Focused Verification and Validation of Advanced Solid Waste Management Conversion Technologies

Phase 2 Study

Prepared for:

New York City Economic Development Corporation
and
New York City Department of Sanitation

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Submitted by:

Alternative Resources, Inc.
1732 Main Street
Concord, MA 01742
(978) 371-2054

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TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 Background and Study Objectives

In September 2004, New York City (City) completed Phase 1 of an evaluation of new and emerging solid waste management conversion technologies[1]. The Phase 1 Study was a cooperative effort between the New York City Department of Sanitation (DSNY) and the New York City Economic Development Corporation (NYCEDC). The Phase 1 Study included 43 technologies, categorized by type: thermal, digestion (aerobic and anaerobic), hydrolysis, chemical processing, and mechanical processing for fiber recovery. Through the Phase 1 Study, the City determined that the technology categories of anaerobic digestion and thermal processing have developed the furthest. Both of these technology types are currently in commercial operation for mixed municipal solid waste (mixed MSW or MSW) outside of the United States, at capacities greater than 50,000 tons per year (i.e., 137 tons per day based on 365 days per year), with commercial meaning a facility is in operation and accepting mixed MSW as an established disposal mechanism. At least one company (Masada OxyNol) is advancing the hydrolysis technology to commercial application, with pilot testing completed in the U.S. and a facility under development in Middletown, New York. The other technology categories included in the Phase 1 Study are at less advanced stages of development for MSW.

Based on the findings of the Phase 1 Study, the City initiated focused, independent verification and validation of information for the most advanced anaerobic digestion, thermal processing, and hydrolysis technologies to determine if, as a next step, development of one or more demonstration facilities for New York City may be warranted as part of a long-term plan for commercial application of such technologies. The goal of the Phase 2 Study was to provide further evidence that the advanced technology categories can reasonably meet potential expectations for City application. Such expectations include diversion of MSW from landfill disposal through beneficial use of the waste, favorable environmental performance, and economic viability. To accomplish this goal, the Phase 2 Study had the following objectives:

- Identify technologies representative of the advanced technology categories, whose sponsor's are willing and able to provide detailed, relevant information for the City's focused verification and validation process.

- Complete an independent technical review and evaluation of the participating technologies, including major system components, site size requirements, mass and energy balances, operating data, products, residue requiring landfill disposal, and technology transfer issues.

- Complete an independent environmental review and evaluation of the participating technologies, including air pollutant emissions, water usage, wastewater discharge, product quality, and residue quality.

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[1] Alternative Resources, Inc. (ARI), Evaluation of New and Emerging Solid Waste Management Technologies, September 17, 2004.

- Summarize and evaluate project economics as estimated by the technology sponsors; provide an independent assessment of the reasonableness of those economics, and compare such costs to those for current export practices.

The objectives of the Phase 2 Study were met, with review and evaluation completed to a level of detail commensurate with the information provided by the participating technology sponsors.

Although only certain anaerobic digestion, thermal processing, and hydrolysis technologies and associated technology sponsors were reviewed in the Phase 2 Study, the intent is not to preclude other companies from participating in the next phase of City activity, should the City move forward with development of a demonstration facility. If the City chooses to develop a demonstration facility, the City would engage in an open procurement process for selection of a technology(ies) and technology sponsor(s) meeting qualification criteria established by the City.

1.2 Report Structure

This Report describes Phase 2 of the City's evaluation of new and emerging solid waste management technologies. Following this Introduction (Section 1), a brief summary of the preceding Phase 1 Study is presented in Section 2 to set the stage for this Report. A description of the methodology that was used to complete the Phase 2 Study is presented in Section 3. Next, Section 4 presents an introduction to the technology categories included in the Phase 2 Study (anaerobic digestion, thermal processing, and hydrolysis).

Technical, environmental and economic evaluations were conducted for the emerging technology categories of anaerobic digestion and thermal processing. An overview of these technology categories and a technical review of the specific technologies participating in the Phase 2 study are provided in Sections 5 and 6, respectively. Section 7 presents the findings of the environmental review, and Sections 8 and 9 present corporate financial information and the results of the economic evaluation for the anaerobic digestion and thermal processing technologies.

A full technical, environmental, and economic evaluation could not be conducted for Masada's hydrolysis technology as part of the City's Phase 2 Study, because of the company's limited ability to provide information. While Masada has completed design and permitting for a facility in Middletown, New York, only limited information was made available since future ownership of the company was uncertain at that time. Recently, ownership issues have been resolved and the project is moving forward. Relevant information that was available for Masada is summarized in Section 10. That section also identifies certain other initiatives taking place in the United States regarding emerging solid waste management technologies.

Section 11 presents the overall findings of the Phase 2 Study.

2.0 OVERVIEW OF PHASE 1 STUDY

In September 2004, the City completed Phase 1 of an evaluation of new and emerging solid waste management conversion technologies. The Phase 1 Study identified and reviewed 43 new and emerging technologies, and compared the technologies to conventional waste-to-energy technology to identify the potential advantages and disadvantages that may exist in pursuing emerging conversion technologies. Conventional waste-to-energy technology was chosen as a point of comparison since it is the most widely used technology available today for reducing the quantity of post-recycled waste being landfilled.

For purposes of the Phase 1 Study, "new and emerging technologies" were defined as technologies (e.g., biological, chemical, mechanical and thermal processes) that are not currently in widespread commercial use in the United States, or that have only recently become commercially operational. Technologies that are commercially operational in other countries, but only recently or not at all in the United States, were defined as "new and emerging" with respect to the United States. Commercial means a facility is in operation and accepting mixed MSW as an established disposal mechanism (i.e., commercial does not apply to projects under development or facilities that were constructed for the purpose of conducting testing and further developing the technology). Proven, commercial solid waste management processes and technologies with widespread use in the United States, such as conventional waste-to-energy, landfilling, and stand-alone material recovery facilities (MRFs), were not considered as part of the Phase I Study.

The Phase 1 Study included a wide search to maximize the identification of new and emerging conversion technologies. The search included a review of unsolicited proposals received by the City in the recent past, along with independent research to expand the list of technologies and technology sponsors. To further widen the search, a Request for Information was issued to gather consistent information from companies offering new and emerging conversion technologies. The search resulted in the identification of 43 technologies, which are listed by category in Table 2-1.

The objective of the Phase 1 Study was to identify, describe and categorize new and emerging conversion technologies based on type of technology, commercial status, and potential applicability to New York City. To meet this objective, a three-step evaluation methodology was developed. The steps progressively applied an increasing level of scrutiny, to allow for a review of all technologies identified but to focus efforts on the most promising technologies. The first-level screening (Step 1) evaluated whether each technology met the study definition of "new and emerging" and assessed whether sufficient information was provided to enable an evaluation of the technology. Thirty-three technologies met these screening criteria, and were further reviewed in Step 2.

Step 2 consisted of a preliminary review of the technologies, through consideration of the following six criteria:

- **Readiness.** The technology must be at a stage of development to be able to be commercially operational within 10 years.

Table 2-1. New and Emerging Technologies Identified in the City's Phase 1 Study (September 2004)

Thermal	Digestion	Hydrolysis
BRI Energy	**Anaerobic:**	Arkenol Fuels
Dynecology	Arrow Ecology and Engineering	Biofine[2]
EBARA	Canada Composting	Masada OxyNol
Ecosystem Projects	KAME/DePlano[1]	
Eco Waste Solutions[2]	New Bio	**Chemical Processing**
Emerald Power/Isabella City	Orgaworld	
Entropic Technologies Corporation[2]	Organic Waste Systems	Changing World Technologies
GEM America	VAGRON[2]	
Global Energy Solutions	Waste Recovery Systems	
Global Environmental Technologies		
GSB Technologies[2]	**Aerobic:**	**Mechanical Processing for Fiber Recovery**
ILS Partners/Pyromex	Mining Organics	
Interstate Waste Technologies	Real Earth Technologies[2]	Comprehensive Resources
Jov Theodore Somesfalean		WET Systems
KAME/DePlano[1]		
Pan American Resources		
Peat International/Menlo Int.		**Other**
Rigel Resource Recovery		
Solena Group[2]		Freight Pipeline Company (Biomass Densification/Refuse Derived Fuel)
Startech Environmental		
Taylor Recycling Facility		Hewitt Communications (Recycling)
Thermogenics		Pratt Industries/VISY Paper[2] (Refuse Derived Fuel)
Zeros Technology Holding[2]		
		Renewable Energy & Resources (Consulting Proposal)
		Waste and Energy Enterprise Amsterdam (Waste-To-Energy)

(1) KAME/DePlano provides both thermal and digestion processes, and is listed in both categories.

(2) Unsolicited proposal only, no vendor response to formal Request for Information received.

- **Size.** The technology must be capable of accepting and processing at least 50,000 tons per year (tpy) of waste.

- **Reliability.** The technology must have operated successfully, processing mixed MSW at a pilot (demonstration) or commercial facility.

- **Environmental Performance.** The technology must be capable of meeting environmental permit and regulatory requirements in New York City and New York State.

- **Beneficial Use of Waste.** The technology must produce a useful and marketable product (e.g., energy and/or other commercial or potentially commercial products).

- **Residual Waste.** The technology must not produce residual waste requiring disposal in excess of 35% by weight of incoming MSW.

Fourteen technologies met the Step 2 criteria, and were further reviewed in Step 3.

The third step of the Phase 1 Study consisted of comparing the relative advantages and disadvantages of the technologies against more detailed evaluation criteria. The detailed, comparative criteria included the Step 2 criteria, along with numerous other technical and economic factors (e.g., utility needs, marketability of products, estimated cost, corporate experience and resources, risk profile, etc.). The 14 technologies that were included in the Step 3 comparative review are listed in Table 2-2. The technologies were categorized as thermal processing, anaerobic digestion, and hydrolysis.

Table 2-2. Technologies Comparatively Reviewed in the City's Phase 1 Study (September 2004)

Thermal Processing	Anaerobic Digestion	Hydrolysis
Dynecology	Arrow Ecology and Engineering	Masada OxyNol
EBARA	Canada Composting	
GEM America	Orgaworld	
Global Energy Solutions	Organic Waste Systems	
Interstate Waste Technologies	Waste Recovery Systems	
Pan American Resources		
Rigel Resource Recovery		
Taylor Recycling Facility		

The results of the Phase 1 Study included the determination that thermal processing and anaerobic digestion are currently in commercial operation for mixed MSW outside of the United States, but neither technology has been commercially applied within the United States. Hydrolysis is not yet in commercial operation for MSW. However, one company (Masada OxyNol) is advancing the technology to commercial application, with pilot testing completed in the U.S. and a facility under development in Middletown, New York.

Based on success demonstrated commercially outside the United States, the Phase 1 Study concluded that anaerobic digestion and thermal processing could be considered for commercial application in the United States, including serving New York City, with suitable project definition and risk sharing between the public and private sectors. Should the potential risk be higher than the public and private sectors would be willing to assume, a demonstration project could be established first, before commercial application. The results of such a demonstration project could be used to establish the basis for commercial application, including project definition and risk sharing. The Phase 1 Study also concluded that hydrolysis could be considered for a demonstration project, perhaps in consort with further development of the project in Middletown, New York.

The Phase 1 Study recommended a focused, detailed review to supplement and verify information provided for the Phase 1 Study to determine if a demonstration facility would warrant consideration for application for New York City MSW. This focused review and verification comprised the scope of the Phase 2 Study.

3.0 PHASE 2 STUDY METHODOLOGY

The Phase 2 Study was structured to provide for focused validation and verification of advanced technology categories through direct interaction with selected companies that supply conversion technologies, and independent due diligence to check claims regarding such technologies. To ensure the most current and detailed information was provided for review and evaluation, information was obtained through a stepped process that began with a letter request for information tailored to each technology sponsor, followed by one-on-one meetings and follow-on communications. Due diligence consisted of independent verification of data presented by the companies, including checking their calculations for mass and energy balances and emission estimates. To the extent information was available, due diligence also included reviewing records of performance and communicating directly (by telephone or email) with those that operate, regulate, or are served by reference facilities. The methodology of the Phase 2 Study is further described below.

3.1 Scope of Study

The scope of the Phase 2 Study consisted of a detailed review of a selected number of individual technologies that are considered to be generally representative of broader technology categories, with the goal of providing assurance that, based on the performance of the selected technologies, the advanced technology categories can reasonably meet potential expectations for City application. Such expectations include diversion of MSW from landfill disposal through beneficial use of the waste, favorable environmental performance, and economic viability.

While the Phase 2 Study was undertaken to determine if a demonstration project is warranted for New York City, the Phase 2 Study was specifically *not* undertaken as any type of procurement. Also, the Phase 2 Study was *not* intended to result in a ranking of the participating technologies, but only to evaluate them as representative of technology categories. At the onset, candidates for participation were explicitly informed of the following in writing:

> *It should be understood that the focused review process will not result in any type of procurement of goods or services, and does not represent a commitment on the part of the City to enter into any type of agreement with the companies that participate. The information provided by respondents will not be used by the City to pre-qualify respondents or in any other way determine eligibility for the purposes of any procurements that may be undertaken in the future. Companies that do not participate in the focused review process will not be precluded, or otherwise disadvantaged, in any procurements that may be undertaken in the future.*

The companies included in the Phase 2 Study are believed to be representative of the most developed technologies within the more advanced technology categories. The commitment of these companies in the City's Phase 2 Study, including the technical, environmental and economic information each of these companies has provided, has enabled the focused review of the advanced, emerging technologies. However, there are likely to be other companies, now or in the future, that may be comparable in development status and performance, and that should be considered during a potential future procurement for a demonstration facility.

Because the City's Phase 2 Study was not undertaken as part of a formal procurement process, participation by the companies was voluntary. As a result, full disclosure of information was not made by the companies, as would occur in a procurement process, and much of the information that was provided was based on planning-level analyses. In some cases, companies were unable to dedicate the extensive resources that would be required to develop detailed analyses, but provided what they could. This was particularly true of companies that had not yet developed a U.S.-based project development team, or that did not own the technology but were a licensed representative in the United States. In other cases, limitations were evident for information that is considered by the companies to be confidential (e.g., corporate financial resources, and details pertaining to private project development efforts). Such confidential information was not provided as part of the Phase 2 Study, because of the intent to review, independently evaluate and disclose all information gathered. Differences in dissemination of information to the public from overseas locations also impacted the availability of information. In most cases, for example, regulatory permits for reference facilities were not available for review. To overcome these limitations inherent in the Phase 2 Study, a significant effort was made to communicate with the companies to gather as much information as possible. The evaluations conducted for the Phase 2 Study and presented in this Report are based on the information that was made available through these efforts.

3.2 Selection of Participating Technologies

For purposes of the Phase 2 Study, the City's objective was to select participating companies that are currently using conversion technologies, commercially, to process mixed MSW, or technologies that have conducted more advanced pilot testing with mixed MSW, and that would have technical, environmental and financial data available for disclosure. Based on the results of the Phase 1 Study completed in September 2004, nine companies were identified as having their technology in commercial operation and processing mixed MSW. All nine of these companies were identified as candidates for participation in the Phase 2 Study (Arrow Ecology & Engineering, Canada Composting, Orgaworld, Organic Waste Systems, Waste Recovery Systems, Ebara, Global Energy Solutions, Interstate Waste Technologies, and Rigel Resource Recovery).

In addition, the Phase 1 Study identified three companies that had completed more advanced pilot testing for mixed MSW. Two of these three companies were identified as candidates for participation (Masada OxyNol and GEM America). The third company that had completed advanced pilot testing was considered but not identified as a candidate for participation (Dynecology). It was determined that the technology offered by Dynecology (briquetting and gasification) is dependent on co-processing sludge and coal and is not viable for MSW alone.

Three additional companies were also identified as candidates for participation in the Phase 2 Study. Two of these companies did not respond to the City's Request for Information in the Phase 1 Study, but available information indicated the possibility that advanced pilot testing had been conducted (Solena Group and Biofine). The third company had conducted pilot testing for components of MSW, with the possibility that additional testing was conducted for mixed MSW (Startech Environmental).

In summary, the following 14 companies, categorized by technology type, were identified as candidates for participation in the City's focused verification and validation of new and emerging conversion technologies:

Anaerobic Digestion
Arrow Ecology & Engineering
Canada Composting
Orgaworld
Organic Waste Systems
Waste Recovery Systems

Hydrolysis
Masada Oxynol
Biofine

Thermal
Ebara
GEM America
Global Energy Solutions
Interstate Waste Technologies
Rigel Resource Recovery and Conversion
Solena Group
Startech Environmental

In April 2005, a two-page questionnaire was distributed by email to the 14 candidate companies identified above, to solicit expressions of interest in participating in the Phase 2 Study. A copy of the questionnaire is included in Appendix A. The questionnaire provided a definition of MSW, for purposes of the Phase 2 Study. The definition was provided to clarify that the City was interested in identifying companies that are currently using conversion technologies to process mixed MSW or a significant fraction of MSW, rather than any one of its component fractions. The definition of MSW that was provided in the questionnaire is repeated below:

> *For the purposes of the City's focused review of advanced, innovative waste management technologies, the following will serve as the definition of mixed municipal solid waste (MSW). MSW is that fraction of the solid waste stream, generated by residents, institutions and non-industrial businesses, post source-separated recycling programs. In New York City, the Department of Sanitation (DSNY) collects MSW from residents and institutions (public and parochial schools, certain cultural institutions, etc.). DSNY does not collect MSW from any New York City businesses; private haulers collect this waste stream. MSW is by its nature comprised of many different types of materials; MSW is not defined as any one of its component fractions. For example, MSW does not mean source-separated organic waste (or bio-waste), or wood waste, or tires, or food waste, etc.*

In addition to defining MSW and soliciting expressions of interest, the questionnaire requested confirmation of commercial operation or pilot/demonstration testing of the technology with MSW (as defined for purposes of the study). The questionnaire also solicited information on the extent of technical, environmental and financial information that would be available from one or more commercial or pilot facilities that use the technology, and that would be disclosed for the City's review and evaluation. Specifically, the questionnaire requested whether the following information would be available and disclosed to the City:

- Process schematics
- Mass and energy balance (i.e., a numerical balance of waste and other materials into the system, and recyclables, products, residue, energy and other materials out of the system)
- Facility site layout and equipment arrangement
- Environmental permits and emissions data
- Operating data
- References
- Development, construction, and operating and maintenance costs
- Market information for products (quantities and revenues)

Completed questionnaires were returned by nine of the companies within the established deadline, and by four more companies in response to follow-up phone calls and email correspondence. Only one company did not respond to the questionnaire or the follow-up communication (Solena Group).

Based on review of the completed questionnaires, including telephone interviews with the companies to confirm and clarify information on the extent of information that would be available for review, nine of the 14 candidate companies were selected for participation. Table 3-1 identifies the nine companies selected for participation.

Table 3-1. Technologies Selected for Participation in the Phase 2 Study

Anaerobic Digestion
Arrow Ecology & Engineering (Wet Anaerobic Digestion; Upflow Anaerobic Sludge Blanket) Orgaworld (1) (Dry Anaerobic Digestion; BIOCEL Process) Organic Waste Systems (Dry Anaerobic Digestion; DRANCO Process) Waste Recovery Systems (Dry Anaerobic Digestion; Valorga Process)
Thermal Processing
Ebara (Fluid Bed Gasification with Ash Vitrification) GEM America (Thermal Cracking Gasification Process) Interstate Waste Technologies (High Temperature Gasification Process) Rigel Resource Recovery and Conversion (Westinghouse Plasma Gasification Process)
Hydrolysis
Masada OxyNol (Waste-to-Ethanol Process)

(1) Orgaworld subsequently withdrew from the Phase 2 Study.

Eight of the nine companies selected for participation represent the more advanced emerging technology categories of anaerobic digestion and thermal processing. These eight companies expressed a willingness to participate in the review process, and affirmed their ability to provide detailed technical, environmental, and financial information for review and evaluation. The ninth company, Masada OxyNol, represents the technology category of hydrolysis (and, more specifically, MSW-to-ethanol). Masada expressed an interest in participation, but disclosed limitations in fully participating in the review process in a timely manner. Despite these limitations, Masada identified valuable technical and environmental information they would be able to provide for review. Specifically, Masada permitted a full-scale commercial plant in New York State, and agreed to provide the permit application, permit, and related documentation.

The following five companies were not selected for participation, primarily due to limitations in providing requested information:

- **Biofine (Hydrolysis).** Biofine expressed a willingness to participate in the review process. Their hydrolysis technology is not in commercial operation, but pilot-scale testing has been conducted. Based on Biofine's completed questionnaire and follow-up communications, it was determined that Biofine had a limited amount of information available for review. As a result, it was determined that Biofine's technology is not significantly advanced for the focused verification and validation established as the scope of the Phase 2 Study. Therefore, Biofine was not selected for participation.

- **Canada Composting (Anaerobic Digestion).** Canada Composting responded to the City's questionnaire, but disclosed that it would not be able to provide the information requested and as such, would not be able to participate in the Phase 2 Study. While the technology is processing mixed MSW, Canada Composting does not have access to information on the relevant facility. Canada Composting would be limited to providing data from a plant in Toronto processing source-separated organic waste, from which certain extrapolations could be made.

- **Global Energy Solutions (Gasification).** Global Energy Solutions (GES) identified numerous installations of their thermal converter in Japan, Germany, Belgium, Korea and the United Kingdom. All of these existing installations are privately owned and operated. GES was unable to confirm that any of the existing installations process mixed MSW as defined for the Phase 2 Study. Further, GES disclosed that it has limitations in providing operating and financial information associated with these privately-owned installations. Because it could not be confirmed that GES would be able to provide technical, environmental and economic data for review, the company was not selected for participation in the Phase 2 Study.

- **Solena Group (Gasification).** The Solena Group was not responsive to the City's questionnaire, or to follow-up correspondence.

- **Startech Environmental (Gasification).** Startech Environmental identified an existing unit in commercial operation in Japan, but confirmed during a follow-up telephone call that the facility processes incinerator ash and not mixed MSW. Startech was requested to provide a summary of pilot testing that has been conducted with mixed MSW, and a disclosure of the extent to which technical and environmental information from such testing would be available for review. In response to the City's request, Startech did not provide any further information to indicate data would be available associated with processing mixed MSW. Because it could not be confirmed that Startech Environmental would be able to provide technical, environmental and economic data for review, the company was not selected for participation in the Phase 2 Study.

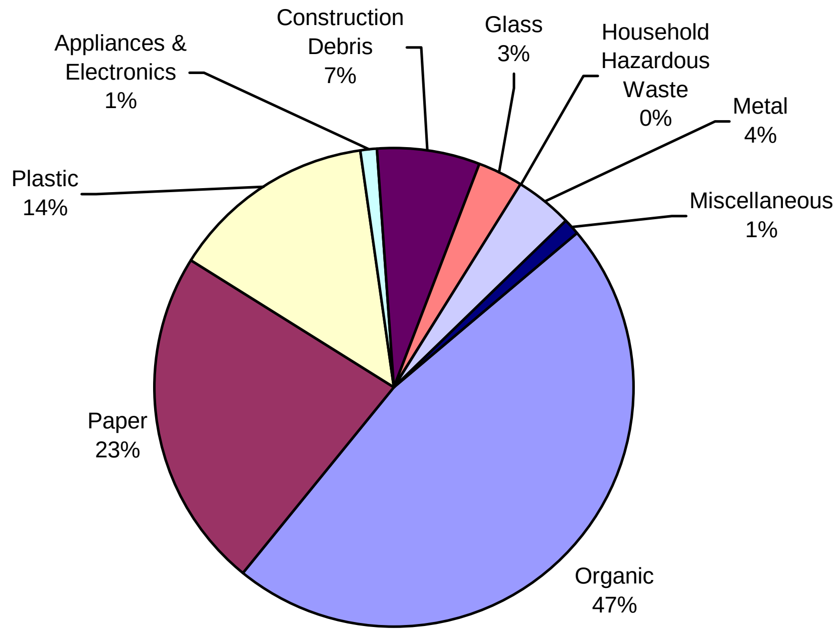
3.3 Supplemental Information Request (SIR)

In May 2005, the City issued a Supplemental Information Request (SIR) to the nine companies selected for participation in the Phase 2 Study. The purpose of a structured SIR was to obtain a consistent set of information from all of the companies participating in the focused review process. The SIR included a detailed transmittal letter providing an overview of the process and details specific to the information requested, and included 17 forms, structured to ensure that the most recent technical, environmental, and cost information for each technology was available for review. Participants were advised that the City was soliciting technical, environmental and cost information for a complete waste processing system; that is, *all* unit operations, including pre-processing, processing, power generation, management of products and process residuals, and any other unit processes integral to the technology (e.g., air pollution control, water treatment and wastewater management).

The SIR differed somewhat for each technology category (i.e., anaerobic digestion, thermal processing, and hydrolysis), particularly regarding the request for mass and energy balance and other technical and environmental information. The differences were necessary to encompass unique elements of the different technology categories. However, the SIR issued to individual companies within the same technology category was the same. Appendix B includes a representative SIR.

The SIR emphasized that the City's review process would be based on information associated with processing mixed MSW, as it is currently set out curbside and collected by DSNY. Participants were reminded that the review would not focus on information associated with processing any individual fraction of MSW, such as source-separated organics. Participants were referenced to the preliminary waste characterization study (PWCS) conducted by DSNY, and given a link to DSNY's website to download the study. The pie chart shown in Figure 3-1 was provided in the SIR, as a summary of data from the PWCS and further clarification that the term MSW means the entirety of materials that comprise the pie chart.

Figure 3-1. DSNY-Collected Mixed MSW Composition by Material Group



For purposes of evaluating cost information, the SIR requested that each company specify an optimum, technology-specific capacity for a smaller-scale demonstration facility and for a larger-scale commercial facility. In support of the specified capacities, the SIR requested details on a relevant reference facility, and a technical approach to transition from the demonstration capacity to the commercial capacity. While specified capacities were to be technology-specific, and were expected to vary for each individual technology based on company knowledge and experience, the SIR established maximum capacities to avoid unreasonably high capacities. The demonstration facility was to be capable of processing no more than 182,500 tpy of MSW, and the commercial facility was to be capable of processing no more than 1,095,100 tpy of MSW. These annual throughputs are equivalent to an average of 500 tons per day (tpd) and 3,000 tpd, respectively, based on 365 days per year. Equivalent daily throughput is calculated using 365 days per year for consistency between technologies, even though waste is not collected by DSNY 365 days per year and facilities may operate for a lesser amount of days to allow for maintenance.

Upon receipt of responses to the SIR, a preliminary review and evaluation was completed to identify data gaps and highlight information requiring clarification. Following the preliminary review, a detailed set of questions was issued to each company requesting additional information and seeking certain clarifications. The questions and clarification requests were tailored to the individual companies.

It was at this stage in the process that one of the nine selected companies, Orgaworld, withdrew from participation in the Phase 2 Study. As previously noted, Orgaworld was unable to submit timely and complete information in response to the SIR. Orgaworld reported the reason to be health issues of their primary contact person. In addition, Orgaworld noted that the company's focus is currently on projects that are of a smaller size and that process source-separated organic materials. The remaining eight companies were carried forward in the Phase 2 Study.

3.4 Technology Presentations

In July 2005, the City scheduled technology presentations for each of the eight participating companies. The objective of the presentations was to clarify information, address data gaps, and engage in discussions necessary for completing a detailed evaluation of each technology. Over the three-day period of July 27-29, 2005, each company was given a two-hour block of time to present an overview of its technology, address discussion topics and questions that resulted from a preliminary review of the SIR responses, and answer questions from City representatives. All eight companies took advantage of the opportunity to meet with the City. In one instance, at the request of the company, a conference call meeting was held in place of an in-person meeting. The City was represented at the meetings by NYCEDC, DSNY (Bureaus of Long-Term Export and Waste Disposal), counsel to the Sanitation and Solid Waste Management Committee of the New York City Council, and consultants to the City for the Phase 2 Study.

3.5 Detailed Review and Evaluation

Following the technology presentations, detailed review and evaluation was conducted for each technology. During this time, communication was maintained with the companies for ongoing clarification of technical, environmental and economic information. As noted previously in Section 3.1 of this Report, certain limitations exist with the information that was available for the Phase 2 Study. These limitations exist despite a significant effort on the part of the companies to comply with the City's request for information.

Detailed review and evaluation consisted of the following:

- **Technical Review and Evaluation.** Technical review and evaluation consisted of: validation of process schematics and major system components, to determine if the process is complete and fully described; confirmation of mass and energy balances, including independent calculations; review of facility site layout and equipment arrangement, focusing on consideration of site size requirements; and, to the extent available, review of operating data and related information for reference facilities and proposed demonstration and commercial facilities.

- **Environmental Review and Evaluation.** Environmental review and evaluation consisted of: independent calculation, review and inter-comparison of environmental performance, including air pollutant emissions (combustion pollutants, acid gases, dioxin, mercury, and greenhouse gases), water usage, wastewater discharge, residues requiring landfill disposal, and quality of products.

- **Economic Evaluation.** An economic analysis was performed to project the order-of-magnitude costs that could be expected from the technologies for commercial-scale projects. The analysis consisted of development of a model, using as inputs detailed capital and operating costs provided by the companies along with projections for quantity of recovered energy, products and residues requiring landfill disposal. The economic evaluation also included a review of corporate and financial information for the participating companies.

Integrated with the technical, environmental and economic evaluations was consideration of technology transfer issues. The advanced, emerging technologies have achieved commercial operation overseas (e.g., Japan, Israel, Europe), but not in the United States. The process of developing a project in the United States based on experiences elsewhere is referred to as "technology transfer". Issues requiring consideration could include differences in waste composition, waste collection practices, end-product markets, and regulatory requirements.

During the process of completing the detailed review and evaluation of the Phase 2 Study, it became apparent that one of the anaerobic digestion companies selected for participation (Organic Waste Systems, or OWS) was unable to provide information pertaining to processing mixed MSW. OWS reported that their technology, referred to as the DRANCO dry anaerobic digestion technology, has been applied most often for source-separated organic waste, but is also used for mixed MSW. In response to the City's Supplemental Information Request, OWS provided information on a reference facility in Belgium that processes 55,000 tpy (151 tpd, on average) of source-separated organic waste. OWS was unable to meet the City's requirement to provide information associated with processing mixed MSW. A review of the OWS anaerobic digestion technology is not included in the body of this Report, since the information provided was not directly applicable for the Phase 2 Study. However, because OWS was initially selected as a participant for the Phase 2 Study and because they did provide certain information regarding their technology that was reviewed and evaluated, information on OWS is provided in Appendix C.

4.0 INTRODUCTION TO TECHNOLOGY CATEGORIES

4.1 Introduction

The Phase 2 Study included a detailed review and evaluation of two categories of emerging solid waste management conversion technologies - anaerobic digestion and thermal processing. The review consisted of a focused verification and validation of information provided by six companies that offer a technology within one of these categories, and that have advanced their individual technologies to commercial application overseas (processing mixed MSW). In addition, the Phase 2 Study included a less detailed review of a third emerging technology category - hydrolysis, based on the MSW-to-ethanol process offered by one company. As previously disclosed, a detailed review was not conducted for hydrolysis, due to limited information available for review at the time of the Phase 2 Study.

The seven conversion technologies that were reviewed and evaluated for the Phase 2 Study are identified in Table 4-1, along with general summary information regarding the technologies. Table 4-1 is located at the end of this Section. An introduction to the three technology categories follows. More detailed technical information on the individual technologies within each category, reviewed as part of the Phase 2 Study, is included in Sections 5 and 6 of this Report.

4.2 Anaerobic Digestion

Digestion is the reduction of carbon-based organic materials through controlled decomposition by microbes, accompanied by the generation of liquids and gases. The biological process of digestion may be aerobic or anaerobic, depending on whether air (containing oxygen) is introduced into or excluded from the process.

