-O-A MSW Combustion Boiler. Multiple potential providers of MSW boilers.	Lower boiler efficiency and energy recovery due to higher excess air requirement of mass-burn combustor.
Power	Thermal sales.	Tied to host viability long term, contract risk. No incremental generation for COA. Staffing increase to man existing and new PP.
Financial	Less equipment -> less maintenance costs. Less equipment-> lower capital cost.	Higher capital cost of dual mass-burn inclined reciprocating grate combustion system. Steam host credit/market risk.
Site Considerations	Less equipment -> smaller footprint.	New land area required (~9 acres) (purchase? lease?). Potential delays in siting and approval due to NIMBY syndrome or re-zoning. New PP building for combustor and front-end material storage. Labor inefficiencies form segregated operations from Unit 7&8.
Environmental	Removal of SO2, HCl, mercury and dioxins by the scrubber/baghouse system. Stabilization of heavy metals in the ash due to alkalinity control from the addition of Ca(OH)2 through the scrubber. No co-firing of natural gas, reduced GHG footprint.	Higher NOx and CO emissions from mass-burn combustion systems.