In the *anaerobic digestion* of MSW, the biodegradable, organic components (e.g., food waste, yard trimmings, garden waste, cardboard, paper) are metabolized by microorganisms in the *absence* of oxygen, producing a biogas (primarily methane and carbon dioxide), a solid byproduct (called "digestate", which is generally considered to be an immature compost), and reclaimed water. In an overview fashion, anaerobic digestion can be described by three primary steps: (1) pre-treatment, or separation/preparation, of the MSW received for processing; (2) digestion of the prepared organic feedstock, and (3) post-treatment of the digestate, to produce a mature compost. Pre-treatment and post-treatment requirements are dependent on the particular digestion technology used, the characteristics of the MSW, and the overall objectives of the project (i.e., whether to maximize diversion of MSW from landfilling through recovery of nondegradable materials and recyclables and through beneficial use of resulting compost, or to more generally stabilize the organic fraction of MSW prior to landfilling). An additional and significant process step is the management and use of the biogas generated during the anaerobic digestion process.

For processing mixed MSW, which was the focus of the Phase 2 Study, pre-treatment or preparation/separation is necessary for separating biodegradable, organic materials from other waste components as well as for size reduction and preparation of the organic feedstock. Pre-treatment will result in residue requiring disposal, generally consisting of sand, stones, broken glass, and other inert materials present in the wastestream. Pre-treatment can be combined with recovery of traditional recyclables that are not readily biodegradable and not of value in the digestion process. Recovered recyclables may include ferrous metal, aluminum, other non-ferrous metal, plastic, and glass.

In general, maximizing the recovery of recyclables and the removal of non-degradable, inert materials during pre-treatment will result in a higher quality compost at the end of the process. For the technologies reviewed as part of the Phase 2 Study, pre-treatment technologies include standard material recovery configurations (e.g., magnets, eddy current separators, screens, and other sorting mechanisms) combined with size-reduction equipment (e.g., shredders, pulpers) and other waste preparation equipment (e.g., mixers). One technology offers a unique, water-based, preparation/separation system that removes recyclables and inert materials and prepares the organic feedstock in an integrated manner with a wet digestion system.

The separation and preparation of biodegradable, organic material from the MSW results in an organic feedstock for the digestion process. The fundamental objective of anaerobic digestion is to produce a large quantity of methane-rich biogas and a small quantity of well-stabilized digestate from the organic feedstock. In all anaerobic digestion technologies, the process occurs in an enclosed, controlled environment (i.e., within the "digester", or "bioreactor"). However, different digestion technologies are available, which produce different results regarding biogas and compost quantity and characteristics. The process may be "wet" or "dry", depending on the percent solids of the organic feedstock in the digester. The process temperature may also be controlled in order to promote the growth of a specific population of microorganisms, with process temperatures ranging from approximately 35-55°C (95-131°F). The process may be conducted in a single-stage or two-stage reactor vessel, and on a continuous or batch basis. Retention times of material in the digester can also vary. For the technologies reviewed as part of the Phase 2 Study, average retention time of solids in the digester range from 21 days for the "dry" digestion process to approximately 80 days for the "wet" digestion process. For the wet process, while the solids retention time is high (80 days), the hydraulic retention time, or the time for the liquid to pass through the digester, is low (i.e., 1 day).

Anaerobic digestion results in a solid byproduct, called "digestate". Digestate is generally immature compost. It consists of organic material that is not readily digestible, along with inorganic material that escaped preprocessing. Digestate is usually in the form of a slurry of varying consistency. Wet digestion technologies produce a digestate with a thinner, or wetter, consistency than dry digestion technologies. The digestate is commonly dewatered, with the liquid returned to the process or managed as a wastewater. The dewatered solids may be screened to removed inorganic materials, and are then aerobically finished to produce stable, mature compost, for sale as a product. For purposes of the Phase 2 Study, all compost is assumed to be delivered to the market for beneficial use. Large-scale, long-term markets are not yet established in the United States for use of compost generated from mixed MSW. However, aerobic MSW compost has existed for more than 20 years and has found beneficial, low-grade use in the United States.[2]

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[2] New York City Department of Sanitation (DSNY), New York City MSW Composting Report, January 2004.

The extent of post-treatment required to achieve a stable, mature compost, as well as the quantity of compost produced, varies based on the digestion technology used. For the two technologies reviewed in detail, the quantity of compost ranges from approximately 14% to 24% by weight of the MSW received. Also, depending on the extent of separation and preparation conducted prior to the digestion process, some technologies require more post-processing than others (e.g., some technologies require screening of digestate prior to aerobic finishing, and/or screening of mature compost, in order to improve the quality of the resulting compost for purposes of beneficial use).

Anaerobic digestion results in a biogas, composed primarily of methane and carbon dioxide. Higher-quality biogas has a higher percentage of methane, with individual digestion technologies producing biogas with methane concentrations ranging from approximately 55% to 80%. Biogas may also include small amounts of contaminants, such as hydrogen sulfide (H_2S). The concentration of H_2S and other contaminants in the biogas generally depends on the characteristics of the MSW. Technologies are available to remove contaminants and otherwise improve the quality of the biogas (i.e., achieve a higher percentage of methane), if such a step is necessary for a particular project. Often without any cleanup steps, the biogas can be beneficially used to generate electricity. For the two anaerobic digestion technologies reviewed as part of the Phase 2 Study, combustion of the biogas in a reciprocating engine has been proposed. The electricity is used to first meet process needs, with the remaining electricity sold to the grid. The net electricity generated for sale can vary significantly, and ranges from 124-250 kilowatt hours per ton of MSW processed (kWh/ton) for the technologies reviewed.

4.3 Thermal Processing

Thermal technologies encompass a variety of processes that use or produce heat, under controlled conditions, to convert MSW to usable products. The organic fraction of MSW is converted to energy, and the inorganic fraction is recovered as products (e.g., metal). Thermal technologies can potentially convert all organic components of MSW into energy (i.e., all carbon and hydrogen-based materials, including plastic, rubber, textiles, and other organic materials that are not converted in biological processes). Thermal processing includes such technologies described as gasification, plasma gasification, pyrolysis, cracking, and depolymerization. Distinctions between the different thermal technologies center around the processing temperature, the means of maintaining the elevated temperatures, and the degree of decomposition of the organic fraction of the MSW. Some of these distinctions are noted below, while others are noted in the detailed technical reviews provided in Section 6 of this Report.

Thermal processing occurs in a high-temperature reaction vessel. For the technologies reviewed as part of the Phase 2 Study, reactor temperatures range from approximately 800°F for a cracking technology to as high as 8,000°F for a plasma gasification technology. Within the reaction vessel, the organic fraction of the MSW is converted to a gas typically composed of hydrogen, carbon monoxide and carbon dioxide gases. This gas is commonly called synthesis gas or “syngas”. Some thermal technologies, such as pyrolysis, cracking and depolymerization, produce a gas that also consists of various low molecular weight organic compounds. For these technologies, the gas is sometimes called a fuel gas rather than a synthesis gas. Thermal technologies sometimes introduce a supplemental fuel (e.g., natural gas, coke, etc.) to improve the quality and consistency of the synthesis gas. Plasma gasification technologies use a supplemental source of energy, most commonly electricity, to produce an electric arc to elevate the temperature and enhance dissociation of the molecules in the MSW. The syngas (or fuel gas) and other products of the thermal technologies represent unoxidized or incompletely oxidized compounds, which in most cases differentiate these technologies from the more complete combustion attained in traditional waste-to-energy (WTE) projects. Advantages of thermal conversion technologies compared to WTE technology include reduced air pollutant emissions, and increased beneficial use of MSW.

With some thermal technologies, such as gasification, the inorganic fraction of MSW is commonly recovered in the form of a vitrified material (i.e., a solid, glassy substance often called "aggregate" or "slag"), mixed metals, industrial salts, chemicals, and other byproducts. Some thermal technologies, such as pyrolysis and cracking, generate a char (i.e., a carbon-based solid) rather than a vitrified product. Depending upon market conditions, these byproducts of thermal processes may have beneficial uses or may require landfill disposal. For the purposes of this Phase 2 Study, the amount of byproducts considered to be a residue requiring disposal, rather than a marketable product, ranges from 0% to approximately 28% by weight of the MSW received for processing.

In an overview fashion, thermal processing of MSW can be described in two primary steps: (1) pre-processing, if required, and (2) thermal conversion, including combustion of the gas to generate electricity. Pre-processing requirements are often very minimal for thermal processing technologies. Except for the common requirement to remove or size-reduce very large, over-sized materials such as furniture and large appliances, many thermal processing technologies do not require size reduction or separation of MSW by component. This is not always the case, though, and two of the thermal technologies reviewed for the Phase 2 Study shred the waste prior to processing. While recyclables such as metals can be recovered in a pre-processing step, and such metals are recovered as recyclables for one of the technologies reviewed, many of the thermal technologies recover the metal after the thermal conversion process.

The thermal conversion process results in a syngas (or fuel gas) and other products, as described above. The gas may be converted to energy by using it as a fuel in traditional boilers, reciprocating engines and combustion turbines. A variety of methods were proposed for the technologies reviewed as part of the Phase 2 Study. While a large amount of electricity can be generated, a large amount of electricity is also needed to support process operations. Net electricity is on the order of 400-500 kWh/ton for most of the technologies reviewed. One technology reviewed (plasma gasification with 37% energy input from fossil fuel) has a net generation of more than 2,200 kWh/ton. As an alternative to energy generation, the syngas may be chemically processed into chemicals such as methanol. However, none of the thermal processing technologies that have been reviewed for the Phase 2 Study are known to be currently producing methanol from syngas.

Some of the thermal technologies pre-clean the syngas prior to combustion using standard, commercially available technology to remove sulfur compounds, chlorides, heavy metals and other impurities. Pre-cleaning the syngas prior to combustion can be more cost-effective than post-combustion controls. Even with pre-cleaning, most technologies apply some post-combustion air pollution control technology. The extent of syngas cleaning and the type of post-combustion air pollution control varies by technology.

4.4 Hydrolysis

Hydrolysis is generally a chemical reaction in which water reacts with another substance to form two or more new substances. Specifically in relation to MSW, hydrolysis refers to a chemical reaction of the cellulose fraction of the waste (e.g., paper, food waste, yard waste) with water and acid to produce sugars. The sugars are then fermented to produce an alcohol, followed by distillation to separate the water from the alcohol and recover a concentrated, fuel-grade ethanol.

Separation of the MSW must take place to first obtain the organic fraction. Glass, metals and plastic can be recovered as recyclables, while non-recyclable inorganics are removed and disposed of as residue. The organic material is then shredded and introduced into a reactor vessel. Acid is added to the reactor vessel as a catalyst, and within the reactor the material is "cooked" to convert complex organic molecules to simple sugars. Since the acid merely catalyzes the reaction and is not consumed in the process, it can be extracted and recycled in the process.

Byproducts of the hydrolysis conversion process include gypsum and lignin. Gypsum, which is a marketable product used in wallboard, is produced from the addition of lime slurry to the process to neutralize the sugar after hydrolysis and remove metals. Lignin, which is the organic, non-cellulose material that is not converted by the acid, can be gasified to generate steam to support process operations.

In most cases, hydrolysis is the first step in a multi-step technology. For example, the additional process steps of fermentation and distillation can be combined with hydrolysis for conversion of the sugars to fuel-grade ethanol. Fermentation of the sugars also produces carbon dioxide, which can be purified, compressed and marketed. Alternately, the sugars can be converted to levulinic acid, which is a commonly-used chemical feedstock for other chemicals with established and emerging markets (e.g., methyl tetrahydrofuran, an oxygenated fuel additive).

Table 4-1. Identification of Technologies Included in the Phase 2 Study

Company (Technology Type)	Reference Facility Location(s)	Recovered Products	Residue (%) [1]
ANAEROBIC DIGESTION *Biological process that reduces the biodegradable, organic fraction of MSW through controlled decomposition by microbes. Decomposition occurs in the absence of oxygen, producing a biogas (methane and carbon dioxide), which can be combusted to produce electricity as well as a compost.*			
Company (Technology Type)	**Reference Facility Location(s)**	**Recovered Products**	**Residue (%) [1]**
Arrow Ecology & Engineering (Wet Anaerobic Digestion Upflow Anaerobic Sludge Blanket)	Tel Aviv, Israel 77,000 tpy (211 tpd)	Recyclables (Ferrous, Aluminum, Plastic) Electric Power (Reciprocating Engine) Compost	23%
Waste Recovery Systems (Dry Anaerobic Digestion; Valorga Process)	Barcelona, Spain 264,552 tpy (725 tpd)	Recyclables (Ferrous, Aluminum, Plastic) Electric Power (Reciprocating Engine) Compost	31%
THERMAL PROCESSING *Chemical reaction that uses or produces heat, under controlled conditions, to convert MSW into usable products. Produces a synthesis gas (hydrogen gases, carbon monoxide, carbon dioxide) from the organic fraction of MSW (carbon and hydrogen-based constituents), which can be combusted to produce electricity. Generates other products such as metal, a vitrified aggregate, and a carbon-based char.*			
Company (Technology Type)	**Reference Facility Location(s)**	**Recovered Products**	**Residue (%)**
Ebara (Fluid Bed Gasification with Ash Vitrification)	Kawaguchi, Japan 138,300 tpy (379 tpd)	Recyclables (Ferrous, Aluminum) Electric Power (Boiler and Steam Turbine) Vitrified Ash/Glassy Slag	6%
GEM America [2] (Thermal Cracking Gasification Process)	South Wales, U.K. 14,600 tpy (40 tpd)	Recyclables (Ferrous, Aluminum) Electric Power (Reciprocating Engine) Char [1]	28%
Interstate Waste Technologies (High-Temperature Gasification Process)	Karlsruhe, Germany 247,500 tpy (678 tpd) Chiba, Japan 120,450 tpy (330 tpd) Kurashiki, Japan 222,833 tpy (610 tpd)	Electric Power (Reciprocating Engine) Mixed Metals Aggregate/Glassy Slag Mixed Industrial Salts Elemental Sulfur Zinc Hydroxide	0%
Rigel Resource Recovery (Westinghouse Plasma Gasification Process)	Utashinai, Japan 100,000 tpy (274 tpd)	Electric Power (Turbine/Generator) Mixed Metals Aggregate/Glassy Slag Hydrochloric Acid Elemental Sulfur	0%
HYDROLYSIS *Chemical reaction in which water, typically with an acid, reacts with the cellulose fraction of MSW (e.g., paper, food waste, yard waste) to produce sugars, with additional process steps to convert the sugars to ethanol or other products.*			
Company (Technology Type)	**Reference Facility Location(s)**	**Recovered Products**	**Residue (%)**
Masada OxyNol [3] (Waste-to-Ethanol Process)	Middletown, NY 350,400 tpy (960 tpd)	Recyclables Ethanol Gypsum Carbon Dioxide	Not Reported

(1) Residue means materials requiring landfill disposal, reported on an approximate basis as a percentage of MSW received. Residue includes certain recyclables (glass, low-grade paper) and products (char) that may not have an established, stable market.

(2) GEM's reference facility is considered to be an advanced pilot facility, since it is not currently operating and was previously operated under limited conditions (i.e., four days per week, six hours per day, for a 12- to 18-month period).

(3) Masada's reference facility is a project that is currently in development, with permits in place along with certain, significant project contracts already executed.

5.0 ANAEROBIC DIGESTION - OVERVIEW AND TECHNICAL EVALUATION

5.1 Introduction to Technologies Reviewed

Two companies offering anaerobic digestion technologies are reviewed in detail in this Report:

- **Arrow Ecology & Engineering (Arrow).** Arrow's anaerobic digestion technology is a two-stage wet process, consisting of an acetogenic bioreactor followed by a methanogenic Upflow Anaerobic Sludge Blanket (UASB) bioreactor. Arrow's digestion technology includes a water-based, up-front, integrated MSW separation and preparation system. Very limited post-processing is required after digestion due to the extensive amount of separation and preparation that occurs before digestion. Dewatering is required, and passive aerobic composting of the resulting digestate may be conducted, if necessary.

- **Waste Recovery Systems, Inc. (WRSI).** WRSI offers the Valorga digestion technology, which is a dry, single-step, plug-flow system. The Valorga digestion system requires waste preparation to consolidate biodegradable organic material. Waste preparation is accomplished by pairing the digestion technology with a traditional, front-end material recovery facility. After digestion, dewatering, aerobic composting of the digestate, and screening of the resulting compost is required to achieve a clean, stable material.

A comparative summary of key technical parameters for these two technologies, for a commercial-scale facility for New York City, is provided in Table 5-1. A detailed description and technical review of each individual technology follows the Table. The description and technical review for each technology are based on application of the technology for a project in New York City processing MSW, with references to technology design features and performance as demonstrated by specified reference facilities.

As described in Section 3.5 of this Report, a third anaerobic digestion company, Organic Waste Systems (OWS), was originally identified to participate in the Phase 2 Study and remained a participant throughout the data gathering and review process. However, OWS was unable to meet the City's requirement to provide information associated with processing mixed MSW. Information provided by OWS focused on a reference facility in Belgium that processes source-separated organic waste. Because the information provided by OWS was not for mixed MSW, it was not directly applicable to the City's Phase 2 Study. A review of OWS and their anaerobic digestion technology is provided in Appendix C of this Report.

Table 5-1. Anaerobic Digestion Technical Summary

Technical Parameter	Arrow	WRSI
Facility Description		
Recommended Annual Throughput (Commercial Facility)	214,000 tpy (586 tpd)	182,500 tpy (500 tpd)
Site Acreage Required	8 acres	14 acres
Pretreatment of MSW		
Description	Water-based, gravitational separation and screening system for integrated separation and preparation	Mechanical sorting for recovery of recyclables and separation of biodegradable organics. Specific equipment components and arrangement not determined
Types of Recyclables Recovered	Ferrous Metal Aluminum Sorted Plastic (Film, HDPE, PET)	Ferrous Metal Aluminum Mixed Plastic Wood
Quantity of Recyclables Recovered	14.7% (31,400 tpy)	9.1% (16,518 tons)
Digestion Process		
Description	ArrowBio two-stage wet process - acetogenic reactor followed by methanogenic Upflow Anaerobic Sludge Blanket (UASB) reactor	Valorga dry, single-step process
Hydraulic Retention Time (1)	1 day	--
Solids Retention Time (2)	80 days	21 days
Post-Treatment of Digestate		
Description	Dewatering using filter press with recycling of process water. Passive aerobic composting on site as a final finishing step, or delivery directly to market. Due to extensive separation in the front-end, water-based system, digestate or compost screening is not required.	Dewatering of digestate using screw presses and belt filter presses. Recycling of process water and discharge of wastewater. Post-digestion, in-vessel, aerobic composting (14 days) for drying/maturation, followed by screening of the compost to remove inert materials that passed through the process
Quantity of Compost Generated	13.7% (29,355 tpy)	24.4% (44,565 tpy)
Biogas Management		
Methane Content	70-80%	55%
Heating Value	11,500 Btu/lb	7,000 Btu/lb
Gross Electricity Generated	300 kWh/ton	218 kWh/ton
Net Electricity Generated	215-250 kWh/ton	124 kWh/ton
Residue Management		
Pretreatment Residue	23.4%	24.4%
Post-Treatment Residue	0%	6.5%
Total Residue Requiring Disposal	23.4% (50,000 tpy)	30.9% (46,173 tpy)

(1) For "wet" digestion processes, such as the Arrow technology, *hydraulic retention time* represents the time for liquids to pass through the digester.

(2) For "wet" and "dry" digestion processes, *solids retention time* is the time solid material remains in the digester before it is removed as a digestate.

5.2 Arrow Ecology & Engineering

Arrow Ecology & Engineering (Arrow), with headquarters in Tel Aviv, Israel, is the project sponsor for the patented ArrowBio wet anaerobic digestion technology. The ArrowBio anaerobic digestion technology is specifically designed to process mixed MSW, because the upfront MSW separation and preparation system is an integrated component of the ArrowBio technology. The system can process sewage sludge and other organic wastes along with MSW.

As summarized below, Arrow has one reference facility, located at a transfer station in Tel Aviv, Israel, which has been processing MSW commercially since late 2003. Arrow's reference facility has a digestion capacity of approximately 77,000 tpy (211 tpd, based on 365 days per year). However, pre-existing space limitations within the layout of the transfer station allowed for installation of only one, rather than two, separation and preparation lines in support of the digestion process. Therefore, Arrow's reference facility can only process approximately 38,500 tpy (105 tpd) of MSW.

ArrowBio Reference Facility	
Name:	Tel Aviv ArrowBio Plant
Location:	Hiriya Israel
Capacity:	38,500 tpy
Type of Waste:	MSW
Owner:	Arrow Ecology & Engineering
Operator:	Arrow Ecology & Engineering
Commercial Operation:	Late 2003

Arrow is actively pursuing development of its technology in other locations. Based on a media release by the Campbelltown City Council on December 6, 2005, Arrow was awarded a contract by the South West Sydney Councils Resource Recovery Project for development of a facility in a western suburb of Sydney, Australia, referred to as "Jacks Gully". The Jacks Gully project is expected to be operational in 2008, and will process 90,000 tpy (247 tpd) of MSW. According to the media release and as confirmed by Arrow, a second project in Australia is under development for another suburb of Sydney (Belrose), with development pending additional commitment of waste to the project. Also, Arrow has reportedly been awarded a contract with the City of Pachuca, Mexico, with further development of that project pending financial due diligence.

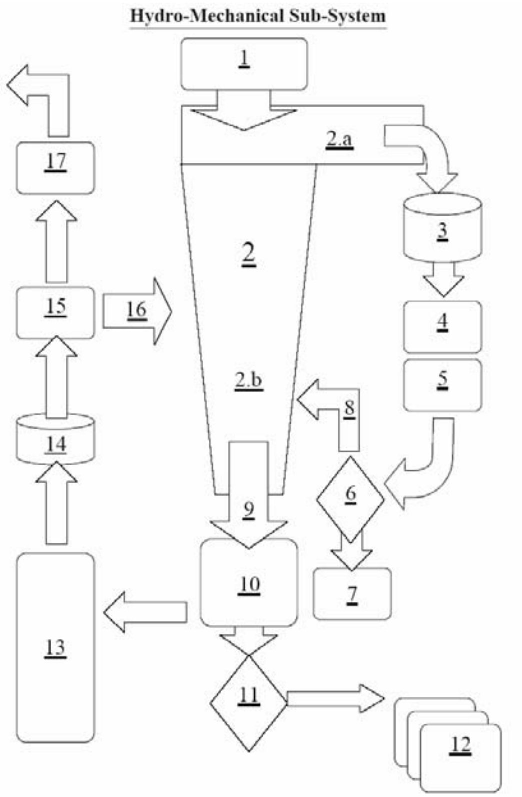
5.2.1 Description of the ArrowBio Technology. The ArrowBio technology consists of two integrated subsystems: (1) physical, water-based separation and preparation, and (2) biological treatment using two-stage anaerobic digestion, including an acetogenic bioreactor and a methanogenic, Upflow Anaerobic Sludge Blanket (UASB) bioreactor. The two components are uniquely integrated. Specifically, the digestion component requires a watery slurry (3-4% solids), similar to a wastewater from municipal sewage, in which the biodegradable organics are dissolved or present as fine particulates. Therefore, water-based separation techniques are used to separate and recover recyclables and remove inorganic materials, while simultaneously preparing the biodegradable organics into a watery slurry. Likewise, the digestion process is a net generator of water. Therefore, water generated during the digestion process is recycled back to the separation and preparation component as process water. These integrated components of the ArrowBio technology are shown in the schematic provided in Figure 5-1, and further described below.

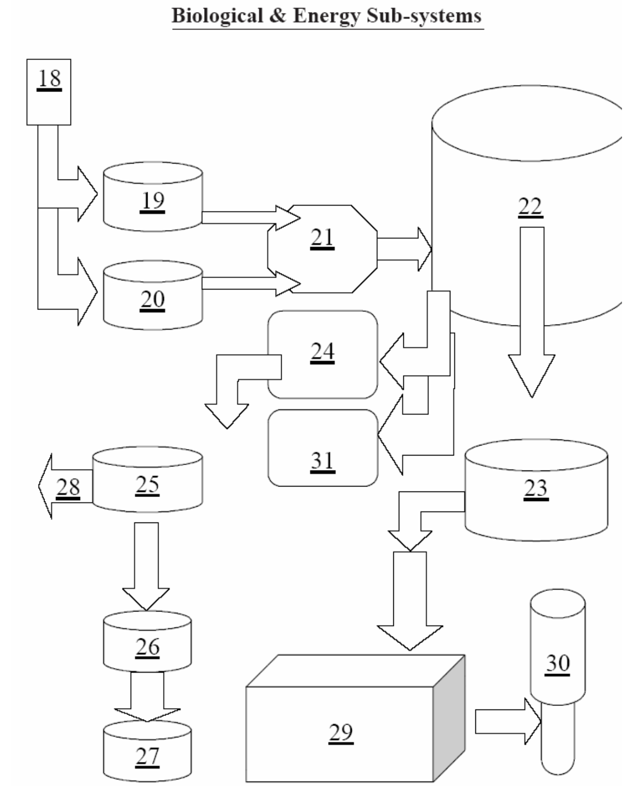
The separation and preparation subsystem of the ArrowBio technology is a water-based system, integrated with traditional mechanical sorting equipment. At the ArrowBio reference facility in Israel, incoming MSW is deposited directly into the water bath as it is received. Proposed Arrow facilities, including those currently planned for suburbs of Sydney, Australia, will likely include a receiving moving floor ahead of the water bath to allow for manual picking of bulky items from the waste as it is being moved to the water bath. Future facilities may also include a bag opener prior to the water bath, to allow for more efficient sorting. The need for an extended walking floor ahead of the water bath as well as the need for a bag opener are determined on a project-specific basis, and as such, represent a technology transfer issue for New York City (i.e., the design details of this component of the technology continues to develop for new Arrow projects, and may require further development for a project in New York City).

The water bath in the ArrowBio system is a flotation tank. Water streams through the flotation tank, separating materials by density. Water is continuously recirculated through the flotation tank, creating a flow current that facilitates separation of materials. The continuous recirculation of the water also keeps the organic material in suspension and reduces odors. The separation of recyclables and inorganic material in the water bath is based upon the differing buoyancy of the fractions of the MSW. Plastics float in water; organic matter tends to stay suspended or is dissolved in water, and heavy materials such as metals, glass, textiles, and inorganic matter sink in water. As the heavy materials sink, they are removed by a submerged walking floor. Upon removal, these heavy materials proceed through a bag opener (trommel screen) followed by magnetic separation for ferrous metal recovery, eddy current separation for nonferrous metal recovery, and manual sorting for other materials such as glass and textiles. The remaining material is returned to the flotation tank for further separation. At the end of the water bath the lighter stream (e.g., plastics), which float, are directed by paddles on the surface of the water bath to an “air float” system, where they are removed from the water bath. Lighter materials proceed through a bag opener, and subsequently automatic and manual separation of plastic for recycling. The organic fraction that is suspended in the water is size-reduced in a hydrocrusher, followed by filtering for additional removal of plastic and inorganic residual (grit). Some of the organic fraction and water is returned to the flotation tank for hydraulic balancing (along with water from the digestion process). The remainder of the prepared organic fraction is pumped to the digestion system as a watery, organic slurry (approximately 3-4% solids).

After material separation and organic preparation, biological treatment occurs in two types of bioreactors constructed in series: an acetogenic bioreactor, followed by a methanogenic bioreactor. Arrow's design uses two acetogenic reactors (in parallel) followed by one

Figure 5-1. Schematic Diagram of ArrowBio Anaerobic Digestion Technology





Schematic process flow diagram
Hydro-Mechanical Sub-System.
1: Receiving moving floor and inspection; 2.a: Tipping pool; 2: Heavy stream moving floor; 2.b: Light stream moving floor; 3 Revolving drum bag opener; 4: Magnetic pickup; 5: Eddy current device; 6: Manual sorting of glass, textiles, stones; 7: bins for glass, textiles, and stones 8: Mini-vat – second chance for organics in heavy stream; 9: Bag opener; 10: Air "float" for plastics removal; 11: Manual separation of different plastics; 12: Plastic containers; 13: Hydro-crusher for biodegradable organics; 14: Filtering of plastics and inorganic residual material; 15: Reservoir for liquid and residual inorganics (grit); 16: Second chance for plastics and inorganic materials and hydraulic balancing; 17: Liquid reservoir and pumps to biological component.

Schematic process flow diagram
Biological and Energy Sub-Systems.
18: Flow from hydro-mechanical sub-system; 19: Acetogenic bioreactor No. 1; 20: Acetogenic bioreactor No. 2; 21: Heater; 22: Methanogenic bioreactor (UASB); 23: Biogas reservoir; 24: Solid-liquid separator; 25: Water separator and hydraulic balance tank; 26: Water treatment and reservoir; 27: Water reservoir; 28: Makeup water to hydro-mechanical subsystem; 29: Genset; 30: Flare; 31: Filter press for excess solids (culture).

methanogenic bioreactor. In the acetogenic reactors, a specialized population of micro-organisms converts the organic material, by fermentation, into alcohols, sugars, and organic acids, which are then readily degradable in the second stage anaerobic reactor, the methanogenic reactor. Organic material must be sufficiently digested in the acetogenic reactor in order to pass through a fine screen into the methanogenic reactor. Fibrous material that is not very susceptible to microbial attack and that is not sufficiently digested cannot pass through this fine screen and is periodically removed from the acetogenic reactor as digestate.

The second stage methanogenic digester is the Upflow Anaerobic Sludge Blanket (UASB) type. UASB digesters have successfully been used to process wastewaters generated by the food- and beverage-processing industries. ArrowBio has applied this success to processing MSW. In the UASB methanogenic bioreactor, micro-organisms convert the alcohols, sugars, and organic acids into biogas, which consists mainly of methane and carbon dioxide, and biomass, also known as digestate. The UASB reactor has a very high solids retention time, which is the average amount of time that the micro-organisms (i.e., solids) remain in the reactor. For the ArrowBio process, the solids-retention time is approximately 75-80 days. The high solids-retention time provides for a highly efficient digestion process, resulting in a biogas with a significantly higher percentage of methane than other anaerobic digestion technologies. Also, the higher-efficiency process results in a lower volume of well-stabilized digestate. Arrow Bio reports that the digestate requires only “passive” aerobic composting for finishing, as the digestate is well stabilized when it leaves the reactor.

A technical review and evaluation of Arrow's anaerobic digestion technology follows.

5.2.2 Proposed Facility Capacity for New York City. As part of the Phase 2 Study, Arrow was requested to designate a capacity for a demonstration facility and a commercial facility for New York City. The capacity was to be specific to Arrow's technology, with size guidelines established by the City.

As summarized below, Arrow designated a demonstration facility with an annual capacity (at 365 days per year) of 90,000 tpy and an availability of 90%, resulting in an annual waste throughput of 81,000 tpy of MSW. This is equivalent to an average daily throughput of 222 tpd, calculated based on 365 days per year. Arrow designated a commercial facility with an annual capacity (at 365 days per year) of 225,000 tpy and an availability of 95%, resulting in an annual waste throughput of 214,000 tpy of MSW. This is equivalent to an average daily throughput of 586 tpd, calculated based on 365 days per year.

Arrow	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	90,000 tpy	225,000 tpy
Annual Availability:	90%	95%
Annual Throughput:	81,000 tpy	214,000 tpy
Avg. Daily Throughput (at 365 days/yr):	222 tpd	586 tpd
Land Area Required:	4 acres	8 acres

Arrow's demonstration facility would consist of two separation/preparation lines and two sets of bioreactors, considered by Arrow to be a single "module". The transition to a commercial facility would be accomplished by adding a second, larger module consisting of three separation/preparation lines and two sets of bioreactors.

5.2.3 Site Layout / Size Requirements for New York City. Arrow originally reported land area requirements would be 2.9 acres for the demonstration facility and 5.9 acres for the commercial facility, with the majority of this land area associated with process tanks and process buildings. The land area originally reported by Arrow excluded any buffer that may be required for surrounding land uses. Also, based on an equipment general arrangement provided by Arrow, additional area would be required for other facility components including roadways, scalehouse, administrative buildings, parking, and material storage. Based on independent calculations and discussions with Arrow, land requirements are more likely on the order of 4 acres for the demonstration facility and 8 acres for the commercial facility. Land requirements appear to be less for the ArrowBio technology than for other anaerobic digestion technologies reviewed, primarily because significantly less post-treatment of the digestate is required.

5.2.4 Mass Balance. The mass balance for a technology is generally a numerical balance of waste and other materials into the system, and recyclables, products, residue, energy, and other materials out of the system.

Based on information provided by Arrow and an independent review of the data, certain components of Arrow's mass balance are reasonable (i.e., quantity of recyclables and residue from the separation and preparation subsystem). However, Arrow was unable to provide detailed mass balance information around the digestion process, specifically regarding the extensive recirculation of water. Further, evaporation occurs from the water bath and the digestate dewatering process, which was not quantified. Specific elements of the mass balance are further discussed below.

5.2.4.1 Recyclables. The ArrowBio process recovers traditional recyclables from the incoming MSW in the water bath. Materials that are recovered in the process include ferrous metal, aluminum, sorted plastics (HDPE, PET and mixed film plastic), and glass. The strength and stability of secondary material markets are expected to vary for these recyclables. However, stable markets are likely to exist for all of these materials except for glass. This is consistent with Arrow's assumption that glass would be recovered, but would be disposed at no cost. For purposes of this study, materials placed in a landfill, even with the possibility of beneficial use at the landfill such as for daily cover material, are considered to be material requiring landfill disposal (i.e., residue). Therefore, glass is not considered to be recovered as a recyclable in the ArrowBio process. With that distinction, the amount of recyclables that would be recovered in the ArrowBio process is as follows:

Material	Amount (%)(1)	Amount (tpy)(2)
Ferrous Metal	1.9%	3,970
Aluminum	0.8%	1,750
Sorted Plastic(3)	12.0%	25,680
Total	14.7%	31,400

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 214,000 tpy.
(3) 70% film plastic, 15% HDPE and 15% PET

Arrow's mass balance assumptions leading to a recovery rate of 14.7% for recyclables is reasonable. Based on information provided to Arrow regarding the composition of the City's wastestream (see Section 3.3 of this report), the ArrowBio front-end process recovers as traditional recyclables approximately 68% of the metal and approximately 86% of the plastic that is in the City's MSW.

5.2.4.2 Residue Requiring Landfill Disposal. During front-end separation and preparation, recyclables and biodegradable organic materials are separated from inorganic and non-biodegradable material (e.g., grit, textiles, rubber, and composite packaging or consumer materials). The fraction that is not recyclable or biodegradable is considered residue requiring disposal at a landfill. For the ArrowBio process, an estimated 23.4% of the MSW received for processing will be residue requiring disposal. This residue includes 2-3% glass that could potentially be recycled with development of a stable secondary market local to the facility. Unlike some other anaerobic digestion technologies, the ArrowBio technology does not generate residue after digestion. This is because the ArrowBio technology includes an extensive, water-based, hydro-mechanical separation and preparation process integral to, and preceding the digestion process, avoiding the need to screen the digestate or the finished compost after the digestion process. As summarized below, all residue is generated during the separation and preparation process.

Material	Amount (%)(1)	Amount (tpy)(2)
Pretreatment Residue	21.4%	45,720
Recovered, Nonrecyclable Glass	2.0%	4,280
Post-Digestion Residue	0.0%	0
Total	23.4%	50,000

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 214,000 tpy.

5.2.4.3 Organic Material Input to Anaerobic Digestion. Based on information provided to Arrow regarding the City's wastestream (see Section 3.3 of this report), approximately 70% of the City's wastestream is organic in nature, including paper. Arrow generally reports that the organic material input to the anaerobic digestion process, in the form of a watery slurry, is typically on the order of 65% of the MSW processed. This percentage is the wet weight and includes the water content of the organic material. Arrow's specific mass balance indicates approximately 62% of the MSW would go to the digestion process as an organic slurry, not specifically accounting for recirculation and evaporation. The organic material is converted into biogas and digestate; also, water is released from the organic matter during the anaerobic digestion process. This water is returned to the water bath, as needed, with the excess disposed as wastewater. Some amount of evaporation also occurs. Arrow did not provide sufficient information to verify the water balance for the process. Arrow estimates that approximately 10-15 gallons of wastewater will be generated for each ton of waste received for processing. For Arrow's suggested commercial facility processing 214,000 tpy of MSW, approximately 2.1 to 3.2 million gallons per year of wastewater could potentially be generated (i.e., approximately 4-6 gallons per minute).

5.2.4.4 Compost Produced. Compost is produced from dewatered digestate, with only passive aerobic finishing, if required (i.e., further stabilization of the digestate via on-site storage, with no active management to mix, turn or otherwise mechanically aerate the material). The compost production rate is approximately 13.7% of the incoming MSW (on a wet weight basis). No screening is conducted on the compost, reportedly because there is little to no foreign man-made material present in the compost and so screening is not required. However, no analytical data was provided to confirm the absence of foreign, man-made material in the compost. As further described in Section 7 of this report (Environmental Evaluation), Arrow provided the results of an independent technical review prepared as due diligence for project development activities in Australia. The independent review included analytical testing of material taken from the digesters (i.e., the digestate, or compost), and reported the material to have a high nutrient value and a low potential for mobility of heavy metals. At the reference facility in Israel, the material has been provided to an agricultural school. Arrow reports that greenhouse trials demonstrate that the material provides excellent results in terms of plant germination, and root and above-ground development.

5.2.5 Energy Balance. Based on information provided by Arrow, an independent analysis of Arrow's energy balance was completed. Relevant information regarding the biogas characteristics and energy generation for the ArrowBio process is as follows:

Parameter	Performance	
Quantity of Biogas Generated:	10.8%	(% by weight of MSW received)
Biogas Composition		
Methane Content:	70-80%	
Carbon Dioxide Content:	20-30%	
Hydrogen Sulfide Content:	<100 ppm	
Heating Value of Biogas:	11,500	Btu/lb
Gross Electricity Generated:	300	kWh/ton of waste received
Net Electricity Generated for Sale:	215-250	kWh/ton of waste received
Energy Conversion Efficiency:	42.4%	

The ArrowBio anaerobic digestion technology produces biogas at a rate approximately equal to 11% of the incoming MSW by weight. The biogas produced in the ArrowBio process consists of methane, typically at a concentration of 70% to 80%, and carbon dioxide at a concentration of approximately 20% to 30%. Arrow also reports that trace amounts of hydrogen sulfide (i.e., less than 100 parts per million), oxygen, and nitrogen are present in the biogas. The ArrowBio technology produces biogas with a higher concentration of methane than other anaerobic digestion technologies reviewed for this study. Test data provided by Arrow for the reference facility in Israel documents 81% methane in a sample of biogas analyzed in December 2003. As reported by Arrow and confirmed by independent calculations, the biogas has a heating value of approximately 11,500 Btu/lb. In comparison, natural gas has a heating value of approximately 23,600 Btu/lb.

Arrow combusts the biogas in a reciprocating engine to produce electricity. The Arrow Bio facility in Israel utilizes a Caterpillar engine; a similar engine would likely be proposed for a project in New York City. As discussed in Section 7, no air pollution control devices are used on the engine. Supplemental fuel (e.g., natural gas) is not used. The gross energy production rate for the ArrowBio technology is reported to be 300 kWh per ton of incoming MSW. The technology requires approximately 50 kWh for internal use, resulting in net electricity generated for export (sale) of approximately 250 kWh per ton of incoming MSW. For economic purposes, Arrow assumes a more conservative net electrical generating rate of 215 kWh per ton of MSW. At 215-250 kWh/ton, Arrow has the highest net electricity generation rate of the anaerobic digestion technologies reviewed for this study. The comparatively high net generation rate corresponds to the comparatively high concentration of methane in the biogas.

An independent analysis was completed of the energy conversion efficiency for the Arrow Bio process. Assuming a biogas generation rate of 210 pounds of biogas generated per ton of incoming mixed MSW (11% generation rate), a conservative average biogas methane content of 74% by weight, and gross generation of 300 kWh of electricity per ton of MSW through combustion of the biogas in a reciprocating engine, the energy conversion efficiency of the engine is estimated to be 42.4%. This calculated engine efficiency is at the high end of efficiencies achievable with reciprocating engines combusting biogas.

5.2.6 Technology References. ArrowBio identified Mr. Danny Sternberg, Association Engineer for the Dan Region Association of Governments Transfer Station, as a reference for the existing Arrow facility in Israel (i.e., Arrow's reference facility). Mr. Sternberg was independently contacted by email and telephone regarding operations of the existing facility.

Mr. Sternberg reported favorably on the performance of the ArrowBio technology. Mechanical problems have occurred, but have been correctable. Problems have occurred with bulky waste such as washing machines, microwave ovens and construction and demolition waste. The design of the existing facility does not readily allow for removal of bulky items prior to dumping incoming waste into the water bath. According to Mr. Sternberg, the existing layout would benefit with an additional (i.e., second) separation/preparation processing line, including a walking floor ahead of the water bath of sufficient length to allow for removal of bulky items. There have been no problems with noise, dust or odors, and no complaints from neighbors. However, the facility is in an industrial area and the closest neighbor is reportedly well over 500 yards away from the facility. Mr. Sternberg reported that the volume of compost generated is small, and that the compost is given to an agricultural school.

Arrow also provided as a reference Mr. Rafael Rodman, an advisor on organic gardening at the Eshel Hanasi agricultural institution, who has conducted greenhouse trials with his students using ArrowBio acetogenic digestate (compost). Mr. Rodman was independently contacted by email regarding his experience with digestate (compost) from the Arrow facility in Tel Aviv. Mr. Rodman confirmed that he has been using the material, which he calls sludge, since the facility began operations. He reports that the material has no odor or visible foreign materials and is beneficial for plant germination. Mr. Rodman reported that there is no commercial use of methanogenic sludge in Israel, but that the facility does not produce significant amounts of this material.

5.3 Waste Recovery Systems, Inc.

Waste Recovery Systems, Inc. (WRSI) is the United States representative for the Valorga anaerobic digestion technology, developed by Valorga International of Montpellier, France. WRSI has offices in Monarch Beach, California.

The Valorga process may be used for treatment of either mixed MSW, or for the source-separated organic fraction of MSW. In addition, sewage sludge or biosolids may be processed with MSW. The Valorga process is considered a “dry” anaerobic digestion process, since it processes organic feedstock with a solids content greater than 30%. The Valorga process may be operated as either a mesophilic process or as a thermophilic process, depending on the temperature at which the digester is operated. The proposed operation for New York City is mesophilic operation, which occurs at a lower operating temperature and requires less internal energy. In mesophilic operation, the temperature within the anaerobic digester will be approximately 40°C (104°F).

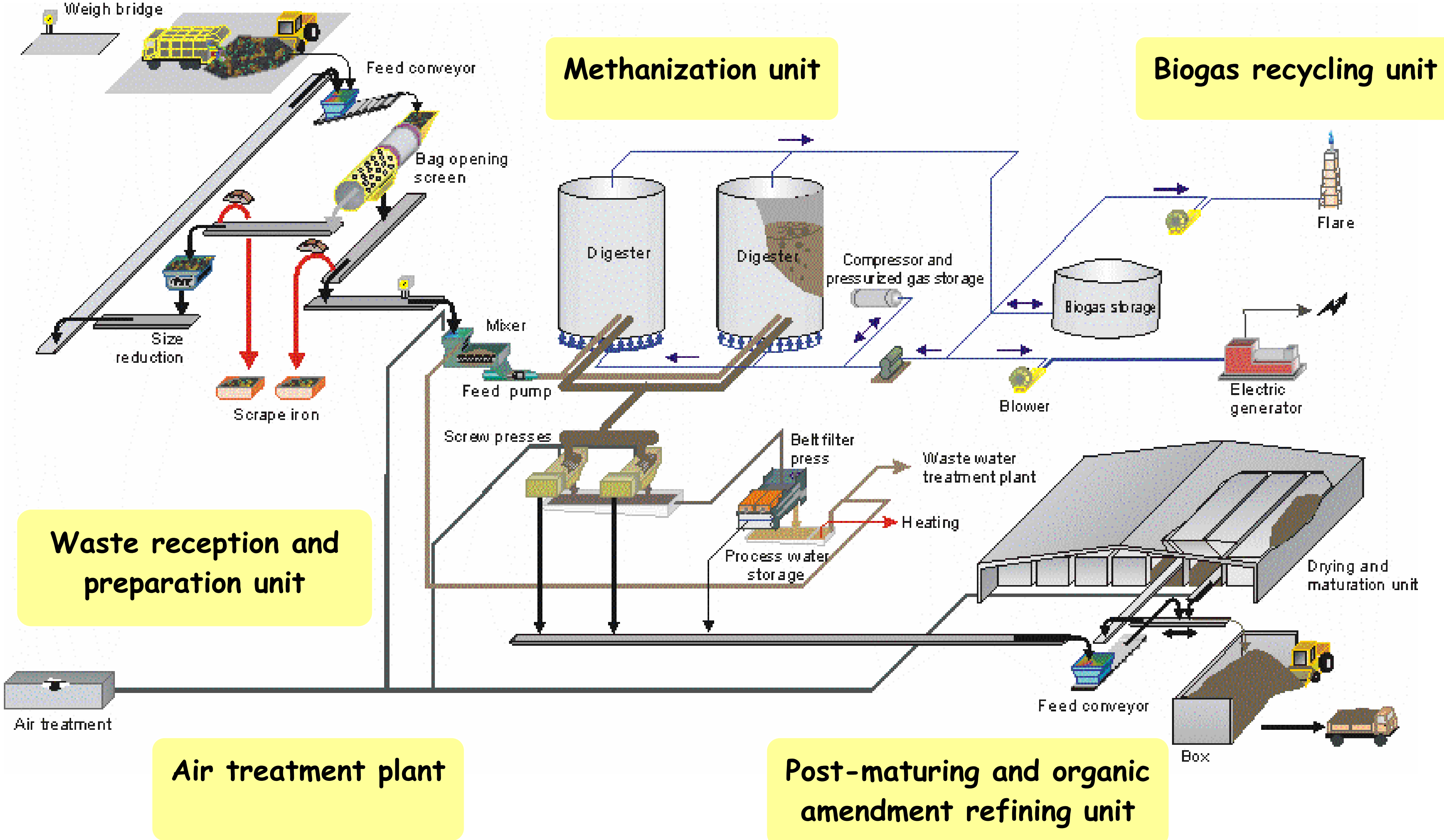
The Valorga anaerobic digestion technology has been operating commercially since 1988, with the first commercial plant (located in France) processing MSW. One of the newest, and largest, Valorga facilities is located in Barcelona, Spain, and also processes MSW. This reference facility began operations in 2004, and processes approximately 264,552 tpy of waste (725 tpd, on average, based on 365 days per year). The facility processes approximately 90% MSW (greater than 240,000 tpy) together with biowaste (source-separated, organic household waste).

WRSI Valorga Reference Facility	
Name:	Eco-Parc II
Location:	Barcelona, Spain
Capacity:	264,552 tpy
Type of Waste:	MSW (90%) and Biowaste (10%)
Owner:	EBESA (Public Entity)
Operator:	URBASER ACS
Commercial Operation:	March 2004

Recently, WRSI and the Valorga technology were selected to develop a 100,000-tpy facility in Palm Desert, California for Waste Management, a private waste collection company. The facility may be operating as early as late 2007. This would be the first, commercially-operated anaerobic digestion facility in the United States processing MSW.

5.3.1 Description of the Valorga Technology. Figure 5-2 provides a schematic of a Valorga facility designed to accept source-separated organic waste (also called biowaste). WRSI, in collaboration with Valorga, was requested to provide a schematic for the facility as proposed for New York City (i.e., depicting the details of the front-end processing system for MSW). While a schematic was provided by WRSI for the Barcelona reference facility, the schematic was not appropriate for inclusion in this report. The diagram was in Spanish, and appeared to include significantly more manual labor than incorporated into the design concept for New York City. Therefore, the schematic provided in Figure 5-2 is included as the best available schematic for the Valorga technology.

**FIGURE 5-2. WASTE RECOVERY SYSTEMS, INC.
SCHEMATIC OF VALORGA ANAEROBIC DIGESTION TECHNOLOGY
(WITHOUT FRONT-END MATERIAL RECOVERY FACILITY)**



For processing mixed MSW, WRSI reports that the system shown in Figure 5-2 would need to be coupled with a traditional materials recovery facility (MRF) at the front-end of the process, to recover recyclables and separate out non-biodegradable materials. The front-end processing would also include separation and size reduction equipment, to achieve a biodegradable organic fraction suitable as feedstock for the digester. Equipment types and configuration have not been specified for the front-end MRF and separation/preparation system. Further consideration of the components and configuration of a front-end MRF for the Valorga technology is considered a technology transfer issue for New York City, since it has not been demonstrated that the waste characteristics in Barcelona are similar to those in New York City (i.e., a different MRF configuration may be required).

To achieve optimal conditions for microbial degradation in the Valorga system, the prepared MSW feedstock must be diluted, inoculated and heated. The exact weight of the material entering the digester is stated to be a critical design parameter for the Valorga process. The material to be digested is weighed on a device that is integral to the conveyor system leading to the digester. The initial moisture content of the incoming waste is also measured, and sufficient dilution water (recycled from the process) is added to achieve a solids content of 30% to 35%. The material is then heated by steam injection to raise the temperature of the mixture to the mesophilic operating temperature, and mixed with a small amount of digested material to inoculate it with anaerobic microorganisms. The prepared material is pumped into the digester, to begin the digestion process.

The Valorga digester is a cylindrical concrete tank, with an inner wall extending vertically across two-thirds of the digester diameter. Prepared material is injected into the digester on one side of the inner wall, and digested material is extracted on the other side of the inner wall. This design ensures sufficient residence time of the material in the digester, preventing "short circuiting", which occurs when material proceeds too rapidly on a direct path from the inlet to the outlet. Material moves through the digester, around the wall, in a plug flow manner, with an average retention time of 16 to 17 days. During digestion, pressurized recirculated biogas is injected through nozzles located in the floor of the digester, mixing the digesting material. This pneumatic mixing is used in place of mechanical mixers, which would be subject to significant wear within the digester.

The digested material is removed from the digester and is dewatered using a screw press. The liquid that is pressed from the digestate in the screw press operation is put through a centrifuge in order to separate the suspended solids from the liquid. The centrifuge centrate (liquid) is recycled back to the digester feed pump for use as dilution water. The dewatered solids from the screw press are combined with the dewatered solids from the centrifuge and are aerobically finished in order to produce a stabilized compost product. Aerobic finishing requires approximately 14 days. After aerobic finishing, the compost is screened to remove inert materials that passed through the process. These inert materials are disposed of as residue.

5.3.2 Proposed Facility Capacity for New York City. As part of the study, WRSI was requested to designate a capacity for a demonstration facility and a commercial facility for New York City. The capacity was to be specific to the Valorga technology, with size guidelines established by the City.

As summarized below, WRSI designated a demonstration facility with an annual capacity (at 365 days per year) of 182,500 tpy and an availability of 100%, resulting in an annual waste throughput of 182,500 tpy of MSW. This is equivalent to an average daily throughput of 500 tpd, calculated based on 365 days per year. The facility would consist of five digesters, and would be able to achieve 100% availability since the facility would be operated for less than 24 hours each day, with maintenance performed during off-hours.

WRSI designated a commercial facility with an annual capacity of 1,095,000 tpy (i.e., the maximum capacity allowed for any technology, for purposes of the study). This is equivalent to an average daily throughput of 3,000 tpd, calculated based on 365 days per year. In discussions with WRSI, it was determined that a 3,000-tpd facility is not currently practical, considering land availability required for this size facility (at least 60 acres). Also, this size facility is significantly larger than the Valorga reference facility. Therefore, for purposes of this study and in discussion with WRSI, the capacity for the commercial facility is considered to be 182,500 tpy (500 tpd), which is the same as the proposed demonstration facility.

WRSI	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	182,500 tpy	182,500 tpy
Annual Availability:	100%	100%
Annual Throughput:	182,500 tpy	182,500 tpy
Avg. Daily Throughput (at 365 days/yr):	500 tpd	500 tpd
Land Area Required:	14 acres	14 acres

5.3.3 Site Layout / Size Requirements for New York City. The total land area required for a Valorga facility designed to process 182,500 tpy is reported by WRSI to be 14 acres. WRSI did not provide a breakdown of land area requirements for the facility sub-systems, such as pre-processing, process tanks, process buildings, and long-term materials storage. WRSI also did not provide a facility site layout or general equipment arrangement of the proposed 500-tpd facility. However, a plant layout diagram provided for the Valorga reference facility in Barcelona, Spain, and the acreage required for other Valorga facilities confirms the reasonableness of the 14-acre site requirement.

5.3.4 Mass Balance. The mass balance for a technology is generally a numerical balance of waste and other materials into the system, and recyclables, products, residue, energy and other materials out of the system. Based on information provided by WRSI and an independent review of the data, the mass balance appears generally reasonable. Specific elements of the mass balance are further discussed below.

5.3.4.1 Recyclables. WRSI proposes to recover traditional recyclables in a front-end MRF that is coupled with the Valorga technology. Materials that are proposed to be recovered include ferrous metal, aluminum, mixed plastics, glass, wood, paper and "other". As further explained in Section 9 of this Report (Economic Analysis), stable secondary material markets are likely to exist for only some of these materials - ferrous metal, aluminum and plastics.

As previously discussed in Section 5.2.4.1 regarding another technology, glass recovered from mixed MSW is expected to require landfill disposal, and is considered to be residue for purposes of this study. Similarly, it is unlikely that paper (other than corrugated cardboard) could be recovered from mixed MSW, of suitable quality to find a stable market. Since WRSI has reported that paper is removed, in part, to establish a proper carbon to nitrogen balance in the Valorga digester, the paper removed in the front-end process is considered to be residue for purposes of this study. "Other" is not sufficiently defined to assume it represents viable recycling, and is also considered residue. Wood is recovered as a recyclable, but assumed to be used on-site as a bulking agent for the post-digestion composting process. With these distinctions, the amount of recyclables that would be recovered by WRSI is as follows:

Material	Amount (%)(1)	Amount (tpy)(2)
Ferrous Metal	3.2%	5,749
Aluminum	0.3%	548
Mixed (Unsorted) Plastic	4.9%	8,943
Wood	0.7%	1,278
Total	9.1%	16,518

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 182,500 tpy.

Based on information provided to WRSI regarding the composition of the City's wastestream (see Section 3.3 of this Report), WRSI recovers approximately 88% of the metal and 28% of the plastic present in the City's waste. The metal recovery rate appears somewhat high, and the plastic recovery rate appears somewhat low. Recovery rates could likely be determined with greater certainty upon further consideration and development by WRSI of the MRF equipment components and configuration.

5.3.4.2 Residue Requiring Landfill Disposal. During front-end separation and preparation, recyclables and biodegradable organic materials are separated from inorganic and non-biodegradable material (e.g., grit, textiles, rubber). The fraction that is not recyclable or biodegradable is considered residue requiring disposal at a landfill.

For the WRSI process, an estimated 30.9% of the MSW received for processing will be residue requiring disposal. The front-end processing will generate an estimated 24.4% residue, including 1.5% glass, 4.6% very low quality paper, and 1% "other" that are removed but not considered to have stable secondary markets. Post-processing screening of compost will generate 6.5% residue. Residue quantities associated with the WRSI system are summarized below.

Material	Amount (%)(1)	Amount (tpy)(2)
Pretreatment Residue	17.3%	31,573
Recovered, Nonrecyclable Glass	1.5%	2,738
Recovered, Nonrecyclable Paper	4.6%	8,395
Recovered, Nonrecyclable "Other"	1.0%	1,825
Post-Digestion Residue	6.5%	11,862
Total	30.9%	56,393

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 214,000 tpy.

5.3.4.3 Organic Material Input to Anaerobic Digestion. The organic material input to the anaerobic digestion is approximately 67% of the incoming MSW. This percentage is the wet weight and includes the water content of the organic material as well as inorganics that are later screened out of the compost.

5.3.4.4 Compost Produced. The compost production rate is approximately 24% of the incoming MSW (on a wet weight basis). WRSI indicated that the quality of the compost, with respect to metals content, is related to the composition of the incoming waste. WRSI stated that laboratory analysis would need to be conducted on the incoming waste in order to estimate the metals content of the finished compost.

WRSI stated that compost produced by the Valorga process in Europe meets the regional quality standards in the relevant governing authorities. WRSI provided certificates of quality for compost produced in the Valorga facilities in Engelskirchen and Freiburg, Germany, including corresponding compost analyses. Notably, however, these facilities both process biowaste and not MSW. The analysis was in German and partially annotated with the English translation for the analyses. The compost analyses provide an overview of the compost standards that are currently in use in Germany. The analyses focused on agricultural information, such as organic matter, percent nitrogen and phosphorus, hygienic approval (level of pathogens) and level of impurities. Additional information on the quality of the compost is provided in Section 7 (Environmental Evaluation).

5.3.5 Energy Balance. Based on information provided by WRSI an independent analysis of Valorga's energy balance was completed. Relevant information regarding biogas characteristics and energy generation for the Valorga technology is as follows:

Parameter	Performance	
Quantity of Biogas Generated:	15.0%	(% by weight of MSW received)
Biogas Composition		
Methane Content:	55%	
Carbon Dioxide Content:	45%	
Hydrogen Sulfide Content:	not provided	(stated to be trace amounts)
Heating Value of Biogas:	7,000	Btu/lb
Gross Electricity Generated:	218	kWh/ton of waste received
Net Electricity Generated for Sale:	124	kWh/ton of waste received
Energy Conversion Efficiency:	41.2%	

The Valorga anaerobic digestion technology produces biogas at a rate approximately equal to 15% of the incoming MSW by weight. The biogas produced in the Valorga process consists of methane, typically at a concentration of 55%, and carbon dioxide at a concentration of approximately 45%. Independent calculations indicate a heating value of the biogas of approximately 7,000 Btu/lb. In comparison, natural gas has a heating value of approximately 23,600 Btu/lb.

The Valorga facility in Barcelona, Spain is equipped with gas engine generators, for purposes of generating electricity from the biogas. No combustion controls are reported to be used on the gas engine generators that are used at the Barcelona facility. For New York City, WRSI proposes to combust the biogas in a reciprocating engine to produce electricity. No air pollution control devices are specified for use on the engine. Supplemental fuel (e.g., natural gas) is not used. The energy production rate is reported to be 218 kWh per ton of incoming MSW. The technology requires approximately 94 kWh for internal use, resulting in net electricity generated for export (sale) of approximately 124 kWh per ton of incoming MSW.

An independent analysis was completed of the energy conversion efficiency for the Valorga process. Assuming a biogas generation rate of 300 pounds of biogas generated per ton of incoming mixed MSW, a biogas methane content of 55% by weight, and combustion of the biogas in a gas engine generator, the energy conversion efficiency of the engine is estimated to be 41.2%. This calculated engine efficiency is at the high end of efficiencies achievable with reciprocating engines combusting biogas.

5.3.6 Technology References. Independent efforts were made to contact the operator of the Valorga reference facility in Barcelona, Spain. WRSI does not have direct contact with the Barcelona facility, and was unable to provide information for direct contact by the City. According to WRSI, Valorga requires that all contact be made through their corporate offices. Repeated attempts were made to contact Valorga's corporate office; however, a response has not yet been received. As a result, an independent technology reference for the Valorga system could not be completed.

The inability to directly contact Valorga references, even with the assistance of WRSI, is reflective of difficulties that can inherently be encountered when dealing with a technology licensee rather than the technology owner. The relationship of a technology supplier with the proposed technology, including ownership and/or license arrangements and related issues regarding long-term access to technical support, is addressed further in Section 8.

6.0 THERMAL PROCESSING - OVERVIEW AND TECHNICAL EVALUATION

6.1 Introduction to Technologies Reviewed

Four companies offering thermal processing technologies participated in New York City's Phase 2 Study:

- **Ebara Corporation (Ebara).** Ebara's thermal technology consists of a fluidized bed gasifier coupled with a high-temperature, ash-melting furnace. The system requires shredding of MSW prior to processing. Recyclable metals (ferrous and aluminum) are recovered from the gasifier reactor. Fuel gas created in the reactor is combusted at a very high temperature in the ash melting furnace. Steam generated from the combustion of the gas is used to generate electricity. The fuel gas enters the ash melting furnace in a "raw" state, containing tar, fine char, and ash residue. These materials are melted in the furnace and extracted as a vitrified, glassy slag, which is marketed to the construction industry as an aggregate.

- **GEM America (GEM).** GEM uses a flash pyrolysis technology, also called thermal cracking, to convert MSW into a synthesis (or fuel) gas that is combusted in a reciprocating engine to generate electricity. The process requires shredding and drying of the MSW. During this pre-processing, recyclable materials are recovered using standard material recovery equipment. The process generates a carbon-based solid material, called char. The char may be potentially useable as a landfill cover material, but due to lack of identified markets is currently considered a process residue that requires disposal.

- **Interstate Waste Technologies (IWT).** IWT's thermal technology is a closed-loop process based on high-temperature gasification with an extended residence time for process gases. The technology simultaneously gasifies organic materials and melts down inert materials. There is no size reduction or separation of the MSW prior to gasification, and no front-end recovery of recyclables. Rather, all MSW is input to the process and is either converted to energy or extracted as a product. Assuming all products can be marketed, which has reportedly been demonstrated at operating facilities in Japan, the technology generates no residue requiring disposal.

- **Rigel Resource Recovery and Conversion Company (Rigel).** Rigel's thermal technology is based on application of the Westinghouse plasma arc gasification system. The Westinghouse technology uses high-temperature ionized air, called plasma, to convert carbon-based materials into a synthesis gas. Inorganic materials leaving the plasma reactor as molten liquid are separated into metals and a glassy slag. There is no size reduction or separation of the MSW prior to gasification, and no front-end recovery of recyclables. Rather, all MSW is input to the process and is either converted to energy or extracted as a product. Assuming all products can be marketed, the technology generates no residue requiring disposal. Rigel's application of the Westinghouse plasma gasification system uniquely includes a significant amount of fossil fuel as energy input to the process. RIgel's application of thermal processing of MSW is uniquely designed to serve as a power plant as much as it is intended to serve as a waste management facility.

A comparative summary of key technical parameters for commercial-scale facilities for these four technologies, for a commercial-scale facility for New York City, is provided in Table 6-1. A detailed description and technical review of each individual technology follows the Table. The description and technical review for each technology are based on application of the technology for a project in New York City processing MSW, with references to technology design features and performance as demonstrated by specified reference facilities.

Table 6-1. Thermal Processing Technical Summary

Technical Parameter	Ebara	GEM	IWT	Rigel
Facility Description Recommended Annual Throughput (Commercial Facility)	1,080,108 tpy (2,959 tpd)	1,006,740 tpy (2,758 tpd)	953,370 tpy (2,612 tpd)	996,000 tpy (2,729 tpd)
Site Acreage Required	36 acres	11 acres	20 acres	35 acres
Pre-treatment of MSW Description	Shredding	Waste sorting, shredding, drying and granulation	No pre-processing	No pre-processing
Types of Recyclables Recovered	Ferrous Metal Aluminum	Ferrous Metal Aluminum	None	None
Quantity of Recyclables Recovered	3.2% (34,689 tpy)	4.0% (40,270 tpy)	0% (0 tpy)	0% (0 tpy)
Thermal Processing Description	Fluid bed gasifier coupled with high-temperature, ash-melting furnace	Thermal cracking (flash pyrolysis)	High-temperature gasification	Plasma arc gasification
Types of Products Recovered	Vitrified, glassy slag	None	Vitrified aggregate; mixed metals; mixed salts; sulfur; zinc	Vitrified, glassy slag; mixed metals; HCl; sulfur
Quantity of Products Recovered	6.7% (72,755 tpy)	0% (0 tpy)	17.0% (171,021 tpy)	23.0% (228,787 tpy)
Residue Management Residue Requiring Disposal	6.1% (66,103 tpy)	28.4% (285,913 tpy)	0% (0 tpy)	0% (0 tpy)
Syngas Management Gross Electricity Generated	547 kWh/ton MSW	603 kWh/ton MSW	772 kWh/ton MSW	2,308 kWh/ton MSW
Net Electricity Generated	383 kWh/ton MSW	533 kWh/ton MSW	493 kWh/ton MSW	2,291 kWh/ton MSW

6.2 Ebara Corporation

Ebara Corporation (Ebara), headquartered in Tokyo, Japan, is the project sponsor for the Twin-Rec fluidized bed gasification technology. The technology treats a variety of waste materials, including MSW, sewage sludge, electronic waste, waste plastics, and automobile shredder residue.

The Twin-Rec technology has been in commercial operation in Japan since 2000, with 25 units currently in operation. Six plants (with sixteen Twin-Rec units in aggregate) are in operation processing MSW. The first Twin-Rec plant fed with MSW began commercial operation in March 2002 (Sakata Area), with two additional plants later in 2002 (Kawaguchi City, Ube City), two plants in 2003 (Chuno Union, Minami-Shinshu Wide Area Union), and one plant in 2004 (Nagareyama City). As summarized below, Ebara's reference facility is the Kawaguchi City Asahi Clean Center, which began commercial operations in November 2002 and is the largest of all Ebara plants that process MSW.

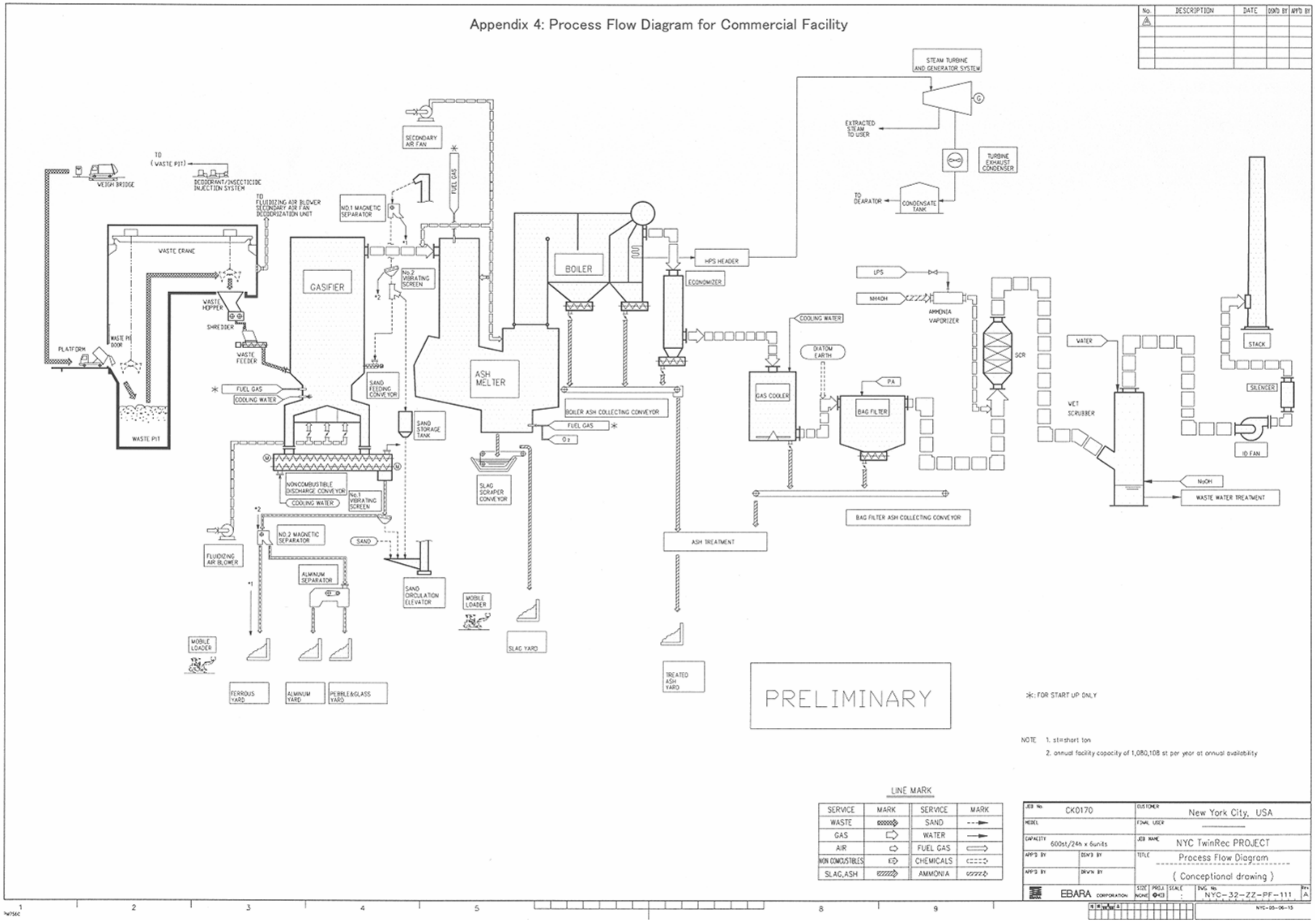
Ebara Reference Facility	
Name:	Kawaguchi City Asahi Clean Center
Location:	Kawaguchi City, Saitama, Japan
Capacity:	138,300 tpy
Type of Waste:	MSW
Owner:	Kawaguchi City
Operator:	Joint Venture of Ebara Engineering Service Corporation and TESCO, Inc.
Commercial Operation:	November 2002

Two additional Ebara Twin-Rec facilities are in development for processing MSW. One plant is being developed in Malaysia, and is expected to be operational in May 2006. Upon completion, the facility in Malaysia will be the largest application of the Twin-Rec technology, with five units processing 300 tpd each (547,500 tpy). Another plant is being developed in Japan, and is expected to be operational in April 2007.

6.2.1 Description of the Ebara Technology. The core components of Ebara's Twin-Rec thermal technology are a fluidized bed gasifier and a high-temperature ash melting furnace. The system requires shredding of the MSW prior to processing. Related facility components include power generation and air pollution control equipment. These core components of the technology are shown in the schematic provided in Figure 6-1 and described below.

MSW is received within an enclosed tipping platform, where waste is discharged directly to a storage pit. Traveling overhead cranes are used to feed the MSW into shredders for size reduction. The waste must be reduced to less than 12-inches in diameter prior to being fed into the gasifier. Shredded waste is stored in an intermediate pit, from which it is fed into the gasifier.

Figure 6-1. Schematic Diagram of Ebara Twin-Rec Technology



The gasifier is a fluidized circulating bed gasifier. Internal to the gasifier is a bed of sand, which is heated, swirled, and blown up (i.e., "fluidized") in heated air currents from the bottom of the reactor. Shredded waste is fed into the reactor via a chute, where it falls by gravity into the fluidized sand bed of the reactor. Gasification takes place within the reactor at atmospheric pressure and at relatively low temperatures of approximately 550-630°C (1,000-1,200°F). The organic components of the MSW (i.e., carbon and hydrogen based material, including food waste, yard waste, paper, plastic, rubber, textiles, etc.) are converted into a fuel gas, which flows upward in the reactor. The fuel gas is in a "raw" state, containing tar, fine char, fly ash, and hydrocarbons, in addition to carbon monoxide (CO) and hydrogen (H_2) typically found in a gasification synthesis gas. For purposes of this Phase 2 Study, the gas is called a fuel gas rather than a synthesis gas, because it is not predominantly CO and H_2. The fuel gas exits the top of the reactor and is carried into the top of the ash melting furnace, as described below.

While the organic components of MSW are gasified and flow out of the top of the reactor along with some light, inorganic components entrained in the gas as particulate matter (e.g., fly ash), dense inorganic materials drop by gravity to the bottom of the reactor. These materials generally consist of glass, metal, and stones. These materials are removed from the bottom of the reactor, along with some of the sand media that is used as the fluidized bed of the gasifier. Because of the relatively low, internal temperature of the gasifier, these materials are removed intact (i.e., unmelted and unoxidized, devoid of contaminants and rust). A vibrating screen is used to recover the sand, which is recirculated back to the gasifier. After screening to recover sand, ferrous metal and aluminum are recovered for recycling using magnets and eddy current separators. Material that is not recovered for recycling or recirculated back into the gasifier is disposed of as a residue. This residue generally consists of inert material such as glass and stones.

Fuel gas and ash leave the top of the gasifier and are carried into the top of the ash melting furnace. Unlike some other gasification technologies, there is no intermediate fuel gas cleanup between the gasifier and the ash melting furnace. The direction of gas flow in the ash melting furnace is downward and cyclonic. Air is injected at various points in the furnace to support the complete combustion of the fuel gas at temperatures ranging from 1,300-1,450°C (2,400-2,600°F). As the fuel gas is combusted, the fine ash particles that have been carried into the furnace collect on the furnace walls and are melted. This molten (i.e., "vitrified") slag flows slowly down the furnace walls and is continuously discharged at the bottom of the furnace. As the slag is discharged, it is immediately cooled in a water bath. This quenching process results in the slag being pulverized into a glassy, granulate material, which is marketed as a construction aggregate. Ebara has successfully marketed the slag in Japan, and reports that tests conducted in Japan show no leaching of heavy metals from the slag. While similar results would be expected for New York City regarding slag quality, the marketability of the slag is considered a technology transfer issue.

The gaseous products of combustion also exit near the bottom of the ash melting furnace, where these gases are directed upward through a boiler followed by an economizer. The high-temperature gases generate steam in the boiler and economizer, which is used to generate electricity in a steam turbine. The electricity is used to meet internal requirements, with excess electricity sold to the grid.

The combustion gas exits the boiler and economizer and passes through an air pollution control system, prior to being discharged from a stack to the atmosphere. First, the gas is cooled, or "quenched", via direct cooling by a water spray. After quenching, diatomaceous earth (a light, crumbly, silica-based material) is injected into the gas stream as a conditioner, to prevent clogging in the downstream bag filter. The conditioned gas passes through the bag filter, also called a "baghouse" or "fabric filter", which removes particulates that escape vitrification in the ash melting furnace. Diatomaceous earth is removed and collected with the particulates. The removed material is considered to be residue that requires landfill disposal; the quality of this residue has not been determined as part of this Phase 2 Study.

After the gas exits the baghouse, it is treated with selective catalytic reduction (SCR) technology. The SCR system generates ammonia from urea, and injects the ammonia into the gas stream. The ammonia reacts with nitrogen oxides (NOx) present in the gas, converting the NOx into nitrogen. After NOx control, the gas passes through a wet scrubber. Water and sodium hydroxide are injected into the scrubber, reacting with the gas to remove sulfur dioxide (SO_2) and hydrogen chloride (HCl) (i.e., acid gases). The scrubber generates wastewater, which is treated on site. Salts recovered from wastewater treatment are disposed of as residue. Gas exiting the air pollution control system is exhausted to the environment through a stack.

A technical review and evaluation of Ebara's Twin-Rec technology follows.

6.2.2 Proposed Facility Capacity for New York City. As part of the Phase 2 Study, Ebara was requested to designate a capacity for a demonstration facility and for a commercial facility for New York City. The capacity was to be specific to Ebara's technology, with size guidelines established by the City.

As summarized below, Ebara designated a demonstration facility with an annual capacity (at 365 days per year) of 128,400 tpy and an availability of 82.2%, resulting in an annual waste throughput of 105,611 tpy of MSW. This is equivalent to an average daily throughput of 289 tpd, calculated based on 365 days per year. Ebara designated a commercial facility with an annual capacity (at 365 days per year) of 1,314,000 tpy and an availability of 82.2%, resulting in an annual waste throughput of 1,080,108 tpy of MSW. This is equivalent to an average daily throughput of 2,959 tpd, calculated based on 365 days per year.

Ebara	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	128,400 tpy	1,314,000 tpy
Annual Availability:	82.2%	82.2%
Annual Throughput:	105,611 tpy	1,080,108 tpy
Avg. Daily Throughput (at 365 days/yr):	289 tpd	2,959 tpd
Land Area Required:	3.2 acres	36 acres

For both the demonstration facility and the commercial facility, Ebara's planned availability of approximately 82% is reasonable. Due to the complex nature of the technology, Ebara would conduct two or three planned shut-downs per year, per unit, for inspection and maintenance. Ebara reports an availability of approximately 77% at its reference facility (Kawaguchi City), following the first few years of operation. In comparison, availability typically achieved in waste-to-energy facilities in the United States is on the order of 85% or higher.

Ebara's demonstration facility would consist of two units. Transition from the demonstration facility to the commercial facility would be achieved by increasing the number of units to six, and scaling up the unit size by a factor of approximately 3.4. Ebara reported that during their transitioning from pilot testing to commercial operation of the technology, they had attempted to scale-up unit size by a factor of 10. Ebara reportedly encountered numerous problems with this large scale-up, including undersizing of the boiler. As a result, Ebara currently recommends limiting scale-up to a factor of approximately 3.

6.2.3 Site Layout / Size Requirements for New York City. The total land area required for the Ebara technology is 3.2 acres for the recommended demonstration facility (105,611 tpy) and 36 acres for the recommended commercial facility (1,080,108 tpy). These land areas are supported by Ebara with dimensioned site layouts, which show inclusion of required site features (i.e., waste receiving, storage and pre-processing; waste processing; power generation; air pollution control; materials storage; administrative areas; roadways and parking, and other features).

6.2.4 Mass Balance. In their response to the City's Supplemental Information Request (SIR), Ebara provided certain of the detailed, mass balance information requested by the City. However, the information provided by Ebara was not substantially complete to enable full closure of the balances on an independent basis. This is likely due, in part, to the complexity of the data request forms and communication issues. In follow-up communications, Ebara provided updated and additional information, which was useful but still did not result in full closure of the mass balance. Air input and stack gas output, along with water balance information, are the predominantly incomplete or unreconciled components of the mass balance. In consideration of these data limitations, evaluation of Ebara's mass balance follows.

Plantwide, the primary mass inputs to the facility are MSW, air, and water. Minor inputs include water treatment reagents and air pollution control reagents. Fossil fuel (natural gas) is used only during plant startup, and is therefore considered not to be part of the steady-state plant mass balance. Water is used for cooling (quenching) the vitrified slag upon discharge from the ash melting furnace, occasional regulation of gasifier temperature, boiler feedwater, flue gas quench, and flue gas caustic scrubbing. Although complete water balance information was not provided, the technology appears to be an importer of water and an exporter of wastewater on a steady state basis. Process water requirements were not clearly specified by Ebara; wastewater discharge is estimated to be approximately 71-78 gallons per ton of MSW processed.

The primary mass outputs from the plant are stack gas (which was not quantified in the mass balance), vitrified ash, recyclable metals, inert materials requiring disposal, air pollution control residues requiring disposal, evaporated water and wastewater. The stack gas consists of the products of combustion from the two-stage combustion process, and is discharged to the atmosphere following after treatment in the air pollution control system. Wastewater discharge includes boiler blowdown, and evaporated water in the stack gas from the quench and caustic scrubber. Additional information regarding stack gas and wastewater discharge is provided in Section 7, Environmental Review.

Specific elements of Ebara's mass balance are further discussed below.

6.2.4.1 Recyclables. As previously described, dense inorganic materials (including ferrous metal and aluminum) drop by gravity to the bottom of the gasification reactor where they are removed. Ferrous metal and aluminum are removed intact (i.e., unmelted and unoxidized, devoid of contaminants and rust) and are recovered as recyclables using magnets and eddy current separators. No other materials are recovered as recyclables.

In summary, the amount of recyclables that would be recovered in the Ebara Twin-Rec process is as follows:

Material	Amount (%)(1)	Amount (tpy)(2)
Ferrous Metal	2.6%	27,742
Aluminum	0.6%	6,947
Total	3.2%	34,689

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 1,080,108 tpy.

Based on information provided to Ebara regarding the composition of the City's wastestream (see Section 3.3 of this Report), Ebara recovers approximately 80% of the metal present in the City's waste. This is a reasonable recovery rate, particularly since the metal is recovered from the dense inorganic material that exits the gasifier rather than from the raw MSW.

6.2.4.2 Products. As previously described, fly ash that is entrained in the fuel gas is turned into a vitrified slag in the ash melting furnace. The slag is continuously discharged at the bottom of the furnace and quenched, resulting in a glassy, granulate material that is marketed as a product for civil construction uses. Ebara reports that approximately 6.7% by weight of the MSW received for processing will be turned into a glassy slag. For a commercial facility with a throughput of 1,080,108 tpy, approximately 72,755 tpy of glassy slag will be generated. The slag is silica-based, and includes impurities encapsulated in the glassy material and rendered inert. Based on Ebara's test data that shows the slag does not leach heavy metals, and based on Ebara's success in marketing the slag generated at operating facilities, the slag is considered a product and not a residue for purposes of this study. If, however, a stable market were not established for the slag in the United States, this material would require disposal as a residue.

6.2.4.3 Residue Requiring Disposal. Residue requiring landfill disposal is generated in Ebara's process from the solid output of the gasifier and as a result of the air pollution control system. An estimated 6.1% of the MSW received for processing will be residue requiring landfill disposal. Approximately half of this residue is inert, solid material (e.g., glass and stones) removed from the gasifier, after recovery of recyclable metals and separation of sand that can be recirculated into the gasifier. Ebara reports that this inert material may be useable as landfill cover material. However, for purposes of this study, all materials delivered to a landfill are assumed to be materials requiring disposal.

Air pollution control residue includes fly ash carried over from the ash melting furnace and diatomaceous earth, which is added ahead of the baghouse to improve system performance. These materials are collected in the baghouse. Air pollution control residue also includes salts from the treatment of wastewater generated by the gas quench and scrubbing systems. Residue quantities generated in the Ebara Twin-Rec process are summarized below.

Material	Amount (%)[1]	Amount (tpy)[2]
Gasifier Residue	3.2%	34,618
Air Pollution Control Residue	2.9%	31,485
Total	6.1%	66,103

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 1,080,108 tpy.

If the glassy slag product were to require landfill disposal, the total amount of residue would increase to 12.8% by weight of the MSW received for processing.

6.2.5 Energy Balance. Energy input to the Ebara Twin-Rec technology comes from the MSW that is processed. Fossil fuel (natural gas) and imported electricity are used during periods of startup, but are not used on a steady-state basis. Energy output is in the form of steam and electricity generated from the steam. Ebara reported energy output information as gross electricity generated, but did not specify energy output in the form of steam.

An independent analysis of Ebara's energy balance was completed. Relevant information is as follows:

Parameter	Performance	
Gross Electricity Generated:	547	kWh/ton of waste received
Net Electricity Generated for Sale:	383	kWh/ton of waste received
Energy Conversion Efficiency:	13% - 15%	(facility-wide)

For a commercial plant processing 1,080,108 tpy of MSW, the gross electricity output is stated to be 547 kWh of electricity per ton MSW received for processing. The technology requires approximately 164 kWh of electricity for internal (parasitic) use, resulting in net electricity generated for export (sale) of approximately 383 kWh per ton of incoming MSW.

The energy conversion efficiency of an Ebara processing plant of commercial scale is calculated to be approximately 13% to 15%. This energy conversion efficiency is somewhat lower than the efficiency achieved with traditional waste-to-energy technology, which generally ranges from approximately 17% to 20% (for net electrical output ranging from 500 kWh/ton to 600 kWh/ton). The Ebara technology draws additional thermal energy from the flue gas in the ash-melting furnace, in order to achieve the elevated temperature that is necessary to vitrify the ash particles. This loss of thermal energy to process needs impacts the energy conversion efficiency of the technology.

6.2.6 Technology References. Ebara identified Mr. Koushiro Okamura, the Mayor of Kawaguchi City, as a reference regarding performance of the Kawaguchi City Asahi Clean Center (Ebara's reference facility) along with other City representatives. Ebara cautioned difficulty in communication in English with the references, and requested we make contact through Ebara to facilitate communication. Initial outreach to the Mayor of Kawaguchi and other City representatives was not successful. As a result, Ebara recommended contact with Mr. Tomio Fuse, a City employee serving as Technical Manager for the facility. Contact was successfully made via email with Mr. Fuse.

Mr. Fuse reported that there have been three issues the City has managed associated with operation of the Kawaguchi City Asahi Clean Center: (1) maintaining a stable market for the slag; (2) reducing consumption of supplemental fuel (natural gas); and (3) maintaining a stable supply of waste to the facility. The facility is owned by the City and operated by a joint venture between Ebara and TESCO, Inc., on behalf of the City. Mr. Fuse reported that Ebara has provided a five-year warranty, which provides certain guarantees including quantity of supplemental fuel (natural gas) and residue discharged to the landfill. Mr. Fuse reported that the facility operates in compliance with environmental laws and regulations, including more stringent facility-specific performance levels set by the City. Mr. Fuse reported two instances of non-compliance; one was fluoride content in wastewater, and the other was a noise level at night. Both problems were corrected. Overall, Mr. Fuse provided a favorable reference for the facility.

6.3 GEM America

GEM America (GEM), located in Summit, New Jersey, is the American subsidiary of GEM International, the owner and patent holder of the GEM Thermal Cracking System. GEM's thermal technology is capable of processing MSW and other types of waste, and has been tested on a variety of waste including MSW, commercial waste, wood waste and plastics. The GEM technology requires pre-processing to create a dried and shredded, prepared waste. The pre-processing equipment is not part of the patented GEM technology, but is included ahead of the GEM technology as part of an overall system design.

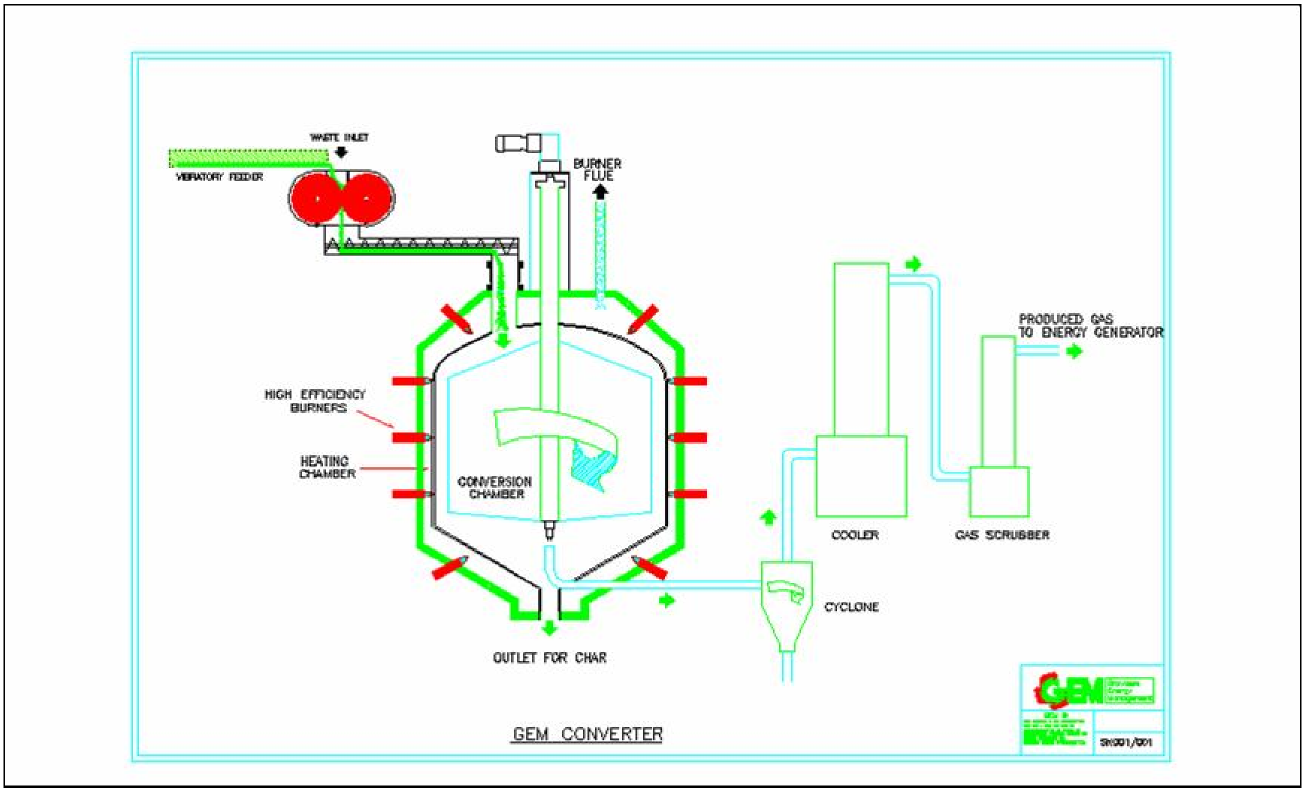
GEM's reference facility is a standard converter unit installed at a private landfill site in South Wales, which is the first, full-scale commercial unit sold by GEM. While the reference facility represents a full-scale commercial installation under private ownership and operation, it operated intermittently for testing and inspection purposes, design modifications, and other reasons specific to the private facility owner and operator (e.g., to accommodate simultaneous testing and modification of an autoclave unit, intended for front-end separation of recyclables). Operation of the GEM converter was limited to four days per week, six hours per day, for a 12- to 18-month period. In this regard, GEM's reference facility is more representative of a full-scale demonstration facility of the converter unit than of a complete commercial facility capable of pre-processing and conversion. As such, the operating history of the GEM reference facility, while illustrative of the capabilities of the technology, does not provide as much information as the other thermal technologies included in the Phase 2 Study.

The capacity of GEM's reference facility is approximately 40 tpd, which is the capacity of a standard GEM converter module. This capacity is the quantity of waste fed to the converter, after recovery of recyclables and drying of the waste. The owner's original plan was to expand to a total of three modules, but such expansion has not yet occurred. The demonstrated operating capacity at the reference facility is approximately 18.5 tpd, which is about half the design capacity. GEM reports that the facility has processed a total of approximately 1,375 tons of MSW over a one-year operating history. The facility is not currently operating, pending plans to re-locate the installation elsewhere. The capacity of GEM's reference facility is significantly less than the capacity that would be necessary for New York City. However, as described later in this Section, GEM would achieve a higher facility capacity by using multiple converters.

GEM Reference Facility	
Name:	Davies Brothers Waste
Location:	Tythegston Landfill Site, South Wales
Capacity:	40 tpd
Type of Waste:	MSW
Owner:	Davies Brothers Waste
Operator:	Davies Brothers Waste
Commercial Operation:	2000-2001

6.3.1 Description of the GEM Technology. GEM's application of the pyrolysis technology for processing MSW includes pre-processing equipment to recover recyclables and to shred and dry the waste, the pyrolysis reactor to convert the prepared waste into a synthesis gas and residual char, synthesis gas cleanup systems, and electricity generation through combustion of the cleaned gas. A schematic diagram of GEM's system is provided in Figure 6-2.

Figure 6-2. Schematic Diagram of GEM Conversion Process



GEM's patented technology does not include the pre-processing equipment. This equipment is added ahead of the converters, using standard material-recovery technology and waste-reduction and drying equipment. Very little information was provided by GEM on the pre-processing step. In some cases, information that was provided was inconsistent or indicated intent to meet the City's needs based on future determination of waste composition and project objectives. Therefore, integration of pre-processing equipment as part of a system design is considered a technology transfer issued for GEM.

Based on available information, pre-processing generally includes waste-sorting equipment (including bag openers and possibly screening equipment), conveying equipment, magnets and eddy current separators for recovery of ferrous metal and aluminum, primary and secondary shredders, dryers, and granulators. Indication was given that plastic could be recovered for recycling, but recovery of plastic was not consistently presented as part of pre-processing and does not appear to be included in the capital and operating cost estimates. Overall, pre-processing results in the removal of oversized material in the waste feed along with glass, both of which are considered residue for purposes of this study. Pre-processing also results in the recovery and recycling of metal. The remaining waste is shredded, dried and granulated, to achieve a waste feed less than 1/16th of an inch in size and with a moisture content of 5%. This granulated, dried waste is stored in silos, and represents the feedstock for the GEM thermal converters.

The prepared waste is passed through rollers to remove air entrained in the waste and then fed into the converter via an air-locked chute, which prevents air from entering the converter. By excluding air from the process, pyrolysis occurs instead of combustion (i.e., thermal conversion in the absence of oxygen). The GEM converter has an inner conversion chamber and an outer heating chamber. The outer heating chamber is equipped with high efficiency burners, which operate on gas generated in the process. This "jacket heating" produces an operating temperature in the converter in the vicinity of 820°F, without subjecting the feed material to a direct flame. It is not clear where the flue gas from the jacket burners is exhausted, but appears to go with the exhaust from the power generating engine to the dryer (used in pre-processing) and then to the atmosphere.

Feed material falls by gravity onto a spinning disk, which throws the material outward against the inner converter walls. As the feed material hits the walls, it pyrolizes very quickly (i.e., within a fraction of a second), which is a reaction called "flash pyrolysis". The pyrolysis process converts the organic material in the feedstock into a synthesis gas, which flows upward and is exhausted from the converter. Analytical data provided by GEM indicate that the synthesis gas generated by pyrolysis is primarily hydrogen (31%), methane (23%), carbon monoxide (19%), and carbon dioxide (18%). The balance of the synthesis gas composition is accounted for by small amounts of oxygen, nitrogen and organic gases of higher molecular weight than methane (e.g., ethene, ethane, propane). Solid material, called char, exits the bottom of the converter through an air-locked discharge. The char has a dry, powdery texture. Analytical data provided by GEM indicate that the char consists primarily of inert material called "ash" (71%) and carbon (19%). The char is considered a residue requiring disposal. The quality of the char (i.e., whether it is a marketable product or a hazardous or non-hazardous residue) is considered a technology transfer issue for New York City.

Upon exiting the converter, the synthesis gas is cooled and cleaned, then fed to a Jenbacher reciprocating engine to generate electricity. The gas is rapidly cooled in a blast cooler, which injects a mist of chilled mineral oil into the gas stream. The mineral oil spray removes particulates and chlorine. Cooling occurs rapidly as the oil vaporizes. The rapid cooling process and removal of chlorine prevents the formation of dioxins and furans. The oil is recirculated until it is no longer useable, at which point it is fed to the conversion process with the prepared MSW. GEM has included references to other cleanup steps, which could be employed as needed. These additional gas cleanup steps include separation of fine particulates from the hot syngas using a cyclone, a second-stage cooler, and de-sulfurization technology (chelated iron or biological) in order to scrub sulfur from the synthesis gas. The need for such additional cleanup steps is a technology transfer issue for New York City.

Exhaust from the engine passes through the dryer (used in pre-processing) and then through a thermal oxidizer (integrated with the dryer for odor control), prior to being vented to the atmosphere. Introduction of the engine exhaust to the dryer burners would act similar to a flue gas recirculation system for reducing thermal NOx emissions from the dryer burners, although, the point of introduction into the dryer is unspecified and may not be through burners. The thermal oxidizer is essentially an afterburner, which provides for complete combustion of carbon monoxide and any remaining volatile organic compounds, thereby controlling emissions of these pollutants.

6.3.2 Proposed Facility Capacity for New York City. As part of the Phase 2 Study, GEM was requested to designate a capacity for a demonstration facility and for a commercial facility for New York City. The capacity was to be specific to GEM's technology, with size guidelines established by the City.

Capacity information submitted by GEM was inconsistent, with a capacity reported for the converters (after pre-processing, including recovery of recyclables and drying) and an annual throughput reported for a complete facility (prior to pre-processing). Based on the reported capacity of the converters and with independent extrapolation using mass balance and availability information provided by GEM, the following capacities have been derived for GEM facilities:

GEM	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	178,500 tpy	1,071,000 tpy
Annual Availability:	94.0%	94.0%
Annual Throughput:	167,790 tpy	1,006,740 tpy
Avg. Daily Throughput (at 365 days/yr):	460 tpd	2,758 tpd
Land Area Required:	4.4 acres	11 acres

The demonstration facility is based on installation of 10 converters, and the commercial facility is based on installation of 60 converters. For both the demonstration facility and the commercial facility, planned availability of the converters is 94%. This availability is somewhat high, and has not yet been demonstrated to be achievable in commercial operation. As described above, the reference facility operated for only 6 hours a day, four days a week, for a period of less than two years.

Transition from the demonstration facility to the commercial facility would be achieved by increasing the number of units. No scale-up of the standard converter size is proposed.

6.3.3 Site Layout / Size Requirements for New York City. GEM has provided inconsistent information regarding the total land area required for a GEM facility. In one instance, GEM suggested 2 acres for a demonstration facility and 5 acres for a commercial facility. However, the best documented information is provided in an equipment layout GEM provided for a demonstration facility consisting of 10 converters. The layout includes feedstock preparation and drying, ten storage silos for prepared fuel, ten converters with integrated energy generation equipment, and a char recovery and loadout area. This equipment requires an area of approximately 189,326 square feet (approximately 4.4 acres). This appear appears to exclude waste receiving, recyclables loadout, roadways and parking, administrative offices, and other related site features. Therefore, 4.4 acres is possibly too low, but is cited for purposes of this Phase 2 Study because additional information is not available. Based on GEM's reporting that the commercial facility would require 2.5 times the area of the demonstration facility, the commercial facility would then require at least 11 acres.

6.3.4 Mass Balance. GEM provided some of the mass and energy balance information requested on forms included in the City's Supplemental Information Request (SIR), but the forms were incomplete and certain information was inconsistent. Independently, GEM provided a detailed mass and energy balance diagram, which was used as the primary source of data for completing the mass balance review.

Plantwide, the primary mass input to the GEM facility is MSW. Fossil fuel (natural gas) is used only during plant startup, and is therefore considered not to be part of the steady-state plant mass balance. No process water use has been stated by GEM. However, if GEM uses a de-sulfurization system for synthesis gas cleanup, some water use should be accounted for.

The primary mass outputs from the plant are front-end recyclables, residue (including oversized materials present in the waste, glass removed during pre-processing, and char generated during the pyrolysis process), evaporated water, and exhaust gas from the thermal oxidizer (which includes products of combustion from the power generating engine, the MSW dryer, and the burners used to heat the converter).

Specific elements of GEM's mass balance are further discussed below.

6.3.4.1 Recyclables

As previously discussed, GEM has not completely developed a design concept for a front-end material recovery system. Only metal recovery is considered a routine part of the operation, with magnets and eddy current separators integrated with the waste shredding equipment. Other materials could be recovered, such as plastic, but labor and equipment do not appear to be included in GEM's capital and operating cost estimates provided for purposes of this Phase 2 Study. Also, glass would presumably be removed from the waste during pre-processing, but as addressed for other technologies recovered glass is considered to be residue requiring landfill disposal. Therefore, the type and amount of recyclables that would be recovered from a GEM facility are generally as follows:

Material	Amount (%)(1)	Amount (tpy)(2)
Ferrous Metal	3.5%	35,236
Aluminum	0.5%	5,034
Total	4.0%	40,270

(1) Percent by weight of MSW received for processing. GEM reported 4% metal recovery, without a designation between ferrous and aluminum. The designation shown above is applied in consideration of the split applied by other technologies.
(2) For a commercial facility with a throughput of 1,006,740 tpy.

Based on information provided to GEM regarding the composition of the City's wastestream (see Section 3.3 of this Report), GEM would be recovering 100% of the metal present in the City's waste. This is not a reasonable recovery rate; other technologies reviewed for this Phase 2 Study have assumed that approximately 68% to 80% of the metal present in the waste would be recovered for recycling. Therefore, GEM's recovery rate for recyclables may be overstated.

6.3.4.2 Products

Except for energy, which is discussed in Section 6.3.5, the GEM process does not generate products. The char, which is the solid byproduct of the pyrolysis process, may have potential use as a landfill cover material. However, for purposes of this study, the char is considered a residue requiring disposal and not a marketable product.

6.3.4.3 Residue Requiring Disposal

The GEM process generates residue at an estimated rate of 28.4% by weight of the waste received for processing. Residue types and quantities generated in the GEM process are summarized below.

Material	Amount (%)(1)	Amount (tpy)(2)
Pre-processing Oversized Material	1.0%	10,067
Glass	3.0%	30,202
Char	24.4%	245,644
Total	28.4%	285,913

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 1,006,740 tpy.

As previously described, the char consists of ash (inorganic material that escapes pre-processing) and residual carbon. The quantity of char will vary, depending on the characteristics of the waste processed in the GEM converter. For example, inert material that is not removed during pre-processing (e.g., glass, stones, metal) will pass through the converter and be mixed in with the char. GEM provided conflicting information regarding the quantity of char that would be generated. In descriptive language and completion of mass balance tables, GEM indicated char would be 17.5% by weight of the MSW received for processing. However, as part of a detailed mass and energy balance schematic, GEM's data show char would be 24.4% by weight of the MSW received for processing. While the quantity of char likely falls somewhere in the range of 17.5% to 24.4%, the more conservative value of 24.4% has been used for purposes of this Phase 2 Study.

6.3.5 Energy Balance. Energy input to the GEM process comes from MSW. Fossil fuel (natural gas) is used during periods of startup, but is not used on a steady-state basis. Energy output is in the form of thermal energy and electricity.

An independent analysis of GEM's energy balance was completed. Based on information provided by GEM, the plant-wide energy balance achieves 45% closure on an output over input basis. This indicates that GEM did not report all plant energy outputs on a gross basis, and instead only reported gross electricity output. Relevant information regarding GEM's electricity output and energy conversion efficiency is as follows:

Parameter	**Performance**	
Gross Electricity Generated:	603	kWh/ton of waste received
Net Electricity Generated for Sale:	533	kWh/ton of waste received
Energy Conversion Efficiency (Plant):	13-18%	
Energy Conversion Efficiency (Engine):	26%	

For a commercial plant processing 1,006,740 tpy of MSW, the gross electricity output is stated to be 603 kWh of electricity per ton MSW received for processing. The technology requires approximately 70 kWh of electricity for internal (parasitic) use, resulting in net electricity generated for export (sale) of approximately 533 kWh per ton of incoming MSW. Additional thermal energy is reportedly also available for export (as heat, in the form of hot water). However, GEM has not sufficiently developed this concept for review and evaluation, and it is unclear if heat export is incorporated into capital cost estimates. Therefore, heat export is not included for purposes of this Phase 2 Study. Heat export, if viable, could provide additional revenue to a GEM project.

The energy conversion efficiency of a GEM facility of commercial scale is stated to be 13-18%. GEM's reported efficiency could not be independently confirmed with the information that was provided. GEM's 13-18% plant-wide efficiency is comparable to those reported or calculated for the other thermal technologies. This efficiency is lower than or comparable to traditional waste-to-energy conversion efficiency, which ranges from approximately 17% to 20% (for net electrical outputs ranging from 500 kWh/ton to 600 kWh/ton). GEM proposes engines for conversion of syngas energy to electricity at a reported efficiency of 26%, which is conisdered reasonable if not conservatively low.

6.3.6 Technology References

GEM has one commercial unit, which is privately owned and operated by Davies Brothers Waste in Tythegston, South Wales. Because there is only a single installation, limited technology references are available for GEM. GEM has not provided direct contact information for the facility owner (Davies Brothers Waste), the host community (Tythegston, South Wales) or the primary regulatory entity. GEM has reportedly approached the owner to facilitate contact. However, no direct contact has been made between the owner and City representatives, and no reference has been obtained to date.

6.4 Interstate Waste Technologies (IWT)

Interstate Waste Technologies (IWT), represented in the United States out of Middleburg, Virginia, and Malvern, Pennsylvania, offers the Thermoselect high-temperature gasification technology, licensed by JFE (a Japanese corporation, formerly Kawasaki Steel Corporation). The technology can process various types of waste, including MSW, construction waste, industrial waste and sewage sludge.

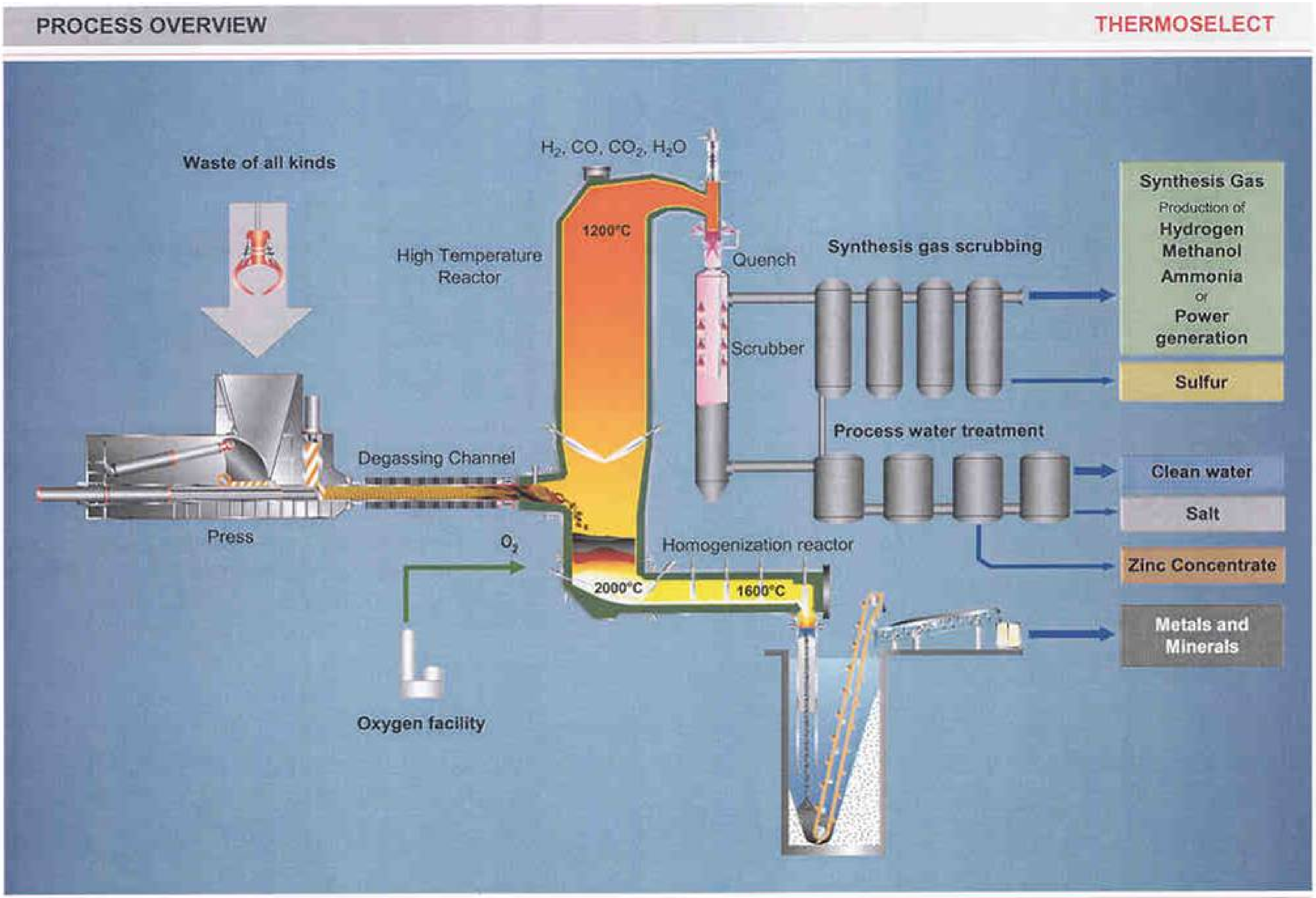
The Thermoselect technology operated at an industrial-scale demonstration and pilot plant in Fondotoce, Italy, from 1992 to 1998 (33,000 tpy or 90 tpd, based on 365 days per year), followed by commercial operation in Karlsruhe, Germany (247,500 tpy or 678 tpd, based on 365 days per year) from 1999 through 2004. The Karlsruhe facility was shut down on December 31, 2004, reportedly because the private owner is divesting itself of that business. IWT reports that the facility was operating satisfactorily for more than two years prior to closure of the facility. The Thermoselect technology is currently in operation at six locations in Japan (Chiba, Mutsu, Kurashiki, Nagasaki, Yorii, and Tokushima), with a seventh location expected to be operational in early 2006 (Izumi). Chiba is the longest-operating facility in Japan. Kurashiki is one of the newest facilities, but has the largest capacity of all the facilities currently in operation. Both of these facilities process MSW along with other types of waste.

As summarized below, IWT suggested three of the Thermoselect installations as reference facilities. All three reference facilities were designed to process MSW and other types of waste, and demonstrate performance of the technology over a period of up to six years.

IWT (Thermoselect) Reference Facilities			
Name:	Karlsruhe Facility	Chiba Facility	Kurashiki Facility
Location:	Karlsruhe, Germany	Chiba, Japan	Kurashiki, Japan
Capacity:	247,500 tpy	120,450 tpy	222,833 tpy
Type of Waste:	MSW, Industrial, Auto Shredder Residue	MSW and Industrial	MSW, Industrial, Plastic Auto Shredder Residue
Owner:	EnBW	JFE	JFE
Operator:	EnBW	JFE	JFE
Commercial Operation:	1999-2004	September 1999	April 2005

6.4.1 Description of the IWT Thermoselect Technology. The core components of IWT's application of the Thermoselect technology include a feed chamber, gasification reactor, synthesis gas cleanup, combustion of the cleaned syngas using a dual-fueled reciprocating engine, and addition of air pollution controls for reduction of emissions from the combustion of the syngas. Support systems include an oxygen plant, water treatment, and cooling towers. Figure 6-3 shows a schematic of the process.

Figure 6-3. Schematic Diagram of IWT's Thermoselect Technology



Waste is received in an enclosed area and discharged to a receiving pit. Overhead cranes are used to load the waste into hoppers that feed the processing lines. No sorting, separation, size reduction, or other pre-processing is conducted prior to loading the waste. Even bulky items (e.g., furniture, appliances, other large waste items) are loaded into the hoppers for processing. Upon loading, waste is compressed using standard, hydraulic scrap metal presses, forcing out air and uniformly distributing liquids (including sludge, if sludge is also being processed). Compacted waste is pushed into a degasification channel, which is indirectly heated using radiant heat from the gasification reactor. Within the heated, degasification channel, water and gases are driven off and some pyrolysis occurs as the feedstock approaches the gasification reactor.

By the time the waste reaches the end of the degasification channel, it has reached an elevated temperature of approximately 570°F. The feedstock is pushed into the reactor. In the high-temperature reactor, waste (in the form of solids and gases) is combined with limited amounts of pure oxygen and natural gas at temperatures as high as 2,200°F, forming a synthesis gas from the organic components of the waste (i.e., carbon and hydrogen based material, including food waste, yard waste, paper, plastic, rubber, textiles, etc.). The syngas leaves the top of the reactor, upon which it is cooled, cleaned and combusted to generate electricity. The inorganic components of the waste, which are primarily metals and silica, melt into a molten liquid ("slag") and move by gravity to the bottom of the reactor. The slag is discharged, upon which it is quenched in a water bath to cool the material. The quenching process turns the slag into a granular product, with the metal and silica-based materials granulating separately due to different physical properties associated with cooling. Magnetic separation is then used to separate the metal granules from the sand-like aggregate. The metal granules are typical of an alloy with iron content greater than 80%, and also containing nickel, copper and traces of other heavy metals. The metal and aggregate are marketed as products.

The synthesis gas created in the high-temperature reactor consists of carbon monoxide (32%), hydrogen (32%) and carbon dioxide (27%), along with nitrogen and water. The syngas exits the top of the gasifier, upon which it flows into a water-jet quench. The quench rapidly cools the gas from approximately 2,000°F to below 200°F in less than one second ("shock cooling"), which prevents the formation of dioxins, furans and other organic compounds. The quenching process removes metals, dusts, hydrogen chloride (HCl) and hydrogen fluoride (HF). The cooled gas is then cleaned to remove sulfur, heavy metals, industrial salts and other impurities. Cleaning is achieved through a series of scrubbers, in which the syngas interacts with a liquid to remove unwanted compounds. First is an acid scrubber, where water is used to remove additional HCl and HF ("acid gases"). The acid scrubber is followed by an alkaline scrubber, which uses sodium hydroxide (NaOH) in solution to further reduce HCl and HF and to reduce sulfur dioxide (SO_2). These scrubbers result in the formation of salts, which IWT collects as a marketable product. The synthesis gas is then passed through a desulfurization process to remove hydrogen sulfide (H_2S). The desulfurization process generates elemental sulfur, which is collected as a marketable product.

After cleaning, the gas is dried and then combusted to generate electricity. The power generating equipment proposed to be used by IWT consists of multiple dual-fueled Pielstick reciprocating engines, which will operate on synthesis gas and supplemental fossil fuel. Air pollution controls are applied to the exhaust from the engines. Specifically, catalytic air pollution control systems are applied to remove NOx and CO from the exhaust gases. As further discussed in Section 7, Environmental Evaluation, catalytic control systems have long been demonstrated for engine exhausts where the primary fuel is natural gas, and should perform comparably for engine exhausts where synthesis gas is the primary fuel.

A technical review and evaluation of IWT's Thermoselect technology follows.

6.4.2 Proposed Facility Capacity for New York City. As part of the Phase 2 Study, IWT was requested to designate a capacity for a demonstration facility and for a commercial facility for New York City. The capacity was to be specific to the Thermoselect technology, with size guidelines established by the City.

As summarized below, IWT designated a demonstration facility with an annual capacity (at 365 days per year) of 247,500 tpy. Based on information provided, availability of approximately 74% has been calculated, resulting in an annual waste throughput of 182,500 tpy of MSW. This is equivalent to an average daily throughput of 500 tpd, calculated based on 365 days per year. Based on information provided by IWT, higher availability (i.e., up to 85.6%) may be achieved for the demonstration facility, which would result in a correspondingly higher throughput. However, this higher throughput would exceed the size guideline established by the City for purposes of this study (i.e., 182,500 tpy or 500 tpd for a demonstration facility). IWT's proposed demonstration facility would consist of two units, and is identical in size to the reference facility that operated for six years in Karlsruhe, Germany.

IWT	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	247,500 tpy	1,113,750 tpy
Annual Availability:	74%	85.6%
Annual Throughput:	182,500 tpy	953,370 tpy
Avg. Daily Throughput (at 365 days/yr):	500 tpd	2,612 tpd
Land Area Required:	5 acres	20 acres

IWT designated a commercial facility with an annual capacity of 1,113,750 tpy (at 365 days per year) and an availability of 85.6%, resulting in a calculated annual waste throughput of 953,370 tpy of MSW. This is equivalent to an average daily throughput of 2,612 tpd, calculated based on 365 days per year. The calculated annual throughput is less than the annual throughput indicated by IWT in its submittal to the City, which was 1,095,000 tpy (3,000 tpd). However, achieving the specified throughput would require an availability of approximately 98%, which is unreasonable considering the complexity of the technology. Based on information provided that shows IWT's three reference facilities operate at an availability of approximately 85.6%, and IWT's stated intention to operate at this availability, the waste throughput for IWT's proposed commercial facility is assumed to be the calculated value of 953,370 tpy (2,612 tpd).

IWT's proposed commercial facility would consist of nine units, all of identical size. No scale-up of unit size would be required, since the unit size for the commercial facility would match the unit size for the demonstration facility, and is a size that has already been put into commercial use. Transition from the demonstration facility to the commercial facility would ideally be achieved by building the demonstration facility on a site of sufficient size and topography to add additional processing and electricity generating modules to reach the size of the commercial facility.

6.4.3 Site Layout / Size Requirements for New York City. The total land area required for the Thermoselect technology is reported to be 5 acres for the recommended demonstration facility (182,500 tpy, 2 units) and 20 acres for the recommended commercial facility (953,370 tpy, 9 units). These land areas are supported by IWT with dimensioned equipment layouts that show approximately 1 acre is required for major equipment components for the demonstration facility, and approximately 4 acres is required for major equipment components for the commercial facility. The balance of the land would be used for other facility components and site features.

6.4.4 Mass Balance. Plantwide, the primary mass inputs to the facility are process and non-contact cooling water (45%), air (32%), MSW (14%), oxygen (8%), fossil fuels (1%), water treatment reagents (0.4%), and synthesis gas cleanup and air pollution control reagents (0.1%). Water uses at the plant include cooling of the gasification reactor, engine cooling, and synthesis gas quench and scrubbing. Air is used as a source of oxygen for the combustion in the reciprocating engines. Oxygen is used in the gasification reactor. Fossil fuel use is attributable to natural gas addition to the gasification reactor and diesel use in the reciprocating engines.

The primary mass outputs from the plant are stack gas (48%), evaporated water (44%), water in waste (6%), metals (1.3%), aggregate (0.9%), and chlorine and sulfur products (0.1%). The stack gas consists of the products of combustion from the reciprocating engines. The evaporated water results from operation of the cooling towers. The metals and the aggregate are drawn off the bottom of the gasification reactor. The chlorine product is incorporated in the mixed industrial salts product, recovered from the quench scrubber effluent during cleaning of the synthesis gas. Elemental sulfur is produced from the chelated iron sulfur-removal process, which is also operated to clean the synthesis gas. There are no process outputs that are required to be disposed of in a landfill. All solid outputs from the plant are considered to be saleable products by IWT.

IWT provided sufficient technical information to enable verification of the plantwide mass balance. Measured as process outputs divided by process inputs, IWT's mass balance achieves 102% closure, which is satisfactory considering the level of detail requested for purposes of this study. IWT also provided sufficient information to enable verification of mass balances around process subsystems. IWT's reactor mass balance achieves 97% closure on an output over input basis, and the power generating equipment achieves 100% closure.

Specific elements of IWT's mass balance are further discussed below.

6.4.4.1 Recyclables. The Thermoselect technology does not include front-end recovery of recyclable materials. All MSW, including large bulky waste, is processed through the gasifier, where it is either converted to a synthesis gas or recovered as a product. Metal that is recovered as a recyclable by certain other technologies is recovered as a product in the Thermoselect technology. Products, including metal, generated in the Thermoselect process are further discussed below.

6.4.4.2 Products. The Thermoselect technology generates electricity from the synthesis gas as well as products from all components of MSW that are not converted to a synthesis gas. Aggregate and mixed metals are generated from the melting of inorganic material in the high-temperature reactor. The aggregate is silica-based, and includes encapsulated impurities that are rendered inert. The mixed metals include iron, aluminum and copper. Industrial salts (sodium chloride, sodium fluoride and other minor salts), sulfur, and zinc hydroxide are generated during the cleaning of the synthesis gas. The products generated in the Thermoselect process are identified and quantified below.

Material	Amount (%)(1)	Amount (tpy)(2)
Aggregate	6.9%	65,297
Mixed Metals	9.1%	87,063
Mixed Industrial Salts	0.8%	7,656
Elemental Sulfur	0.2%	1,471
Zinc Hydroxide	1.0%	9,534
Total	17.0%	171,021

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 953,370 tpy.

The total quantity of products generated in the Thermoselect process amounts to approximately 17% by weight of the MSW received for processing. If IWT were unable to successfully market these products, the materials would require disposal as a residue. However, these materials are currently being marketed as products at the operating facilities in Japan, and were marketed at the Karlsruhe reference facility in Germany while that plant was in operation. For purposes of this study, and based on information provided by IWT, it is assumed that IWT would successfully find markets for these products. Based on information provided to IWT regarding the composition of the City's wastestream (see Section 3.3 of this Report) and technical information provided by IWT, the types and quantities of products are reasonable.

6.4.4.3 Residue Requiring Disposal. Based on the assumption that all products can be marketed, which is supported based on performance at existing facilities, the Thermoselect process generates no residue requiring disposal in a landfill.

6.4.4.4 Wastewater Treatment and Discharge. Thermoselect facilities are designed for zero wastewater discharge. The technology incorporates a number of conventional water treatment systems to convert process discharges to useable process and/or cooling water. Treatment systems include settling and precipitation to capture and remove solids, which are returned to the high-temperature reactor. Other treatment methods used include neutralization, ion exchange, reverse osmosis, and evaporation.

6.4.5 Energy Balance. Energy input to the Thermoselect process comes from MSW (87%) and supplemental fuel (13%). Natural gas is used as a supplemental fuel in the high-temperature gasification reactor and diesel fuel is used in the engines. Gross energy output is attributable to electricity (22%), flue gas losses (14%), and other losses (65%).

An independent analysis of IWT's energy balance was completed. Based on information provided, the plantwide energy balance achieves 104% closure on an output over input basis. This independent calculation indicates substantially all inputs and outputs have been reported by IWT, within the level of detail required for this study. IWT also provided sufficient information to enable verification of the energy balance on a subsystem basis. The reactor energy balance achieves 90% closure on an output over input basis, which indicates that some energy output of the reactor has not been accounted for. It is possible that this is energy that is used for the heating of the contents of the degasification channel that leads to the reactor. The energy balance around the power generating equipment achieves 99% closure, which is acceptable for purposes of this study.

Relevant information regarding IWT's electricity output and energy conversion efficiency is as follows:

Parameter	Performance	
Gross Electricity Generated:	772	kWh/ton of waste received
Net Electricity Generated for Sale:	493	kWh/ton of waste received
Energy Conversion Efficiency (Plant):	15%	
Energy Conversion Efficiency (Engines):	41%	(Dual-fuel, Pielstick engines)

As summarized above, a commercial plant processing 953,380 tpy of MSW is expected to generate 772 kWh of electricity per ton of waste processed. This estimate is based on information provided by the City to IWT regarding the energy composition of the MSW (i.e., assuming a heating value of 5,100 Btu/lb). IWT documented how the actual electricity generation rate would increase, should the heating value actually be higher than reported. IWT's Thermoselect process is energy intensive, requiring 279 kWh/ton of MSW to meet internal (parasitic) power needs. Considering gross generation and parasitic needs, the quantity of electricity available for export is estimated to be 493 kWh/ton of MSW.

Based on information provided by IWT, the gross energy conversion efficiency of the high-temperature gasification reactor is estimated to be 54%. This calculated conversion efficiency is based on the heat input provided by the MSW and the natural gas, versus the heat output of the cleaned synthesis gas. On a plantwide basis, the energy conversion efficiency of a Thermoselect facility of commercial scale is calculated to be approximately 15%. This energy conversion efficiency is somewhat lower than the efficiency achieved with traditional waste-to-energy technology, which generally ranges from approximately 17% to 20% (for net electrical output ranging from 500 kWh/ton to 600 kWh/ton).

IWT proposes multiple, dual-fuel Pielstick engines. Input to the engines would be 95% synthesis gas and 5% fossil fuel. The energy conversion efficiency of the engines, verified with independent calculations, is estimated by IWT to be approximately 41%. This estimated engine efficiency appears reasonable.

6.4.6 Technology Reference. IWT was requested by the City to provide a reference for the Thermoselect technology. IWT provided three of its facilities as references, but requested that communication be established through Dr. Wulf Kaiser, Thermoselect's lead engineer, primarily due to language barriers. Direct contact information was not provided for any of the facilities. Communication has been established with Dr. Kaiser, who is reportedly working to put the City in contact with the facilities. However, as of the completion of this Phase 2 Study, contact with a direct reference had not been established.

6.5 Rigel Resource Recovery and Conversion Company (Rigel)

Rigel Resource Recovery and Conversion Company (Rigel) is a project team that would engineer and build a facility based on application of the Westinghouse plasma arc gasification system. Rigel is not yet an incorporated company, but team members are located in the United States (including Baltimore, Maryland) and abroad. The Westinghouse plasma gasification system is in use processing various types of waste, including MSW and sewage sludge. Rigel's application of the Westinghouse plasma system to the processing of MSW is new, with no existing facilities that combine the system components as planned by Rigel. Rigel's application of the Westinghouse technology is unique among the thermal conversion technologies reviewed for the Phase 2 Study, in that energy generation is not limited to beneficial use of synthesis gas but is considered a significant, independent component of system design via an integrated combined cycle power plant.

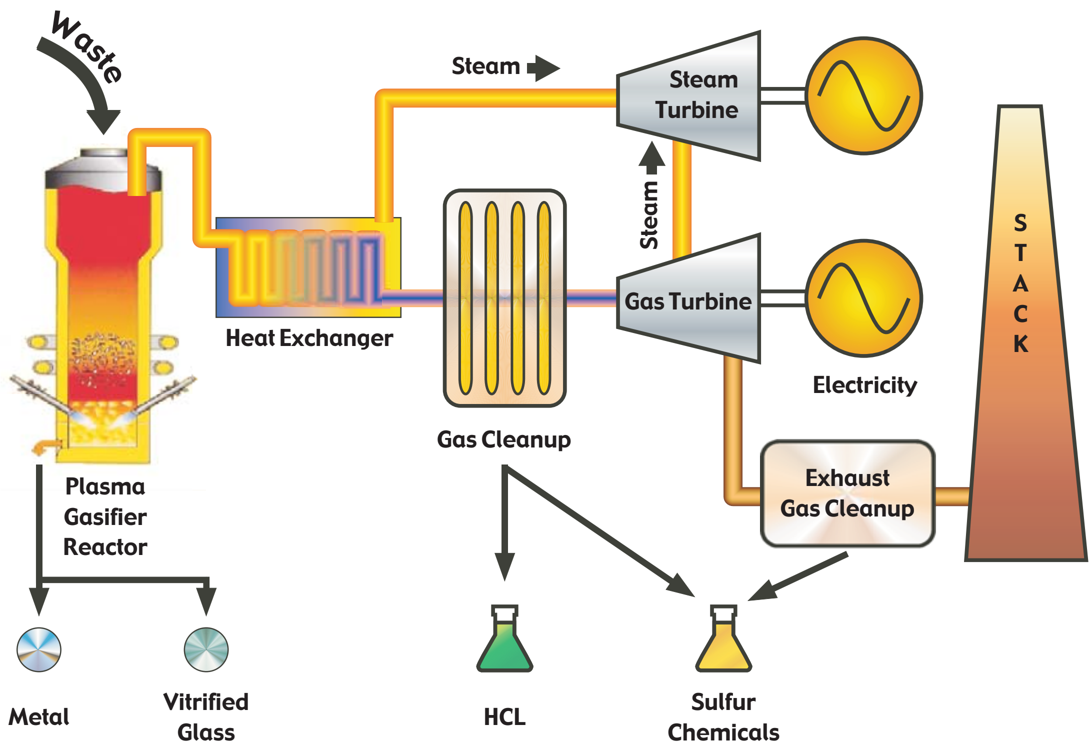
The Westinghouse plasma gasification system is commercially operational for MSW at three locations in Japan, and a pilot plant and research facility is located in Pennsylvania. The three facilities in Japan were built by Hitachi. The first plant was a pilot plant with a capacity of 5 tpd. Since then, two additional facilities have been constructed. As summarized below, Rigel's reference facility is the Hitachi plant located in Utashinai, Japan. This facility has a capacity of 100,000 tpy of MSW (274 tpd, based on 365 days per year) or 55,000 tpy of auto shredder residue. The facility has been in operation for about two years, and typically processes a combination of MSW and auto shredder residue.

Rigel Reference Facility	
Name:	Eco-Valley Utashinai Plant
Location:	Utashinai, Japan
Capacity:	100,000 tpy MSW or 55,000 tpy auto shredder residue
Type of Waste:	Mix of MSW and auto shredder residue
Owner:	Joint Venture, including Hitachi
Operator:	Eco-Valley
Commercial Operation:	in operation for approximately 2 years

6.5.1 Description of Rigel Technology. Rigel's application of the Westinghouse plasma system to the processing of MSW includes the gasification reactor and torch, synthesis gas cleanup, combustion of the cleaned synthesis gas using a General Electric combustion turbine, and addition of air pollution controls for reduction of air pollutants from the turbine. A schematic diagram of Rigel's waste conversion system is provided in Figure 6-4, and the technology is further described below.

Incoming waste is deposited on a tipping floor. Large oversized items (greater than one meter in size) are removed and shredded, then returned to storage on the tipping floor for processing. After any pre-processing, waste enters the top of the reactor and accumulates within the chamber. Plasma torches located at the bottom of the reactor generate ionized air that is between 5,000°F and 8,000°F. Because oxygen within the reactor is limited, the waste does not burn. Instead, the organic material is converted to a synthesis gas. Gas

Figure 6-4. Rigel Waste Conversion System



moves up through the accumulating waste and exits the top of the reactor, upon which it is cooled in a series of high-temperature heat exchangers. This results in the generation of steam and allows for the production of electricity in a steam turbine. After cooling, the synthesis gas is cleaned, compressed, and used in a gas turbine to generate electricity. Inorganic material present in the waste, such as metals, glass, and silica, are liquefied by the plasma torches. Other than metals, all inorganic matter becomes vitrified or molten glass. The metals and glass flow out of the bottom of the reactor, where they are quenched in a water bath. The metal and glass form into pebbles, or fragments, and are separated for sale as products.

Rigel's conversion system includes synthesis gas cleanup and preparation for feed to the combustion turbine, which is accomplished using the following equipment, listed in the sequence it is applied:

- a cyclone for particulate matter removal;
- an acid (HCl) scrubber for removal of chlorine particulate matter;
- a condenser for removal of the water in the synthesis gas;
- a wet electrostatic precipitator (WESP) for particulate matter and metals removal;

- a compressor, which incidentally removes additional water in the synthesis gas; and
- biological sulfur production for removal of sulfur and additional removal of particulate matter and metals.

The power-generating equipment used by Rigel consists of a General Electric combustion turbine, a duct burner, a heat recovery steam generator and a steam generator.

Rigel's technology is capable of processing MSW with a wide range of characteristics, along with many other types of waste. However, certain waste characteristics (i.e., moisture content and chemical analysis) will impact the tons of MSW each reactor will process, the MSW feed rate, the economics of the process, the coke and silica that have to be added to the reactor, and the quantity of syngas that will go to the turbine. Therefore, MSW composition, and particularly a chemical analysis of the MSW to be processed, is considered by Rigel to be a technology transfer issue for moving forward with project-specific development activities for New York City.

A technical review and evaluation of Rigel's plasma gasification technology follows.

6.5.2 Proposed Facility Capacity for New York City. As part of the Phase 2 Study, Rigel was requested to designate a capacity for a demonstration facility and for a commercial facility for New York City. The capacity was to be specific to the Rigel's plasma gasification technology, with size guidelines established by the City.

As summarized below, Rigel designated a demonstration facility with an annual capacity (at 365 days per year) of 182,500 tpy and an availability of 91%, resulting in an annual waste throughput of 166,000 tpy of MSW. This is equivalent to an average daily throughput of 455 tpd, calculated based on 365 days per year. Rigel designated a commercial facility with an annual capacity (at 365 days per year) of 1,095,000 tpy and an availability of 91%, resulting in an annual waste throughput of 996,000 tpy of MSW. This is equivalent to an average daily throughput of 2,729 tpd, calculated based on 365 days per year.

Rigel	Demonstration Facility	Commercial Facility
Annual Capacity (at 365 days/yr):	182,500 tpy	1,095,000 tpy
Annual Availability:	91%	91%
Annual Throughput:	166,000 tpy	996,000 tpy
Avg. Daily Throughput (at 365 days/yr):	455 tpd	2,729 tpd
Land Area Required:	8 acres	35 acres

For both the demonstration facility and the commercial facility, Rigel's planned availability of approximately 91% is at the high end of the range that would be considered reasonable for a technology of this complexity. Data was not provided for the reference facility, to demonstrate this availability could be achieved.

Rigel's demonstration facility would consist of one unit. Transition from the demonstration facility to the commercial facility would be achieved by increasing the number of units to six, without any scaling up of the unit size, and upgrading the power-plant component of the facility. Rigel expressed reservations concerning the construction of a demonstration facility, for economic reasons, and suggested moving directly to a larger-scale commercial facility on the basis that the technology has already been adequately demonstrated.

6.5.3 Site Layout / Size Requirements for New York City. The total land area required for Rigel's plasma gasification technology is 8 acres for the recommended demonstration facility (166,000 tpy) and 35 acres for the recommended commercial facility (996,000 tpy). These land areas are supported by Rigel with dimensioned site layouts, which show inclusion of required site features (i.e., waste receiving, storage and pre-processing; waste processing; power generation; air pollution control; materials storage; administrative areas; roadways and parking, and other features).

6.5.4 Mass Balance. Rigel provided extensive and detailed mass and energy balance information beyond that requested in the City's data-collection process. This facilitated a thorough review of the Rigel process.

Rigel deviated from use of the requested ultimate analysis composition and heating value for MSW, which was provided in the City's Supplemental Information Request ("SIR", see Section 3.3 of this Report). Rigel derived a new, New York City-specific, MSW composition and heating value from the detailed MSW characterization study data from the New York City Solid Waste Management Plan (2004), and from an EPA document attributing certain ultimate analysis compositions and heating values to the various individual MSW components. As a result, Rigel used a different ultimate analysis than the other technologies, and a higher heating value of 6,128 Btu per pound versus 5,100 Btu per pound as provided in the SIR. These differences affected the amount of glassy slag, metals, HCl and sulfur produced by the facility, as well as the amount of heat input due to MSW claimed. However, the data developed by Rigel to support their mass and energy balance are reasonable.

Plantwide, the primary mass inputs to the facility are air (93% - 95%), MSW (3% - 6%), and fossil fuels (1%). Air is used to generate the plasma gas for the reactor and as a source of oxygen for the combustion in the gas turbine. The fossil fuels used are coke, supplied to the reactor, and natural gas, supplied to the combustion turbine.

The primary mass outputs from the plant are stack gas (96% - 98%), evaporated water (1% - 3%), glassy slag (0.5% - 1.1%), metals (0.12%), and chlorine and sulfur products (0.03%- 0.06%). The stack gas consists of the products of combustion from the gas turbine. The evaporated water results from operation of the cooling towers when there is a net water surplus at the plant, which is the steady-state condition represented in the mass balance. The glassy slag and the metals are drawn off the bottom of the gasification reactor. The chlorine product is HCl, recovered from the HCl scrubber effluent during cleaning of the synthesis gas. Elemental sulfur is produced from the biological sulfur production process, which is also operated to clean the synthesis gas.

Rigel's plantwide mass balance achieves 100% closure, on an output over input basis.

Specific elements of Rigel's mass balance are further discussed below.

6.5.4.1 Recyclables. Rigel's technology does not include front-end recovery of recyclable materials. All MSW, including large bulky waste, is processed through the gasifier, where it is either converted to a synthesis gas or recovered as a product. Metal that is recovered as a recyclable by certain other technologies is recovered as a product in the Rigel technology. Products, including metal, are further discussed below.

6.5.4.2 Products. The plasma gasification technology generates electricity from the synthesis gas as well as products from all components of MSW that are not converted to a synthesis gas. The following products are generated:

- **Glassy Slag.** Glassy slag consists of inorganic materials that do not volatilize in the gasification process and do not separate out as mixed metals after discharge from the reactor. The slag is primarily silica based, and includes impurities that are encapsulated in the glassy material and rendered inert. Materials fed to the reactor that contain silica and contribute to the glassy slag product are MSW, coke, and silica flux (i.e., a sand-like material, used to promote vitrification of the glassy slag). In addition, particulate matter captured in the cyclone during the cleaning of the synthesis gas is fed to the reactor, to enable encapsulation of the particulate within the slag. This "recycle stream" of particulate matter is not included in the Rigel mass balance, and as a consequence, the quantity of glassy slag product generated may be estimated by Rigel to be slightly lower than would be estimated if the recycle stream were accounted for.

- **Mixed Metals.** The mixed metals product consists of a relatively homogenous mixture containing metals such as iron, aluminum and copper.

- **Hydrochloric Acid.** Hydrochloric acid (HCl) is recovered from removal of chlorine by the air pollution control system. HCl is recovered as a product in an aqueous solution, which may be concentrated.

- **Elemental Sulfur.** Elemental sulfur is a product of the removal of sulfur from the synthesis gas using a biological process.

- **Air Pollution Control Metals.** The air pollution control metals are a product that is not specifically accounted for by Rigel. This product is syngas particulate, with concentrated metals, which is collected by filtration from the effluents from the HCl scrubber and the wet electrostatic precipitator. Analysis of the mass balance information provided by Rigel indicates that up to 2.75% of the MSW input could result in this product. The result of this analysis was confirmed by Rigel.

As quantified below, products generated in the Rigel gasification process amount to approximately 23% by weight of the MSW received for processing. If Rigel were unable to successfully market these products, the materials would require disposal as a residue. For purposes of this study, and based on information provided by Rigel and other thermal gasification companies, it is assumed that Rigel would successfully find markets for these products.

Material	**Amount (%)[(1)]**	**Amount (tpy)[(2)]**
Glassy Slag	13.3%	131,970
Mixed Metals	3.5%	35,278
Hydrochloric Acid	3.3%	32,499
Elemental Sulfur	0.2%	1,650
Air Pollution Control Metals	2.7%	27,390
Total	23.0%	228,787

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 996,000 tpy.

6.5.4.3 Residue Requiring Disposal. Based on the assumption that all products can be marketed, the Rigel plasma gasification process generates no residue requiring disposal in a landfill.

6.5.4.4 Wastewater Treatment and Discharge. Rigel's plasma gasification technology is designed for zero wastewater discharge. Therefore, there is no treatment system for sewerable wastewater. However, there are a number of water treatment systems at the plant to convert discharges from processes to useable process and/or cooling water. The details of these internally operating systems were not disclosed.

6.5.5 Energy Balance. On an energy basis, the plantwide input for the commercial facility designated by Rigel is 63% as MSW and 37% as fossil fuel. Gross energy output, amounting to 5,777 kWh of electricity and kWh thermal energy per ton of MSW, is attributable 40% to electricity, 5% to flue gas, and 55% to other losses. The gross electricity output is stated to be 2,308 kWh per ton of incoming MSW. Electricity use is the primary parasitic demand of the plant and is stated to be used at a rate of 17 kWh per ton of MSW, leaving 2,291 kWh per ton of MSW for net export. The energy conversion efficiency of the commercial plant has been independently estimated to be 37%, compared to Rigel's claim of 40%. The difference appears to be attributable to a difference in the heating values used for the fossil fuels.

Rigel’s plantwide energy balance achieves 100% to 104% closure on an output over input basis. This slight deviation from 100% closure is not consequential at the level of detail available at this stage of information gathering.

In comparison to traditional waste-to-energy, the energy conversion efficiency of the Rigel technology is significantly higher. Traditional waste-to-energy conversion efficiency ranges approximately from 17% to 20%. The energy conversion efficiency of the Rigel commercial plant is estimated at 37% to 40%.

Relevant information regarding Rigel's electricity output and energy conversion efficiency is as follows:

Parameter	**Performance**	
Gross Electricity Generated:	2,308	kWh/ton of waste received
Net Electricity Generated for Sale:	2,291	kWh/ton of waste received
Energy Conversion Efficiency (Plant):	37%	
Energy Conversion Efficiency (Engines):	50%	

6.4.6 Technology Reference. Efforts were initiated to contact references for the Hitachi facilities in Japan, but contact was not made at the time the Phase 2 Study was completed. Difficulties in making contact with references is attributed to the fact that Rigel is not an owner or licensee of the Westinghouse technology.

7.0 ENVIRONMENTAL EVALUATION

7.1 Overview of Environmental Evaluation

As part of the Phase 2 Study, a review and evaluation of the environmental performance of anaerobic digestion and thermal technologies was completed. The evaluation focused on the following environmental issues:

- Air pollutant emissions (combustion pollutants, acid gases, dioxin and mercury, and greenhouse gases)
- Water usage
- Wastewater discharge
- Solid waste requiring landfill disposal
- Product quality

For each of the environmental indicators listed above, the environmental performance for the various conversion technologies has been inter-compared, and compared with modern waste-to-energy (WTE) facilities as a benchmark. WTE has been selected as a benchmark because it is the technology used most today, in the United States, to reduce the quantity of waste landfilled, and results in the recovery of energy and certain materials (e.g., ferrous metal). Modern WTE facilities are those that use good combustion practices and add-on emission control devices (e.g., precipitators, baghouses, scrubbers, NOx control, carbon injection) to meet regulatory standards and permit conditions.

To enable these evaluations, the City solicited and reviewed environmental performance data from the companies participating in the Phase 2 Study. In addition, details of environmental performance were elicited from the companies in one-on-one meetings. Finally, independent assessments of expected environmental performance were undertaken as a due diligence effort.

To enable benchmarking of the conversion technologies against WTE facilities, the typical ranges of environmental performance for WTE facilities were characterized by considering both the minimum performance levels required by regulatory standards and the typically-better actual performance levels normally achieved.

Table 7-1 and the text that follows the table provide a summary of environmental performance, including inter-comparison of the conversion technologies and benchmarking against modern WTE technology. More detailed review follows in Sections 7.2 through 7.6.

Table 7-1. Summary of Environmental Performance: Inter-comparison of the Conversion Technologies and Benchmarking against Waste-to-Energy

	ANAEROBIC DIGESTION TECHNOLOGIES		THERMAL CONVERSION TECHNOLOGIES			
	ArrowBio	**WRSI**	**Ebara**	**GEM**	**IWT**	**Rigel**
AIR POLLUTANT EMISSIONS						
▪ Combustion Pollutants						
Particulate Matter (PM)	↑↑	↑↑	□	□	□	□
Carbon Monoxide (CO)	□	□	↑	↑	↑↑	↑↑
Nitrogen Oxides (NOx)	↓	↓	↑	↑	↑	↑
▪ *Acid Gases (SO_2+HCl)*	↑	↑	↑↑	↑↑	↑↑	↑↑
▪ Toxic Air Pollutants						
Dioxin	↑↑	↑↑	↑	↑	↑	↑
Mercury	↑↑	↑↑	□	□	□	□
▪ Greenhouse Gases	↓	↓	□	□	□	↑
WATER USAGE	↑↑	↑↑	No Rating (Insufficient Data)		□	↑
WASTEWATER DISCHARGE	↓	↓	↓	□	□	□
WASTE REQUIRING LANDFILLING	↑	□	↑	□	↑↑	↑↑

Very Advantageous ↑↑ Advantageous ↑ Neutral □ Disadvantageous ↓ Very Disadvantageous ↓↓

The conclusion of the environmental evaluation is that in general, anaerobic digestion and thermal processing technologies are shown to offer better environmental performance than conventional WTE facilities. In comparing anaerobic digestion technologies with thermal processing technologies, neither can clearly claim superior environmental performance overall. Each technology category has strengths and weaknesses relative to the other. Some of the more important environmental performance differences identified in this Phase 2 Study are briefly discussed below.

Anaerobic Digestion

Air Pollutant Emissions. The sponsors of the anaerobic digestion technologies do not report emissions estimates for dioxin or mercury, and it is likely that combustion of digester biogas does not generate significant emission levels of either pollutant (see Section 7.2.3). By comparison, small emissions of both dioxin and mercury do result from the thermal processing technologies and WTE facilities. Having lower emissions of toxic air pollutants is an advantage for the anaerobic digestion technologies.

The anaerobic digestion technologies have higher emissions of nitrogen oxides (NOx) associated with the combustion of biogas than the thermal processing technologies, when the emissions are stated in units of pounds of NOx emitted per ton of MSW received. NOx emissions are an element in forming smog. The NOx emissions from combustion of biogas are higher than from WTE facilities as well. The higher emissions of NOx for the anaerobic digestion technologies result from the particular equipment they most commonly use to convert biogas to electric energy (a reciprocating engine, without NOx emission control). Those engines are well-known to emit higher levels of NOx compared with other types of fuel combustion equipment. Although engine selection may be a factor in reducing NOx emissions, in general, higher NOx emissions are a disadvantage for the anaerobic digestion technologies.

The anaerobic digestion technologies reduce greenhouse gas emissions because the electric energy generated by combusting the digester biogas displaces energy now generated with fossil fuels. However, greater greenhouse gas reductions are provided by the thermal processing technologies and also by WTE facilities. This is because both the thermal processing technologies and WTE facilities convert a greater portion of the fuel value of MSW to energy that displaces fossil-fuel energy generation.

Water Usage. Anaerobic digestion technologies require little to no fresh water for process operations, which is advantageous compared to the thermal processing technologies and WTE facilities.

Wastewater Discharge. Anaerobic digestion technologies have either a zero discharge of process wastewater, or a small discharge. Most thermal processing technologies and WTE facilities have zero discharge as a design objective. For those anaerobic digestion technologies having a small discharge of process wastewater, the associated environmental disadvantage would not be significant.

Solid Waste Requiring Landfill Disposal. The amount of disposable solid waste resulting from the anaerobic digestion technologies varies, but for the technologies reviewed the amount of residue is less than or similar to the quantities of the disposable ash residue generated by WTE facilities. This is environmentally disadvantageous, relative to the thermal processing technologies that generate no disposable solid waste (assuming the products can be marketed), or much smaller quantities of disposable solid waste. In addition, should the compost product of anaerobic digestion not find markets (or not meet local permitting standards for beneficial use) and require landfilling, then the amount of material requiring landfill disposal would exceed amounts generated by WTE.

Thermal Processing Technologies

Air Pollutant Emissions. The thermal processing technologies have emissions of NOx, CO, and acid gases that are lower than emissions from combusting biogas generated by the anaerobic digestion technologies and also lower than emissions from WTE facilities. The lower NOx emissions for the thermal technologies are advantageous, given the significance of NOx emissions in smog formation.

While emissions of dioxin from the thermal processing technologies appear to be at least ten times less than the well-controlled emission levels from WTE facilities, the level of mercury emissions from the thermal processing technologies remains somewhat uncertain. It appears that the mercury emission levels from the thermal processing technologies may be on a par with the controlled emissions from WTE facilities. Lower dioxin emissions for the thermal processing technologies is an advantage compared with WTE facilities. The thermal processing technologies reduce greenhouse gas emissions because the electric energy they generate displaces fossil fuel generation. The thermal technologies provide generally about the same degree of greenhouse gas reduction as do WTE facilities. This is because both the thermal technologies and WTE facilities convert most of the fuel value of MSW to energy that displaces fossil-fuel energy generation. The thermal processing technologies and WTE facilities are similarly advantageous in providing reductions in greenhouse gas emissions.

One gasification technology reviewed for the Phase 2 Study uses energy generation equipment that is particularly efficient (a combined-cycle gas combustion turbine). Accordingly, that particular technology provides a greater reduction in greenhouse gas emissions than the other thermal technologies and WTE facilities.

Water Usage. For the thermal processing technologies, the amount of process water required varies by technology sponsor, and ranges from being substantially less than required by WTE facilities, to being of similar magnitude. Again, by comparison, anaerobic digestion technologies require little to no fresh water input for process usage.

Wastewater Discharge. The thermal processing technologies are generally zero discharge for process wastewater, as is typical for WTE facilities. However, one of the thermal technologies included in the Phase 2 Study does have a small discharge of process wastewater. The thermal technologies and WTE facilities, both typically zero-discharge, have a small environmental advantage regarding wastewater discharge over the anaerobic digestion technologies, for which some technologies have a very small discharge.

Solid Waste Requiring Landfill Disposal. The thermal processing technologies generate substantially less solid waste requiring landfill disposal than do the anaerobic digestion technologies and WTE facilities, which is a significant environmental advantage. Even if markets do not materialize for the products, thermal technologies would still offer the greatest diversion of waste from landfill disposal of all the conversion technologies and WTE facilities.

7.2 Air Emissions

Anaerobic digestion and thermal conversion technologies, as well as WTE facilities, emit air pollutants in various amounts and of different environmental significance. For anaerobic digestion and thermal technologies, air emissions are primarily associated with exhaust gases from the combustion of the biogas and synthesis gas generated from the organic fraction of MSW. In comparison, emissions from WTE facilities are associated with stack gases from the direct combustion of MSW. For purposes of this study, air pollutants have been grouped into four general classes, and key indicator pollutants have been identified within each class:

- ***Standard combustion pollutants*** emitted when any fuel (including MSW, or gas produced from MSW) is combusted. These standard combustion pollutants include particulate matter (PM), nitrogen oxides (NOx), and carbon monoxide (CO).

- ***Acid gases*** that can be emitted when MSW, or gas produced from it, are combusted. These include sulfur dioxide (SO_2) and hydrogen chloride (HCl).

- The ***toxic air pollutants*** of greatest public concern, deriving from historical controversy over such emissions from WTE facilities. These pollutants are dioxin and mercury.

- ***Greenhouse gas emissions***, principally carbon dioxide (CO_2), but also including methane and nitrous oxide. Emissions of CO_2 are most commonly associated with combustion of fossil fuel (coal, oil, natural gas). Methane emissions are associated principally with landfills and also with agriculture. Nitrous oxides result from fuel combustion and also from land-application of nitrogen-bearing fertilizers and composts.

Companies that participated in the Phase 2 Study were requested to provide detailed air-emissions information of specific types and in specified formats, including supporting documentation such as permit information and test data. Information was elicited through written data requests, and also during one-on-one meetings and follow-up telephone and email correspondence with the individual companies. Several participating companies were able to supply a good fraction of the extensive data requested, while others were able to provide some of the requested information. In a few cases, relevant data was provided, but not of the types requested. Overall, technical documentation was sparse for the emissions data that was provided, making it difficult to independently verify the data. The wide variation in the quantity and quality of emissions data that the participating companies supplied reflects the facts that (1) these technologies have no commercial operating experience in the U.S., and differing degrees of commercial operating experience abroad, and (2) the environmental performance requirements in Europe, the Mideast and Asia, where the operating experience exists, are different from those in the U.S.

Where possible, the emission levels provided for the anaerobic digestion and thermal technologies have been presented and inter-compared in this Report, and the emissions for these conversion technologies have been compared with emissions from modern, WTE facilities. Some informative conclusions have been reached based on quantitative comparisons, while many conclusions have been drawn based on qualitative comparisons of emissions. The emissions data supplied for some technologies was intended to reflect typical emission levels based on actual emissions tests, while for other technologies, the emissions data were engineering estimates, intended to represent maximum (not-to-exceed) emission levels. It would be technically inappropriate to compare typical emissions from one technology with maximum emissions for another.

It would be reasonable to ask, “what are the air emissions standards to which conversion technologies will be held, and will the technologies be able to meet those standards?” There are existing emission standards that will apply legally to all of the technologies, but typically, the technologies will have to meet even stricter emission limits that are imposed during the air permitting process. Those stricter limits must reflect the most stringent emissions-control methods available at the time of permitting for the particular technology being permitted. The emissions limits that will be imposed are not known. Importantly, however, based on review of the expected air emissions from the technologies and knowledge of available control methods and permitting procedures in New York State, there is no technological or regulatory reason why any of the conversion technologies could not acquire needed air quality permits. While applicable emission standards (permit limits) are presently unknown, there is sufficient information on hand to enable the expected actual emission levels of air pollutants to be estimated for the conversion technologies, assuming anticipated emission controls, as applicable. Therefore, this evaluation of air emissions has been based on comparing the expected actual emissions.

Discussions follow regarding the air pollutant emissions from the conversion technologies – the combustion-related pollutants, acid gases, dioxin and mercury, and greenhouse gases.

7.2.1 Standard Combustion Pollutants (PM, CO, NOx)

Particulate Matter (PM)

Anaerobic digestion and thermal processing technologies, as well as WTE facilities, have small emissions of particulate matter associated with combustion of the biogas, syngas, or MSW, as applicable (see Table 7-2).

Table 7-2. Particulate Matter Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Requested but Not Provided	No Add-On Controls Post-Combustion	Not Applicable	Engine mfg. test data.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Requested but Not Provided	No Add-On Controls Post-Combustion	Not Applicable	Requested but not provided.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	58 [(a)] 24-hr avg.	Fabric Filter and Wet Scrubber 99.8%	0.12 [(b)] 24-hr avg.	Local (Japanese) permit limits.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	No Add-On Controls Post-Combustion	Not Applicable	Some raw concentration data from stack testing were provided.
IWT (thermal gasification)	Dual Fuel Reciprocating Engine, Syngas plus Diesel Fuel	0.047 [(b), (c)]	No Add-On Controls Post-Combustion	Not Applicable	Engine test data using syngas and diesel fuel.
Rigel (plasma gasification)	Combustion Turbine, Syngas plus Natural Gas Fuel	0.12 [(c), (d)]	No Add-On Controls Post-Combustion	Not Applicable	Mass balance using estimated carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	Not Applicable	Not Specified	0.19 [(e), (f)] (24 mg/dscm @ 7%O_2 or 0.01 gr/dscf @7%O_2) filterable, 1-hr avg.	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III, Subchapter A Subpart 219-2	Not Applicable	Not Specified	0.19 [(e), (f)] (0.01 gr/dscf @7%O_2) filterable,1-hr avg.	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (gas & diesel fueled)	US EPA AP-42 Table 3.4-1 (10/1996)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	IWT
4-Stroke Lean Burn Engine (gas fueled)	US EPA AP-42 Table 3.2-2 (7/2000)	0.00017 – 0.00020 filterable, 1-hr avg. [(g), (h)] 0.022 – 0.025 condensable, 1-hr avg.[(g, (h)]	No Add-On Controls Post-Combustion	Not Applicable	GEM (syngas fuel); Arrow and WRSI (biogas fuel)
Combustion Turbine (gas fueled)	US EPA AP-42 Table 3.1-1 (4/2000)	0.028 filterable, 1-hr avg. [(i)] 0.069 condensable, 1-hr avg. [(i)]	No Add-On Controls Post-Combustion	Not Applicable	Rigel

(a) Ebara used 16% ash in MSW as provided in the RFI. This is equivalent to approximately 323 lb ash/ton MSW a.r., as stated on Form 8 by Ebara. Ebara stated that the gasifier removal rate of ash is 82%, leaving 58 lb ash / ton MSW a.r. leaving the gasifier as unvitrified flyash.

(b) As provided by vendor.

(c) Averaging period requested but not specified, assumed 1-hr.

(d) ARI estimated based on Rigel mass balance statement for the commercial plant given 14.58 lb PM/hr and 125 tons/hr of MSW input.

(e) ARI estimated based on regulatory limit of 0.01 gr/dscf @ 7%O2 and assumed HHV and F-Factor.

(f) Assumed HHV of MSW of 4,500 Btu/lb, USEPA Method 19 F-Factor of 9,570 dscf/MMBtu at 0% oxygen.

(g) Based on emission factors of 9.91E-3 lb/MMBtu condensable PM and 7.71E-5 lb/MMBtu filterable PM, depending on engine load conditions.

(h) Based on ARI derived estimates of biogas production from Arrow of 2.57 MMBtu/ton MSW a.r. and WRSI of 2.19 MMBtu/ton MSW a.r. Arrow's biogas production rate was derived by ARI from Arrow's data showing 210 lb biogas/ton MSW a.r. at a higher heating value of 740 Btu/scf, and an ARI derived molecular weight of the biogas of 23.00 lb/lbmol given Arrow's stated gas composition. WRSI's biogas production rate was derived by ARI from OWS's data showing 300 lb biogas/ton MSW a.r. at a higher heating value of 550 Btu/scf, and an ARI derived molecular weight of the biogas of 28.60 lb/lbmol given OWS's stated gas composition.

(i) Based on an emission factor of 0.0047 lb/MMBtu condensable PM and 0.0019 lb/MMBtu filterable PM; and Rigel heat input rates (HHV) to the combustion turbine of 8.395 MMBtu/ton MSW a.r. due to syngas and 6.203 MMBtu/ton MSW a.r. due to natural gas for the commercial facility (total fuel heat input 14.60 MMBtu/ton MSW a.r.)

The thermal processing technologies and WTE facilities require efficient control methods to achieve small emission levels of PM; the anaerobic digestion technologies have small emissions without the need for emission controls. Comparatively, PM emissions from the thermal processing technologies appear similar to emissions from WTE facilities. PM emissions from anaerobic digestion technologies should be less than for thermal processing technologies and less than from WTE facilities.

With the thermal processing technologies, significant amounts of PM can be generated during the production of syngas. In addition, a comparatively minor amount of PM is also generated when the gas is burned as a fuel.

Most of the thermal technologies remove the PM from the syngas prior to gas combustion (GEM, IWT, Rigel). In that case, PM is normally cleaned from the gas using wet-scrubbing techniques, and in some cases, using additional methods such as a wet electrostatic precipitator. One thermal technology (Ebara) does not clean PM from the gas prior to gas combustion. Rather, it cleans the PM from the flue gas which results from gas combustion. PM control in that case is accomplished with a fabric filter and a wet scrubber.

With traditional WTE facilities, the process of combusting a solid fuel (MSW) results in substantial quantities of PM being generated and caught up with the combustion gases. For modern WTE facilities, control of PM emissions is accomplished using a fabric filter after the combustion process.

With the anaerobic digestion technologies, the process of digesting MSW produces a biogas fuel. Unlike thermal technologies that have a high flow of gas through the process and "carry out" PM, the biological process of digestion does not impart any significant amount of PM to the biogas that is produced. Emissions of PM are created, however, when the biogas is subsequently combusted as a fuel to produce energy.

No PM emissions data were supplied by the anaerobic digestion technology companies. Theoretically, it would be expected that PM emissions from combustion of biogas from anaerobic digestion would be lower than emissions from either the thermal processing technologies or WTE. This is because (1) no significant carry-out of PM from the digestion process would be expected (unlike with the other processes), and (2) anaerobic digesters convert a much lower fraction of the MSW processed to fuel gas than do thermal processing technologies or WTE facilities (there is less gas to combust), since digestion converts only the biodegradable, organic fraction of MSW to a fuel gas while gasification converts potentially all organic constituents to a fuel gas.

Regarding the thermal conversion technologies, dissimilarities in the form and quality of the PM emission data supplied by the various sponsors make explicit inter-comparisons difficult. However, the PM emissions levels supplied by three of the thermal processing technologies (Ebara, IWT, Rigel) appear to be roughly comparable (approximately 0.1 pounds of PM emitted per ton of MSW processed). In addition, the PM emissions from the thermal technologies appear to be about the same as the levels emitted by WTE facilities (< 0.2 pounds of PM per ton of MSW).

Carbon Monoxide (CO)

Emissions of carbon monoxide result from combustion of fuels, including combustion of the syngas produced by thermal technologies and combustion of the biogas produced by anaerobic digesters. CO also results from the combustion of MSW at WTE facilities. In addition, CO can be formed during gasification, when the carbon present in MSW is not fully oxidized to carbon dioxide during the gasification process (see Table 7-3).

Emissions of CO from the combustion of digester biogas are expected to be high, relative to emissions from the thermal technologies, and about the same as CO emissions from WTE facilities. Regulators may require add-on CO emission controls for a project in New York City, but would do so only if such controls are technically feasible. CO emission controls are expected to be feasible for the thermal technologies, and in fact, are already proposed by most of the companies as described below. For the anaerobic digestion technologies, the technical feasibility of CO control methods for biogas combustion is uncertain, and none of companies proposed such controls as part of this Phase 2 Study. While CO control methods might be feasible for WTE facilities, such controls may require significant modifications to conventional facility designs, and have not been implemented to date in the U.S.

There are technical uncertainties with the CO emissions data supplied by the anaerobic digestion companies. All the digestion technologies plan to combust the biogas in a standard, reciprocating engine to generate electric power (with no add-on emissions controls for CO). The CO emissions levels provided by the anaerobic digestion companies vary, and are significantly greater or smaller than emissions estimated by independent calculations. Based on the independent calculations, the estimated, uncontrolled emission rate for CO is roughly 1 lb per ton of MSW processed. This is about the same emission rate as for modern WTE facilities (typically, 0.2 to 1 lb per ton of MSW processed), which also operate in the U.S. without add-on CO emission controls. The CO emissions from combustion of digester biogas are similar to WTE emissions, despite the fact that anaerobic digestion converts much less of the fuel value of MSW to energy than do WTE facilities. The high CO emissions for combustion of digester biogas result from the fact that the technology normally used to generate energy from digester biogas (reciprocating engines, without CO emission control) has high CO emission characteristics.

Table 7-3. Carbon Monoxide Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	65 (a), (b), (m)	No Add-On Controls	Not Applicable	Engine mfg. test data.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	0.0012 (a), (b), (m)	No Add-On Controls	Not Applicable	Requested but not provided.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	0.25 (a) 24-hr avg.	No Add-On Controls	Not Applicable	Local (Japanese) permit limits.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	Thermal Oxidizer	Requested but Not Provided	Some raw concentration data from stack testing were provided.
IWT (thermal gasification)	Dual Fuel Reciprocating Engine, Syngas plus Diesel Fuel	Requested but Not Provided	Unspecified catalytic controls – no percent removal given.	0.035 (a) 24-hr avg.	Engine test data using syngas and diesel fuel, with APC percent removal applied by calculation.
Rigel (plasma gasification)	Combustion Turbine, Syngas plus Natural Gas Fuel	0.22 (b), (c)	May use SCONOX – ARI assumes 90%	0.022 (b), (d)	Combustion turbine test data.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	0.94 (e), (f) (100 ppmdv @ 7%O_2) 4-hr avg.	No Add-On Controls	Not Applicable	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III,Subchapter A Subpart 219-2	Combustion Index Monitoring (g) 99.9% 8-hr avg. 99.95% 7-day avg.	No Add-On Controls	Not Applicable	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (gas & diesel fueled)	US EPA AP-42 Table 3.4-1 (10/1996)	7.53 (h)	Oxidation Catalyst or 3-Way Catalyst May Be Feasible ARI Assumes 90%	0.75	IWT
4-Stroke Lean Burn Engine (gas fueled)	US EPA AP-42 Table 3.2-2 (7/2000)	0.69 – 1.43 (i), (j)	Oxidation Catalyst 70% - 90% (likely feasible for syngas fuel but not feasible for biogas fuel)	0.14 – 0.29(k)	GEM (syngas fuel); Arrow and WRSI (biogas fuel)
Combustion Turbine (gas fueled)	US EPA AP-42 Table 3.1-1 (4/2000)	0.22 (l)	Oxidation Catalyst or SCONOX ARI Assumes 90%	0.022	Rigel

Table 7-3, Continued. Carbon Monoxide Emission Rates

(a) As provided by vendor.

(b) Averaging period requested but not specified.

(c) ARI estimated based on Rigel mass balance statement for the commercial plant given 27.68 lb CO/hr and 125 tons/hr of MSW input.

(d) Rigel provided conflicting information in the submittal. The mass balance cited Selective Catalytic Reduction (SCR) as the combustion turbine control technology and did not take credit for control of CO. Elsewhere in the application, Rigel noted that SCONOX would be used, which controls both NOx and CO. ARI estimated a nominal control efficiency for SCONOX and applied it to Rigel's uncontrolled CO number to estimated a controlled emission rate.

(e) ARI estimated based on regulatory limit of 100 ppmdv @ 7%O2 and assumed HHV and F-Factor.

(f) Assumed HHV of MSW of 4,500 Btu/lb, USEPA Method 19 F-Factor of 9,570 dscf/MMBtu at 0% oxygen.

(g) New York State regulations do not set a concentration limit for CO similar to the Federal limit. Instead, monitored levels of CO are incorporated into a combustion index (CI) formula where CI = (CO_2 x 100) / (CO_2 + CO), where CO_2 and CO are concentrations in ppmdv.

(h) Based on an emission factor of 1.16 lb/MMBtu and IWT heat input rates (HHV) to the engine of 6.14 MMBtu/ton MSW a.r. due to syngas and 0.35 MMBtu/ton MSW a.r. due to diesel (total fuel heat input 6.49 MMBtu/ton MSW a.r.).

(i) Based on emission factors ranging from 0.317 to 0.557 lb/MMBtu, depending on engine load conditions.

(j) Based on ARI derived estimates of biogas production from Arrow of 2.57 MMBtu/ton MSW a.r. and WRSI of 2.19 MMBtu/ton MSW a.r. Arrow's biogas production rate was derived by ARI from Arrow's data showing 210 lb biogas/ton MSW a.r. at a higher heating value of 740 Btu/scf, and an ARI derived molecular weight of the biogas of 23.00 lb/lbmol given Arrow's stated gas composition. WRSI's biogas production rate was derived by ARI from OWS's data showing 300 lb biogas/ton MSW a.r. at a higher heating value of 550 Btu/scf, and an ARI derived molecular weight of the biogas of 28.60 lb/lbmol given OWS's stated gas composition.

(k) Assumed 80% (average) level of control.

(l) Based on an emission factor of 0.015 lb/MMBtu and Rigel heat input rates (HHV) to the combustion turbine of 8.395 MMBtu/ton MSW a.r. due to syngas and 6.203 MMBtu/ton MSW a.r. due to natural gas for the commercial facility (total fuel heat input 14.60 MMBtu/ton MSW a.r.)

(m) Data presented as reported by vendor, but inconsistent with independent calculations.

The CO emissions data supplied for the thermal technologies indicated emission levels of approximately 0.2 to 0.3 lb CO per ton of MSW processed, without add-on emission control. Again, by comparison, uncontrolled emissions of CO from modern WTE facilities are typically in the range of 0.2 to 1 lb per ton of MSW processed. Uncontrolled CO emissions for thermal technologies are slightly lower than for WTE facilities, likely because the combustion efficiency is inherently higher for combustion of gaseous fuels than solid fuels. There is less opportunity for CO and other products of incomplete combustion to form with gaseous fuel combustion.

It is possible that for a demonstration project in New York City, CO emission rates lower than the uncontrolled emission rates indicated above may be sought by State permitting authorities. If so, a catalytic control device could be applied to the thermal processing technologies as an add-on control method to achieve those emission reductions. In fact, two of the thermal technologies (IWT, Rigel) currently propose catalytic-control methods for their CO emissions. GEM indicates it plans to use a different, but similarly effective method to control CO emissions – a thermal oxidizer (i.e., an afterburner). Based on the limited data supplied, the thermal conversion technologies could achieve controlled CO emissions of roughly 0.03 lb CO per ton of MSW processed, a full order-of-magnitude lower than WTE emissions of 0.2 to 1 lb per ton (which are not controlled in the U.S.).

For the anaerobic digestion technologies, it is uncertain whether a CO catalytic control device would be required for the combustion of biogas, because the CO control devices may not be feasible for this type of technology. Gas from digestion of MSW contains trace amounts of compounds called siloxanes. Based on independent discussions with the vendors of catalytic control devices, there is a significant technical concern, specifically with digester gas combustion, that the siloxanes could impede the operation of the catalytic control devices used to abate emissions of CO (and, as noted below, also nitrogen oxides). Technologies exist to remove siloxanes from the gas prior to combustion, but removal efficienies may not be sufficient and may be costly. Accordingly, for the anaerobic digestion technologies only, there is presently considerable doubt that add-on control devices could be applied to reduce emissions of CO and NOx associated with combustion of biogas. This notwithstanding, the anaerobic digestion technologies can likely be permitted without the controls, if the control methods are clearly shown to be infeasible. That is, regulators normally issue permits without requiring emission control, in circumstances where the available control methods are demonstrated to be infeasible.

Nitrogen Oxides (NOx)

As with CO, nitrogen oxide (NOx) emissions result from combustion of fuels, including combustion of the syngas produced by thermal technologies, combustion of biogas prducted by anaerobic digesters, and combustion of MSW at WTE facilities (see Table 7-4). Regulators can be expected to impose strict limits on NOx emissions. This is because the New York City Metropolitan Region does not comply with Federal ambient air standards for ozone (smog), and NOx emissions contribute to the formation of smog.

Table 7-4. Nitrogen Oxides Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	50 (a), (b), (k)	No Add-On Controls	Not Applicable	Engine mfg. test data.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	0.016 (a), (b), (k)	No Add-On Controls	Not Applicable	Requested but not provided.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	Requested but Not Provided	Selective Catalytic Reduction (SCR)	0.49 (a) 24-hr avg.	Local (Japanese) permit limits.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	Requested but Not Provided	Requested but Not Provided	Some raw concentration data from stack testing were provided.
IWT (thermal gasification)	Dual Fuel Reciprocating Engine, Syngas plus Diesel Fuel	Requested but Not Provided	Unspecified catalytic controls – no percent removal given.	0.0012 (a), (b)	Engine test data using syngas and diesel fuel, with APC percent removal applied by calculation.
Rigel (plasma gasification)	Combustion Turbine, Syngas plus Natural Gas Fuel	1.23 (c), (b)	SCR or SCONOX – Vendor assumes 75%	0.31 (b), (d)	Combustion turbine test data.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	4.64 (e), (f) (300 ppmdv @ 7%O_2) 24-hr avg.	Selective Non-Catalytic Reduction (SNCR) 50%	2.32 (e), (f) (150 ppmdv @ 7%O_2) 24-hr avg.	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III, Subchapter A Subpart 219-2	Not Applicable	Lowest Achievable Emission Rate (LAER) Pct. Removal Unspecified	Must be determined via the permitting process.	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (gas & diesel fueled)	US EPA AP-42 Table 3.4-1 (10/1996)	17.52 (g)	SCR or 3-Way Catalyst May Be Feasible ARI Assumes 90%	1.75	IWT
4-Stroke Lean Burn Engine (gas fueled)	US EPA AP-42 Table 3.2-2 (7/2000)	1.86 – 10.47 (h), (i)	SCR 90% (likely feasible for syngas fuel but not feasible for biogas fuel)	0.19 – 1.05	GEM (syngas fuel); Arrow and WRSI (biogas fuel)
Combustion Turbine (gas fueled)	US EPA AP-42 Table 3.1-1 (4/2000)	1.45 (j)	SCR or SCONOX ARI Assumes 75%	0.36	Rigel

Table 7-4, Continued. Nitrogen Oxide Emission Rates

(a) As provided by vendor.

(b) Averaging period requested but not specified.

(c) ARI estimated based on Rigel mass balance statement for the commercial plant given 39 lb NOx/hr and 125 tons/hr of MSW input.

(d) Rigel provided conflicting information in the submittal. The mass balance cited Selective Catalytic Reduction (SCR) as the combustion turbine control technology and took credit for 75% control of NOx. Elsewhere in the application, Rigel noted that SCONOX would be used, which controls both NOx and CO.

(e) ARI estimated controlled emissions based on regulatory limit of 150 ppmdv @ 7%O2 and assumed HHV and F-Factor. Uncontrolled emissions are based on nominal 50% control for 300 ppmdv @ 7%O_2.

(f) Assumed HHV of MSW of 4,500 Btu/lb, USEPA Method 19 F-Factor of 9,570 dscf/MMBtu at 0% oxygen.

(g) Based on an emission factor of 2.7 lb/MMBtu and IWT heat input rates (HHV) to the engine of 6.14 MMBtu/ton MSW a.r. due to syngas and 0.35 MMBtu/ton MSW a.r. due to diesel (total fuel heat input 6.49 MMBtu/ton MSW a.r.).

(h) Based on emission factors ranging from 0.847 to 4.08 lb/MMBtu, depending on engine load conditions.

(i) Based on ARI derived estimates of biogas production from Arrow of 2.57 MMBtu/ton MSW a.r. and WRSI of 2.19 MMBtu/ton MSW a.r. Arrow's biogas production rate was derived by ARI from Arrow's data showing 210 lb biogas/ton MSW a.r. at a higher heating value of 740 Btu/scf, and an ARI derived molecular weight of the biogas of 23.00 lb/lbmol given Arrow's stated gas composition. WRSI's biogas production rate was derived by ARI from OWS's data showing 300 lb biogas/ton MSW a.r. at a higher heating value of 550 Btu/scf, and an ARI derived molecular weight of the biogas of 28.60 lb/lbmol given OWS's stated gas composition.

(j) Based on an emission factor of 0.099 lb/MMBtu and Rigel heat input rates (HHV) to the combustion turbine of 8.395 MMBtu/ton MSW a.r. due to syngas and 6.203 MMBtu/ton MSW a.r. due to natural gas for the commercial facility (total fuel heat input 14.60 MMBtu/ton MSW a.r.)

(k) Data presented as reported by vendor, but inconsistent with independent calculations.

Based on analyses conducted, NOx emissions from the thermal technologies appear to be substantially less than from WTE facilities. Based on independent calculations, NOx emissions from the anaerobic digestion technologies (reciprocating engine, without NOx control) are expected to be higher than the controlled NOx emissions from the thermal technologies by a factor of ten, and slightly higher than controlled emissions from WTE facilities. The energy generation equipment used by the anaerobic digestion technologies inherently generates more NOx emissions than gasifiers or WTE facilities, and, as noted above, NOx control technologies (i.e., catalytic control devices) are not likely to be feasible and, therefore, not likely required for anaerobic digestion.

As with CO, there are technical uncertainties with the NOx emissions data supplied by the anaerobic digestion technologies. The NOx emission levels vary, and are significantly greater or smaller than emissions estimated by independent calculations. Based on the independent calculations, the uncontrolled emission rate for NOx associated with combustion of biogas is estimated to be approximately 2 to 10 lb per ton of MSW processed. This is higher than the emission rate for modern WTE facilities, which are required to use NOx emission controls and typically achieve levels of 1 to 2 lb per ton of MSW processed. The NOx emissions from anaerobic digestion technologies are higher than from the thermal technologies, despite the fact that anaerobic digestion converts much less of the fuel value of MSW to energy than does thermal processing. As with CO, the high NOx emissions for anaerobic digestion result from the fact that the technology normally used to generate energy from digester biogas (reciprocating engines, without NOx emission control) has inherently high NOx emissions characteristics.

For the thermal technologies, there was generally insufficient emissions data supplied to determine with certainty that any one of the technologies inherently generates lower uncontrolled NOx emissions than any other, or less NOx than WTE facilities. The one exception is the Rigel gasification technology, which likely has lower generation of uncontrolled NOx emissions than WTE facilities. Rigel supplied detailed NOx emissions data, which indicate that the Rigel technology generates uncontrolled NOx at a rate of approximately 1 pound NOx per ton of MSW processed. This is lower than the uncontrolled NOx generation rate for modern WTE facilities, typically at 2 to 4 pounds of uncontrolled NOx per ton of MSW processed. This observation of lower NOx generation for Rigel is not surprising given that the energy generation technology used by Rigel is a gas combustion turbine. Gas-combustion turbines inherently generate less NOx than combustion of solid fuels in boilers, such as the MSW combustion boilers used at WTE facilities.

Three thermal technology sponsors (Ebara, IWT, Rigel) plan to use the top level of NOx control, which is catalytic reduction (e.g., SCR or SCONOx). No information on NOx emission control was supplied by one of the sponsors (GEM). The controlled emission rate of NOx for the thermal technologies is expected to be < 0.5 pounds NOx per ton of MSW processed. This is less than the typical controlled emission rate for WTE facilities in the U.S. of 1 to 2 pounds per ton of MSW processed. The thermal technologies have lower controlled emissions of NOx because they plan to use a NOx control method (catalytic reduction) that is more effective than the non-catalytic control technique used historically at WTE facilities in the U.S.

The NOx control technique planned by the thermal technology suppliers (catalytic reduction, e.g., SCR) is used on WTE facilities abroad, but not to date in the U.S., owing to some lingering concerns over technical reliability and costs. The thermal conversion technologies would appear to offer an advantage over traditional WTE as regards add-on NOx emissions control. The thermal conversion technologies produce a gas that is free of trace compounds known to interfere with the ability of SCR to control NOx emissions. Such catalyst-fouling agents are found in the flue gas produced by WTE plants. In addition at WTE facilities, re-heating of the flue gas, at considerable cost, is required to operate SCR. Flue gas re-heat would generally not be needed for SCR operation with the thermal conversion technologies. This means that NOx control via SCR would likely be more effective, more reliable, and substantially less expensive with the thermal conversion technologies than with a traditional WTE facility.

7.2.2 Acid Gases (SO_2 and HCl)

The thermal conversion technologies, as well as traditional WTE facilities, operate at very high temperatures. Because of this, most of the chlorine and sulfur compounds present in the MSW are converted to gaseous forms, and are ultimately emitted as hydrogen chloride (HCl) and sulfur dioxide (SO_2), respectively. Both pollutants contribute to acid gas emissions. Unlike the high-temperature thermal technologies, the biological process of anaerobic digestion would convert a much smaller amount of chlorine and sulfur compounds to gaseous forms, and would have lower emissions of HCl and SO_2 associated with combustion of biogas (see Tables 7-5 and 7-6).

The uncontrolled emissions of both HCl and SO_2 from the thermal conversion technologies are significant, and require control. The same is true for modern WTE facilities. Emissions of acid gases from the anaerobic digestion technologies are likely not large enough to warrant control. While there are differences in the acid-gas emission levels among the technology classes – uncontrolled emissions from anaerobic digestion technologies, and controlled emissions from the thermal technologies and WTE facilities – the emission levels in all cases are very small. The environmental significance of those emissions differences is likely to be very minor.

Only limited SO_2 and HCl emissions information was supplied by the anaerobic digestion companies. Independent calculations of acid gas emissions from the combustion of biogas indicate that the uncontrolled acid-gas emissions from anaerobic digestion technologies may be in the range of 0.06 to 0.5 pounds of acid gas per ton of MSW processed. That *uncontrolled* emission of acid gas from the anaerobic digestion technologies would be roughly similar to the *controlled* emissions from thermal technologies. Based on data reviewed, the thermal conversion technologies have controlled emissions in the range of 0.01 to 0.1 pound of acid gas emitted per ton of MSW. Regarding WTE facilities, the regulatory maximum emission allowed is 0.9 pounds of acid gas per ton of MSW processed (actual emissions are less).

Table 7-5. Normalized[(a)] Hydrogen Chloride Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Process Feed Inputs[(b)] (lb HCl/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Stack Emissions (lb HCl/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Chlorine in Biogas Fuel	Not Requested [(c)]	No Biogas Scrubbing Specified	Not Requested [(c)]	Not applicable.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Chlorine in Biogas Fuel	Not Requested [(c)]	No Biogas Scrubbing Specified	Not Requested [(c)]	Not applicable.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	2.06 [(d)]	Diatomaceous Earth Injection, Fabric Filter & Wet (Caustic) Scrubber 98.5%	0.031 [(d)] 24-hr avg. (arithmetic or geometric mean not specified)	Local (Japanese) permit limits.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	H2S Removal from Syngas Using Unspecified Technology Removal Eff. Not Stated	Requested but Not Provided	Some raw concentration data provided.
IWT (thermal gasification)	Chlorine in MSW Inputs to the Gasification Reactors plus Chlorine in Diesel Inputs to Dual Fuel Engines	2.06 [(d)]	Wet Scrubbers & Acid Scrubber (Syngas Cleanup) 99.5%	0.0010 [(e), (f), (g)] 24-hr avg. (arithmetic or geometric mean not specified)	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
Rigel (plasma gasification)	Chlorine in MSW and Coke Inputs to the Gasification Reactors	2.06 [(e), (h)]	Cyclone & HCl Scrubber (Syngas Cleanup) 99%	0.021 [(e), (i), (j)]	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Process Feed Inputs[(b)] (lb HCl/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Stack Emissions (lb HCl/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	2.06 [(k), (l)]	Spray Dryer Absorber & Fabric Filter 95% [(m)]	0.10 [(n)] (25 ppmdv @ 7%O_2)[(m)] 24-hr geometric mean	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III,Subchapter A Subpart 219-2	2.06 [(k), (l)]	Spray Dryer Absorber & Fabric Filter 90% [(o)]	0.21[(p)] (50 ppmdv @ 7%O_2) [(o)] 8-hr average	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (syngas & diesel fueled)	Mass Balance with IWT Syngas Chlorine Content and 15 ppmw Cl Diesel	2.06 [(f), (l)]	IWT Nominal Scrubber Removal of 99.5%	0.0010 [(f), (q)]	IWT
4-Stroke Lean Burn Engine (biogas fueled)	Mass Balance with Anaerobic Digestion Biogas Chlorine Content	Data Not Available	No Add-On Controls Post-Combustion	Data Not Available	Arrow and WRSI (biogas fuel) (Comparability of GEM to this benchmark cannot be assessed)
Combustion Turbine (syngas & NG fueled)	Mass Balance with Rigel Syngas Chlorine Content	2.06 [(h)]	Nominal Scrubbing Removal of >99%	0.021 [(e), (r)]	Rigel

(a) MSW content of chlorine normalized to RFI specification of 0.1%, equivalent to 2 lb Cl/ton MSW or 2.06 lb HCl/ton MSW.

(b) Quantity of HCl in process feed is based on vendor input in terms of chlorine content, using a conversion factor of 1.03. Statement of inputs in terms of HCl makes comparison of removal efficiencies among the technologies easier to review.

(c) ARI did not request HCl emissions data from the anaerobic digestion technology providers due to the nature of the process.

(d) As provided by vendor.

(e) Contribution due to natural gas introduction into the syngas reactor (IWT) or supplemental combined cycle fueling (Rigel) has been considered to have an insignificant impact on stack emissions of HCl relative to the other process chlorine inputs.

(f) IWT apparently assumes the chlorine content of diesel is negligible.

(g) IWT supplied estimate stated as 0.0096 lb HCl/ton MSW a.r.

(h) Based on Rigel mass balance for the commercial scale plant. MSW input is normalized by ARI to 2 lb Cl/ton MSW or 2.06 lb HCl/ton MSW (Rigel used 0.72% Cl in MSW, equivalent to 14.38 lb Cl/ton MSW, rather than 0.1% Cl, equivalent to 2 lb Cl/ton MSW). Coke chlorine input is not accounted for by Rigel.

(i) Averaging period requested but not specified, assumed 1-hr.

(j) Derived by application of 99% Rigel nominal HCl scrubber removal of chlorine from the syngas to the ARI normalized input to the syngas reactors of 2.06 lb HCl/ton MSW.

(k) Federal and State regulations do not presume a particular chlorine input for MSW combusted in a mass burn boiler.

(l) For normalizing purposes, ARI assumes input to be equivalent to the other technologies shown for comparison. That is, the chlorine content of the MSW is assumed to be 2 lb Cl/ton MSW or 2.06 lb HCl/ton MSW.

(m) The Federal regulation currently allows a dual standard of 95% control or 25 ppmdv at 7%O2 (24-hr geometric mean), whichever is less stringent.

(n) Equivalent to 95% control of ARI assumed (normalized) MSW chlorine input. The 25 ppmdv at 7%O2 alternate standard yields a lower emission rate that 0.10 lb HCl/ton MSW.

(o) The State regulation currently allows a dual standard of 90% control or 50 ppmdv at 7%O2 (8-hr average), whichever is less stringent.

(p) Equivalent to 90% control of ARI assumed (normalized) MSW chlorine input. The 50 ppmdv at 7%O2 alternate standard yields a lower emission rate that 0.20 lb HCl/ton MSW.

(q) IWT estimated using wet scrubbing and acid scrubbing removal process given a nominal removal efficiency of 99.5%. When applied to the syngas chlorine content, this results in a contribution to the stack emissions of 0.0010 lb HCl/ton MSW.

(r) Rigel estimated using cyclone and HCl scrubbing removal process given a nominal removal efficiency of 99%.

Table 7-6. Normalized[(a)] Sulfur Dioxide Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Process Feed Inputs[(b)] (lb SO_2/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Stack Emissions (lb SO_2/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Sulfur in Biogas Fuel	0.058 [(c), (d)]	No Biogas Scrubbing Specified	0.058 [(c), (d)]	ARI estimated based on biogas production rate and Arrow upper bound concentration of H2S in biogas.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Sulfur in Biogas Fuel	0.20 [(e)]	No Biogas Scrubbing Specified	0.20 [(e)]	EPA AP-42.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	~4.00 [(f)]	Diatomaceous Earth Injection, Fabric Filter & Wet Scrubber 97.8%[(f)]	0.089 [(f)] 24-hr avg. (arithmetic or geometric mean not specified)	Local (Japanese) permit limits.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	H2S Removal from Syngas Using Unspecified Technology	Requested but Not Provided	Some raw concentration data provided.
IWT (thermal gasification)	Sulfur in MSW Inputs to the Gasification Reactors plus Sulfur in Diesel Inputs to Dual Fuel Engines	4.00 from MSW [(f)] (will be controlled) 0.002 from diesel[(h)] (will be uncontrolled)	Chelated Iron Sulfur Removal (Syngas Cleanup of H2S) 99.7%	0.014 [(f), (g)] 24-hr avg. (arithmetic or geometric mean not specified)	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup, plus sulfur from diesel input to engines.
Rigel (plasma gasification)	Sulfur in MSW and Coke Inputs to the Gasification Reactors	5.68 [(g), (i)]	Biological Sulfur Production (Syngas Cleanup of H2S) 99.5%	0.028 [(g), (j), (k)]	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Process Feed Inputs[(b)] (lb SO_2/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Stack Emissions (lb SO_2/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	4.00 [(l), (m)]	Spray Dryer Absorber & Fabric Filter 80% [(n)]	0.80 [(o)] (29 ppmdv @ 7%O_2)[(n)] 24-hr geometric mean	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III, Subchapter A Subpart 219-2	Not Pertinent	Spray Dryer Absorber & Fabric Filter Removal% Not Defined	As permitted, site specifically, to meet Ambient Air Quality Standards	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (syngas & diesel fueled)	Mass Balance with IWT Syngas Sulfur Content and 15 ppmw S Diesel	4.00 from MSW [(m)] 0.0005 from diesel [(p)]	Nominal Chelated Iron S Removal of >99.9%	0.0045 [(g), (q)]	IWT
4-Stroke Lean Burn Engine (biogas fueled)	Mass Balance with Anaerobic Digestion Biogas Sulfur Content	0.058 – 0.54 [(d), (r)]	No Add-On Controls Post-Combustion	0.058 – 0.54 [(d), (r)]	Arrow and WRSI (biogas fuel) (Comparability of GEM to this benchmark cannot be assessed)
Combustion Turbine (syngas & NG fueled)	Mass Balance with Rigel Syngas Sulfur Content	5.68 [(i)]	Nominal Biological S Removal of >99.5%	0.028 [(g), (s)]	Rigel

Table 7-6, Continued. Normalized Sulfur Dioxide Emission Rates

(a) MSW content of sulfur normalized to RFI specification of 0.1%, equivalent to 2 lb S/ton MSW or 4 lb SO_2/ton MSW.

(b) Quantity of SO_2 in process feed is based on vendor input in terms of sulfur content, using a conversion factor of 2. Statement of inputs in terms of SO_2 makes comparison of removal efficiencies among the technologies easier to review.

(c) Calculated by ARI based on Arrow supplied data of <100 ppm H_2S in biogas and biogas production rate of 3,467 scf per ton of MSW.

(d) Biogas standard conditions were assumed by ARI to be 1 atmosphere and 60 degrees F (US standard conditions for pipeline natural gas). No scrubbing of the biogas is applied and there are no add-on SO_2 removal controls post combustion in the engine, therefore, mass input to the engine equals mass output from the engine.

(e) Estimated by WRSI using AP-42 (general reference). The AP-42 approach for engines is a mass balance with no controls for sulfur emissions, therefore, the WRSI estimate is assumed to be based on the H_2S concentration of the biogas and the biogas production rate per ton of MSW input to the process.

(f) As provided by vendor.

(g) Contribution due to natural gas introduction into the syngas reactor (IWT) or supplemental combined cycle fueling (Rigel) has been considered to have an insignificant impact on stack emissions of SO_2 relative to the other process sulfur inputs.

(h) ARI backcalculated the IWT sulfur contribution of the diesel fuel given 0.014 lb SO_2/ ton MSW at the stack. The cleaned syngas would contribute 4 lb SO_2/ton MSW, but 99.7% control is applied, resulting in only 0.012 lb SO_2/ton MSW at the stack. ARI thus deduces that IWT added 0.002 lb SO_2/ton MSW input due to the sulfur in the diesel, which is uncontrolled.

(i) Based on Rigel mass balance for the commercial scale plant. MSW input is normalized by ARI to 2 lb S/ton MSW or 4 lb SO_2/ton MSW (Rigel used 0.16% S in MSW, equivalent to 3.2 lb S/ton MSW, rather than 0.1% S, equivalent to 2 lb S/ton MSW). Coke sulfur input is as stated by Rigel at 0.88% of coke input. Approximately 6 tons per hour of coke, contributing 105 lb S/hr (equivalent to 0.84 lb S/ton MSW or 1.68 lb SO_2/ton MSW), are added to the reactor concurrent with 125 tons per hour of MSW.

(j) Averaging period requested but not specified, assumed 1-hr.

(k) Derived by application of 99.5% Rigel *estimated actual* biological sulfur production removal of sulfur from the syngas to the ARI normalized input to the syngas reactors of 5.68 lb SO_2/ton MSW. Rigel also provided a *nominal* biological sulfur production removal of sulfur from the syngas of 95%, which is a conservative representation comparable to a regulatory or permit limit.

(l) Federal regulations do not presume a particular sulfur input for MSW combusted in a mass burn boiler.

(m) For normalizing purposes, ARI assumes input to be equivalent to the other technologies shown for comparison. That is, the sulfur content of the MSW is assumed to be 2 lb S/ton MSW or 4 lb SO_2/ton MSW.

(n) The Federal regulation currently allows a dual standard of 80% control or 29 ppmdv at 7%O_2, whichever is less stringent.

(o) Equivalent to 80% control of ARI assumed (normalized) MSW sulfur input. The 29 ppmdv at 7%O_2 alternate standard yields a lower emission rate that 0.80 lb SO_2/ton MSW.

(p) ARI estimated based on 17.5 lb diesel per ton MSW (given by IWT in their mass balance), and use of Ultra Low Sulfur diesel (15 ppmw S).

(q) ARI estimated using chelated sulfur removal process given a vendor published H_2S removal efficiency of >99.9%. When applied to the syngas sulfur content, this results in a contribution to the stack emissions of 0.004 lb SO_2/ton MSW. The diesel emissions will be uncontrolled, for a contribution of 0.0005 lb SO_2 per ton MSW.

(r) Calculated by ARI based on anaerobic digestion vendor supplied estimates of H_2S content of the biogas ranging from <100 ppmv (Arrow) to 800 ppmv (OWS), and biogas production rates ranging from 3,467 scf per ton MSW received at the plant to 3,983 scf per ton MSW received at the plant.

(s) ARI estimated using biological sulfur removal process given a vendor published H_2S removal efficiency of >99.5%.

The acid gas emission levels can be summarized as follows for comparison:

Technology	Acid Gas Emission (lb per ton of MSW processed)
Anaerobic Digestion	0.06 to 0.5 (emitted uncontrolled)
Thermal Conversion	0.01 to 0.1 (controlled)
WTE Facilities	< 0.9 – regulatory maximum (controlled)

Comparing the above emission levels, the acid gas emissions from the thermal conversion technologies are the lowest, with emissions from the anaerobic digestion technologies a little higher, and emissions from WTE facilities a little higher still.

Sufficient acid gas emissions data were provided by three of the thermal conversion companies (Ebara, IWT, Rigel) to enable inter-comparison and comparison with the regulatory maximum emission levels allowed for WTE facilities. The emissions data are summarized in Table 7-7. Consistent with the information used for this Phase 2 Study regarding the characteristics and composition of the City's MSW, the emissions for the thermal technologies are all normalized based on the assumption that the City's MSW has sulfur and chlorine contents of 0.1% each. Emissions are given in units of pounds of pollutant emitted per ton of MSW processed.

From the data presented in Table 7-7, it is apparent that all the thermal conversion technologies, as well as WTE facilities, control their acid gas emissions with very high efficiency, resulting in small acid-gas emissions in all cases. The acid gas control techniques used by the thermal conversion technologies achieve higher control efficiencies than the control technique used on WTE facilities in the U.S. Accordingly, the acid gas emissions (SO_2 and HCl, combined) from the thermal technologies will generally be a little lower than from WTE facilities.

Table 7-7. Acid Gas Emissions from the Thermal Conversion Technologies (SO_2 and HCl)

Technology	Sulfur Dioxide (SO_2) Emissions			Hydrogen Chloride (HCl) Emissions		
	Uncontrolled (lb SO_2 / ton MSW)	Controlled (lb SO_2 / ton MSW)	Control Efficiency	Uncontrolled (lb HCl / ton MSW)	Controlled (lb HCl / ton MSW)	Control Efficiency
Ebara	4	0.09	98% (wet scrubbing of sulfur from flue gas)	2	0.03	99% (wet scrubbing of chlorine from flue gas)
IWT	4	0.01	99+% (iron chelation of syngas sulfur)	2	0.01	99% (wet scrubbing of chlorine from syngas)
Rigel	6	0.03	99+% (biological removal of syngas sulfur)	2	0.02	99% (wet scrubbing of chlorine from syngas)
WTE	4	< 0.8	> 80% (dry scrubbing of sulfur from flue gas)	2	< 0.1	> 95% (dry scrubbing of chlorine from flue gas)

7.2.3 Dioxin and Mercury

Dioxin

Dioxin is the term often used to collectively describe a large number of chemical species making up the dioxin and furan families of compounds. Dioxin emissions from all of the conversion technologies, as well as from modern WTE facilities, are expected to be very small. As further described below, dioxin emissions from anaerobic digestion technologies are likely to be small (without add-on control), and those emission levels are likely to be lower than dioxin emissions from the thermal conversion technologies. The dioxin emissions from both types of conversion technologies appear to be lower than from WTE facilities (see Table 7-8).

Popular concern over dioxin emissions originated with controversy over emissions from first-generation WTE facilities in the U.S. Dioxin can form when a carbon-containing fuel that also contains chlorine (e.g., MSW) is combusted. Oxygen must be present at a critical stage for dioxin formation to occur. In addition, the presence of trace levels of certain metals (e.g., copper) in the fuel being combusted (or in the flue gas) can markedly increase the formation of dioxin. Dioxin formation is low when the combustion efficiency is high; i.e., dioxin formation is low when combustion takes place at a very high temperature, and that high temperature is maintained uniformly throughout the combustion zone. Conversely, excessive levels of dioxin can result when pockets of incomplete combustion develop within the combustion zone; i.e., pockets where the combustion temperature is markedly low. In general, it is more difficult to maintain a high combustion efficiency when combusting a solid fuel (e.g., MSW itself, as for WTE facilities) than when combusting a gaseous fuel (e.g., gas made from MSW, such as biogas for anaerobic digestion technologies and syngas for thermal technologies). Accordingly, combusting a gaseous fuel would generally present a lower potential for dioxin formation than combusting a solid fuel, all other factors being the same.

WTE facilities are historically noted for their potential to generate dioxin emissions. This is because they combust a fuel – MSW – that contains the requisite carbon, chlorine, and trace metals to produce dioxin. As a solid-fuel combustor, the potential for pockets of incomplete combustion with WTE facilities is higher than for gaseous fuel combustors. While these factors mean that high dioxin levels can be *generated* at WTE facilities, control methods applied at modern WTE facilities are very effective in reducing the actual dioxin *emissions* to small levels. Those control methods at modern WTE facilities include maintaining optimal combustion efficiency, cooling the flue gas to suppress dioxin formation and to remove dioxin via condensation, and injecting carbon into the flue gas to further remove dioxin via adsorption.

Table 7-8. Dioxin/Furan Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Not Requested [(a)]	No Add-On Controls Post-Combustion	Not Applicable	Not requested.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Not Requested [(a)]	No Add-On Controls Post-Combustion	Not Applicable	Not requested.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	No Add-On Controls Post Combustion	Not Applicable	Some raw concentration data from stack testing were provided.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	Requested but Not Provided	Diatomaceous Earth Injection, Fabric Filter & Wet Scrubber Removal % Not Stated	6.70×10^{-13} [(b)] ITEQ, 24-hr avg.	European Union Directive 2000/76/EC limitation.
IWT (thermal gasification)	Dual Fuel Reciprocating Engine, Syngas plus Diesel Fuel	1.94×10^{-13} [(b), (c)] ITEQ	No Add-On Controls Post Combustion	Not Applicable	Appears to be based on test data – verification needed.
Rigel (plasma gasification)	Combustion Turbine, Syngas plus Natural Gas Fuel	1.67×10^{-11} [(c), (d)] ITEQ or Total Mass Basis (basis not identified)	No Add-On Controls Post Combustion	Not Applicable	Basis requested but not provided.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Uncontrolled Emissions (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	No Data Available	Carbon Injection Removal % Not Stated	1.62×10^{-9} [(e), (f)] ITEQ, 1-hr avg. (13 ng/dscm @ 7%O_2 Total Mass Basis)	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III, Subchapter A Subpart 219-2	No Data Available	Carbon Injection Removal % Not Stated	1.62×10^{-9} [(f), (g)] ITEQ, 1-hr avg. (0.2 ng/dscm @ 7%O_2 ITEQ Basis)	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (gas & diesel fueled)	US EPA AP-42 Table 3.4-1 (10/1996)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	IWT
4-Stroke Lean Burn Engine (gas fueled)	US EPA AP-42 Table 3.2-2 (7/2000)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	GEM (syngas fuel); Arrow and WRSI (biogas fuel)
Combustion Turbine (gas fueled)	US EPA AP-42 Table 3.1-1 (4/2000)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	Rigel

Table 7-8, Continued. Dioxin/Furan Emission Rates

(a) ARI did not request D/F emissions data from the anaerobic digestion technology providers due to the nature of the process.

(b) As provided by vendor.

(c) Averaging period requested but not specified, assumed 1-hr.

(d) ARI estimated based on Rigel stated concentration of 0.00067 nanograms per dry std. cubic meter @ 12% O_2 (~2.93E-13 gr/dscf @ 12%O_2) and ARI estimated stack exhaust flow rate for the commercial plant of 49,953,674 dscf @ 12%O_2. Rigel stated concentration is not specified as either ITEQ or total mass. The ARI estimate of the exhaust flow rate is based on Rigel mass rates for stack gas constituents (totaling 4,010,712 lb/hr for the commercial plant). Rigel defines the predominate constituents of the stack gas at approximately 11.10% O_2, 75.04% N_2, 6.33% H_2O, 0.90% Ar, and 6.63% CO_2, on a wet, volumetric basis.

(e) ARI estimated based on regulatory limit of 13 nanograms per dry std. cubic meter (~5.68E-9 gr/dscf @ 7%O_2), on a total mass basis, and assumed HHV and F-Factor. Per 60 FR 65396 (December 19, 1995) the equivalent to 13 ng/dscm @7%O_2, total mass basis, is estimated to be 0.1 – 0.3 ng/dscm @ 7%O_2, ITEQ basis, or 0.2 ng/dscm @ 7%O_2 (~8.74E-11 gr/dscf @ 7%O_2) on average.

(f) Assumed HHV of MSW of 4,500 Btu/lb, USEPA Method 19 F-Factor of 9,570 dscf/MMBtu at 0% oxygen.

(g) ARI estimated based on regulatory limit of 0.2 nanograms per dry std. cubic meter (~8.74E-11 gr/dscf @ 7%O_2), ITEQ basis, and assumed HHV and F-Factor.

Dioxin emissions data were not supplied by the anaerobic digestion companies, likely because such data do not exist. There has never been a concern for potential dioxin emissions with the combustion of biogas from anaerobic digestion facilities. Likewise, the small levels of dioxin resulting from the combustion of MSW landfill gas, which is similar to biogas from anaerobic digestion, have never been considered significant in the U.S. The biogas from the digesters does not likely contain dioxin, because the biological processes that produce the gas from MSW do not create dioxin. When the biogas is combusted to generate energy, it is unlikely that dioxin is produced in significant amounts. This is because the biogas is not expected to contain significant amounts of chlorine and certain organic compounds that are precursors to dioxin formation, and because a high combustion efficiency can readily be maintained with combustion of a gaseous fuel.

The thermal conversion technologies would be expected to have a lower potential than WTE facilities to generate dioxin emissions. This is because much less oxygen is needed in the process than is required for MSW combustion at WTE facilities. One of the thermal technologies evaluated (GEM) is a pyrolysis process that uses near-zero oxygen in converting MSW to gas; thus, that particular technology should theoretically not generate dioxin emissions. The thermal conversion technologies generally do not appear to require add-on control methods, directed specifically at dioxin. The low-oxygen characteristics of thermal conversion processes, as well as a very high operating temperature, likely explain the inherently low dioxin emissions profile for these technologies.

In addition to emission rates summarized in Table 7-8, the dioxin emission levels for the thermal conversion technologies are presented in Table 7-9 for inter-comparison and for comparison with emissions from modern WTE facilities as a benchmark.

Table 7-9. Dioxin Emissions from the Thermal Conversion Technologies

Technology	Dioxin Emission (ITEQ) (Billionth of a pound of dioxin per ton MSW processed)
Ebara	0.001
IWT	0.0001
Rigel	0.01
GEM	Data not furnished in requested units.
WTE	0.1 to 1

ITEQ = Toxic Equivalent Emissions of Dioxins/Furans, International Protocol

The dioxin emissions from the thermal conversion technologies, as well as WTE emissions, are all at very small levels. That said, the emission levels from the thermal conversion technologies are distinctly less than from WTE facilities, by at least a factor of ten. In inter-comparing the dioxin emission levels for the thermal technologies, one should not infer that the emission levels would necessarily differ, despite the data in the table suggesting such differences. This is because the technology sponsors used differing technical bases to develop their emission estimates (i.e., calculated estimates, test results, regulatory limits).

The reasons that the dioxin emissions from the thermal conversion technologies are less than from WTE facilities may possibly be explained by the following factors:

- The thermal conversion technologies produce a syngas or fuel gas in an oxygen-starved environment and in one case (GEM), in a near-zero-oxygen environment. The oxygen needed to generate dioxin is less available in these processes, compared with WTE facilities. Some thermal conversion technologies also operate at a very high temperature and this breaks down dioxins that may have formed.

- Combustion of syngas or fuel gas to produce energy achieves a higher combustion efficiency than combusting a solid fuel such as MSW; this minimizes the opportunity for dioxin production.

- Unlike MSW combustion in WTE facilities, the combustion of syngas or fuel gas generated from MSW does not produce significant amounts of carbon-containing fly ash that can act as a dioxin precursor. Also with combustion of the syngas or fuel gas, fewer trace metals are likely to be present in the combustion flue gas (than with WTE facilities). This means less opportunity for metals to act as a catalyst to promote dioxin formation in the flue gas.

Mercury

No significant mercury emissions are expected from the anaerobic digestion technologies. There remains uncertainty regarding the emissions of mercury from the thermal conversion technologies, compared with mercury emissions from WTE facilities. It presently appears that mercury emissions from thermal conversion technologies and from WTE facilities may be similar, with efficient control methods being necessary for both technology types (see Table 7-10).

The biogas produced by the anaerobic digesters is generally assumed not to contain significant quantities of mercury. This is because the biological processing of MSW that produces the gas does not generate enough heat to volatilize a significant amount of the mercury present in the MSW. Given no significant mercury expected in the biogas, there would not be a significant mercury emission resulting when the biogas is combusted as a fuel to produce energy. If the mercury present in MSW does not volatilize into the biogas, then that mercury must reside in the compost product (and/or in process wastewater discharges).

Table 7-10. Mercury Emission Rates

CONVERSION TECHNOLOGIES					
Vendor and Technology	**Pollutant Source**	**Process Feed Inputs (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Basis of Emission Rate**
Arrow (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Not Requested [a]	No Add-On Controls Post-Combustion	Not Applicable	Not requested.
WRSI (anaerobic digestion)	4-Stroke Spark Ignited Engine, Biogas Fuel	Not Requested [a]	No Add-On Controls Post-Combustion	Not Applicable	Not requested.
Ebara (gasification & vitrification)	Combustion Stage of Gasifier, MSW Fuel	Requested but Not Provided	Diatomaceous Earth Injection, Fabric Filter & Wet Scrubber Removal % Not Stated	Requested but Not Provided	Vendor stated Hg emissions as MSW input dependent and therefore did not provide data.
GEM (pyrolysis)	4-Stroke Spark Ignited Engine, Syngas Fuel	Requested but Not Provided	Reactor and Syngas Cleanup 100%	Requested but Not Provided	Some raw concentration data were provided.
IWT (thermal gasification)	Dual Fuel Reciprocating Engine, Syngas plus Diesel Fuel	0.00068 [b], [c]	Syngas Cleanup [d] 87%	0.000079 [b], [c]	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
Rigel (plasma gasification)	Combustion Turbine, Syngas plus Natural Gas Fuel	0.20 [b], [e]	Syngas Cleanup [f] 99.82%	0.00036 [b], [g]	Mass balance using 100% carryover from syngas reactor and nominal APC removal efficiencies for syngas cleanup.
BENCHMARK TECHNOLOGIES					
Technology	**Reference**	**Process Feed Inputs (lb/ton MSW a.r.)**	**Add-On Control Technology and Percent Removal**	**Controlled Emissions (lb/ton MSW a.r.)**	**Vendors of Comparable Conversion Technologies**
Waste-to-Energy (Mass Burn)	Federal Regulation 40 CFR 60 Subpart Eb Large, New MWC	No Data Available	Carbon Injection 85% [h]	0.00065 [h], [i] (0.08 mg/dscm @ 7%O_2 or 3.5E-5 gr/dscf @7%O_2) 1-hr avg.	All vendors for comparative purposes. Ebara as comparable technology.
Waste-to-Energy (Municipal & Private Solid Waste Combustion Facilities)	NY State Regulation Chapter III, Subchapter A Subpart 219-2	No Data Available	Carbon Injection 85% [j]	0.00023 [i], [j] (0.028 mg/dscm @ 7%O_2 or 1.2E-5 gr/dscf @7%O_2) 1-hr avg.	All vendors for comparative purposes. Ebara as comparable technology.
Dual Fuel Reciprocating Engine (gas & diesel fueled)	US EPA AP-42 Table 3.4-1 (10/1996)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	IWT
4-Stroke Lean Burn Engine (gas fueled)	US EPA AP-42 Table 3.2-2 (7/2000)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	GEM (syngas fuel); Arrow and WRSI (biogas fuel)
Combustion Turbine (gas fueled)	US EPA AP-42 Table 3.1-1 (4/2000)	No Data Available	No Add-On Controls Post-Combustion	Not Applicable	Rigel

(a) ARI did not request Hg emissions data from the anaerobic digestion technology providers due to the nature of the process.

(b) Averaging period requested but not specified, assumed 1-hr.

(c) As provided by vendor.

(d) IWT syngas cleanup consists of quench, packed-bed alkali scrubber, packed-bed wet scrubber, sulfur scrubber and gas dryer, which results in an overall removal efficiency of 87%. Individual syngas cleanup removal efficiencies are not stated.

(e) ARI estimated based on Rigel mass balance statement for the commercial plant given 25 lb Hg/hr and 125 tons/hr of MSW input.

(f) Rigel syngas cleanup consists of cyclone (10%), HCl scrubber (90%), wet electrostatic precipitator (95%), and biological sulfur production (60%). The cumulative, overall control efficiency which results from these individual control efficiencies is 99.82%.

(g) ARI estimated based on Rigel mass balance statement for the commercial plant given 0.045 lb Hg/hr and 125 tons/hr of MSW input.

(h) ARI estimated based on regulatory limit of 80 micrograms per dry std. cubic meter (~3.5E-5 gr/dscf @ 7%O2) and assumed HHV and F-Factor. An allowable alternative limit is 85% control. A source may use whichever limit is least stringent (either percent removal or concentration limit) to comply.

(i) Assumed HHV of MSW of 4,500 Btu/lb, USEPA Method 19 F-Factor of 9,570 dscf/MMBtu at 0% oxygen.

(j) ARI estimated based on regulatory limit of 28 micrograms per dry std. cubic meter (~1.2E-5 gr/dscf @ 7%O2) and assumed HHV and F-Factor. An allowable alternative limit is 85% control. A source may use whichever limit is least stringent (either percent removal or concentration limit) to comply.

Two of the thermal technologies (IWT, Rigel) supplied mercury emissions data; however, quantitative inter-comparison of those emission levels is not technically appropriate. That is because the mercury levels present in the MSW processed at the various reference plants in Europe and Japan may differ significantly between countries, which can markedly affect mercury emissions. Information was requested regarding mercury levels in MSW at the reference facilities, but insufficient data was provided. The presence of mercury in MSW, and its impact on mercury emissions, is a technology transfer issue.

The high temperatures needed to gasify MSW result in most of the mercury present in the MSW being volatilized into the gas. Without effective gas clean-up and/or effective emission control, the emissions of mercury would likely be excessive when the gas is combusted to generate energy. Three of the thermal technologies (GEM, IWT, Rigel) clean mercury from the syngas, prior to combusting the gas. One technology (Ebara) does not clean mercury from the gas, but rather, uses add-on emission controls when combusting the gas as a fuel (i.e., a wet scrubber). All methods used by the thermal technologies to clean mercury from the syngas or control flue-gas emissions appear to achieve a control efficiency of approximately 90% or more. This compares with WTE facilities that also typically achieve greater than 90% removal.

Like the thermal conversion technologies, WTE facilities similarly operate at high enough temperatures to volatilize excessive amounts of mercury into the flue gas and effective control is required. In the U.S., mercury emissions from WTE facilities are controlled by injecting carbon into the flue gas to adsorb the mercury. This affords very high (>90%) control of mercury. With the mercury amounts present in domestic MSW, the controlled emissions of mercury from WTE facilities are generally in the range of 0.07 to 0.7 thousandths of a pound per ton of MSW combusted. This range represents 10% to 100% of the current regulatory emission limit for mercury emission from WTE facilities. Because the mercury control techniques used on the thermal conversion technologies appear to provide mercury removal levels similar to the high levels achieved at WTE facilities, it is expected that the controlled emissions from the thermal technologies will be roughly comparable with levels emitted by WTE facilities. There remains uncertainty in this conclusion, however, (1) because only limited data was provided by most technology sponsors regarding the fate of mercury in their processes, and (2) because the levels of mercury present in MSW could differ between the U.S. and the countries abroad where the reference facilities for the thermal technologies are in operation.

7.2.4 Greenhouse Gases

Emissions of greenhouse gases from human activity (anthropogenic emissions) are of concern, because such anthropogenic emissions are suspected of contributing to global warming by many climate experts. There are a number of carbon-containing gases, as well as certain other gases, that are designated as greenhouse gases, because of their ability to trap heat. These include carbon dioxide, methane, nitrous oxide, and others.

The most important greenhouse gas is carbon dioxide (CO_2), and methane is next most important in terms of emission levels globally.

CO_2 is the most important greenhouse gas because it is emitted in far greater quantities globally than any other greenhouse gas. The most important anthropogenic emission source is the combustion of fossil fuels (oil, natural gas, coal) for transportation, energy production, and other uses.

While anthropogenic emissions of methane are smaller than emissions of CO_2, the methane emissions are still a significant factor in terms of global warming concerns. This is because, while the amount of methane emitted is much less than for CO_2, methane is far more efficient in trapping heat, pound for pound of gas, than is CO_2. The most important anthropogenic sources of methane emissions are landfills, followed by oil and gas extraction, and agriculture[3].

Landfill disposal of MSW generates methane-rich landfill gas within the landfill, as the MSW decomposes anaerobically. All of the methane gas generated becomes a new, greenhouse gas emission, except for any portion that is collected and then combusted for energy recovery (or combusted via flaring). While methane emissions have steadily declined since 1990 due to increases in the amount of landfill gas collected and combusted, decomposition of waste within landfills continues to be the largest source of anthropogenic methane emissions in the U.S.[4] All landfills have greenhouse gas emissions, because none are able to collect and control 100% of the methane gas that is generated. Currently, EPA estimates that modern landfills typically collect gas with an efficiency of approximately 75%[5]. This means that 25% is being emitted as a greenhouse gas.

Waste management practices that divert MSW from landfill disposal do not generate significant emissions of methane, thus avoiding the methane greenhouse gas emission associated with landfills. Furthermore, conversion technologies that generate energy from MSW (or from gaseous fuel that is produced from MSW) can reduce greenhouse gas emissions in an additional manner. They do this by generating electric power using a renewable fuel to displace electric power generation with fossil fuel at a base-load electric generating station.

Combusting a renewable fuel has a neutral effect on greenhouse gas emissions, and when the energy produced also displaces fossil fuel energy generation, this results in a net reduction in greenhouse gas emissions. By contrast, the emissions of CO_2 resulting from fossil-fuel energy generation represent a new emission of carbon to the atmosphere. That is because the carbon being emitted had previously been

[3] U.S. EPA, 2005. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003", EPA 430-R-05-003, U.S. EPA, Washington, D.C., April 15, 2005, pp. ES-4 and 262.
[4] USEPA, 2005. Ibid.
[5] USEPA, 2002. "Solid Waste Management and Greenhouse Gases, A Life-Cycle Assessment of Emissions and Sinks," 2nd Edition, EPA 530-R-02-006, May 2002, p. 102.

sequestered from the environment, deep in the ground over millennia. Only recently had that carbon been extracted in the form of coal, oil, or natural gas for use as a fuel.

From the above discussion, it is apparent that many factors come to bear on determining whether a particular technology causes a net decrease or increase in greenhouse gas emissions. Quantitative determinations in this regard are complex, and detailed quantitative information was not available for any of the conversion technologies reviewed in the Phase 2 Study. However, an informed, qualitative assessment of greenhouse gas emissions has been performed, enabling inter-comparison of the conversion technologies, and comparison with WTE facilities as a benchmark. This assessment considered the major factors influencing greenhouse gas emissions, but not all factors. For example, it did not include the greenhouse gas emissions from transporting compost to the land-application site, or transporting the solid by-products of thermal technologies to markets. As such, this does not represent a complete lifecycle analysis of greenhouse gas emissions.

Results of the assessment indicate that anaerobic digestion technologies, thermal conversion technologies, and WTE facilities can all achieve a significant, net reduction in greenhouse gas emissions. The net reduction is due: (1) to the diversion of solid waste from landfilling, which results in avoidance of landfill emissions of methane; and (2) to the fact that electric energy is generated with renewable fuels, and that energy displaces base-load fossil-fuel generation.

Greenhouse gas emissions are assessed in detail below.

Thermal Conversion Technologies

The thermal conversion technologies convert most of the carbon content of the input MSW to electric energy output, as do conventional WTE facilities. In addition, three of the four thermal technologies (Ebara, GEM, and IWT) perform this conversion to net electric output with roughly the same efficiency (approximately 15%) as do WTE facilities. WTE facilities in the U.S. have a net electric output efficiency in the range of approximately 17% to 20%. This means that the electric output of the Ebara, GEM, and IWT technologies would displace fossil-fuel electric generation to approximately the same extent as WTE facilities. Accordingly, the Ebara, GEM, and IWT technologies would provide a similarly favorable reduction in greenhouse gas emissions as do waste-to-energy facilities, through displacement of fossil-fuel electric generation.

An exception is the Rigel technology. Rigel employs a combined-cycle combustion turbine to generate electric energy, which is more efficient than the energy generating equipment used by the other thermal technologies (reciprocating engines; steam boilers) and by standard WTE facilities (steam boilers). Rigel's net generating efficiency is approximately 37%, which is comparable to base-load, fossil-fuel electric generating stations (which are approximately 30% to 40% efficient). This high efficiency boosts Rigel’s greenhouse gas performance, relative to the other thermal technologies and WTE facilities.

Rigel uniquely uses a substantial amount of fossil fuel, relative to MSW. However, Rigel's combustion of fossil fuel would have a neutral effect on net greenhouse gas emissions. Because the energy-generating efficiency of Rigel is approximately the same as at a base-load fossil fuel power plant, Rigel's greenhouse gas emissions from fossil fuel combustion would be offset by corresponding reduced emissions at the base-load power plant. The total amount of greenhouse gas from fossil fuel combustion would not change.

Anaerobic Digestion

The electric output from the anaerobic digestion technologies would displace fossil-fuel electric generation at base-load power stations. In addition, the emissions from electrical generation at an anaerobic digestion facility would result from combusting a renewable fuel (biogas). Accordingly, generating electric power with biogas from an anaerobic digestion facility would result in a net reduction in greenhouse gas emissions. While significant, the reduction would not be as great as that achieved by the thermal conversion technologies and WTE facilities, which convert a greater fraction of MSW to electric power, and hence displace more fossil-fuel power generation and fossil fuel emissions.

7.3 Water Use

All technologies require water for sanitary uses; however, sanitary requirements are minor. Some technologies also require a water input for process uses. Process water use varies by technology.

Anaerobic digestion technologies typically do not require the addition of fresh water for their processes. Process water needs are generally met with water reclaimed from the water content of the MSW. Arrow reports that its anaerobic digestion technology may have an occasional need for a small, fresh water input to optimize biological activity in the digester. Otherwise, Arrow also meets process water needs with water reclaimed from the water content of the MSW. By comparison, a WTE facility using "wet cooling" generally requires approximately 600 gallons of process water per ton of MSW processed.

Regarding the thermal processing technologies, Ebara indicated that it requires a process water input, but data supplied on the magnitude were uncertain. GEM had indicated zero process water draw, but later added a wet scrubber for emissions control to its conceptual design. It is uncertain whether the scrubber requires a fresh water input. IWT requires a water draw of 773 gallons per ton of MSW processed, and Rigel requires 230 gallons per ton of MSW. It appears that the thermal processing technologies generally require a water input, but the amount of water draw may vary significantly among the technologies. The water requirements of the thermal conversion technologies may range from being similar to the water required by WTE facilities, to being substantially less.

7.4 Wastewater Discharge

The norm for all of the conversion technologies is zero discharge of process wastewater, or only a small discharge. Zero discharge is the typical design objective for modern WTE facilities. For the thermal conversion technologies, three of the technology sponsors indicated their technologies have zero process wastewater discharge (GEM, IWT, Rigel). Ebara indicated a process wastewater discharge of 78 gallons per ton of MSW processed. For the anaerobic digestion technologies, Arrow and WRSI indicated process wastewater discharges in the range of 10 to 30 gallons per ton of MSW processed.

Ebara and Arrow provided information on the expected characteristics of the wastewater that would be discharged to the municipal sewer system. These wastewater characteristics are summarized in Table 7-11. WRSI stated that a project-specific laboratory analysis would be required to determine wastewater characteristics. Based on information provided by the New York City Department of Environmental Protection, Bureau of Wastewater Treatment, discharge limits applicable to the conversion technologies would be determined on a case-by-case basis, dependent on factors such as flow rate and facility location. Therefore, applicable discharge limits are not currently known and are therefore not indicated in Table 7-11.

Table 7-11. Summary of Wastewater Characteristics

Parameter	Arrow	Ebara
Quantity	10 to 15 gallons/ton MSW	71 to 78 gallons/ton MSW
Biological Oxygen Demand (BOD)	20 mg/L	[20 mg/L
Chemical Oxygen Demand (COD)	150 to 200 mg/L	[20 mg/L
Total Suspended Solids (TSS)	10 to 30 mg/L	[30 mg/L
pH	8.3 mg/L	5.8 to 8.6 mg/L
Total Nitrogen	no information provided	no information provided
Phosphorus	<0.5 mg/L	no information provided
Arsenic	<0.1 mg/L	no information provided
Cadmium	<0.01 mg/L	<0.05 mg/L
Copper	<0.05 mg/L	<1.5 mg/L
Lead	<0.1 mg/L	<0.1 mg/L
Mercury	<0.05 mg/L	<0.005 mg/L
Molybdenum	<0.05 mg/L	no information provided
Nickel	<0.05 mg/L	no information provided
Selenium	<0.05 mg/L	no information provided
Zinc	<0.05 mg/L	<2.5 mg/L
Chlorides	486 mg/L	no information provided

7.5 Solid Waste Requiring Landfill Disposal

The types of solid waste requiring disposal for the various conversion technologies and WTE facilities are summarized as follows:

- *Anaerobic digestion technologies* – solid residue varies by technology sponsor, depending on the preprocessing and screening configuration for the technology. Residue typically consists of non-biodegradable material such as grit and particles of glass, plastic, rubber, textiles, and non-recovered recyclable items.

- *Thermal conversion technologies* – solid waste residue varies by technology sponsor. IWT and Rigel claim zero waste requiring disposal. Ebara generates fly ash that requires disposal. GEM generates a char material that requires disposal, or that could possibly be used as landfill cover material. GEM provided analytical data documenting that the char is predominantly carbon. The concentration of metals in the Char was reported to be less than 100 parts per million for most metals (including mercury, cadmium, lead, arsenic and cobalt).

- *Waste-to-energy facilities* – in the U.S., the solid waste residue consists typically of bottom ash and fly ash, combined.

For purposes of the Phase 2 Study, any solid residues that are destined to landfills, whether for disposal or for use as a daily cover material, have been assumed to be disposable solid waste. The solid waste disposal rates for the conversion technologies were previously disclosed in Sections 5 and 6 of this Report. These rates are summarized in Table 7-12.

Table 7-12. Residue Requiring Landfill Disposal (Percent by Weight of MSW Received for Processing)

Technology	Residue Requiring Landfill Disposal (%)
Anaerobic Digestion	
Arrow	23.36%
WRSI	30.9%
Thermal Processing	
Ebara	6.12%
GEM	28.4%
IWT	0%
Rigel	0%

7.6 Product Quality

The thermal conversion technologies generate a variety of products, including mixed metals, mixed salts, sulfur, zinc, and a glassy slag/vitrified ash. These products may require testing to demonstrate they are not hazardous waste. IWT, which generates all of these products in its thermal conversion technology, stated that these products have consistently been demonstrated to not be hazardous. Analytical data was not available for independent confirmation of the characteristics of the products from IWT or the other thermal technologies.

The anaerobic digestion technologies generate a compost product. New York State has established standards for compost that would apply to compost made from mixed MSW. Those standards limit the amounts of metals (e.g., mercury) and pathogens (e.g., bacteria) that are allowable in the compost, and establish physical standards (i.e., particle size, percent inert material) for product use. Anaerobic digestion technology sponsors were requested to describe quality standards applicable to compost produced at the reference facilities, and to provide available test data demonstrating the compost meets such standards. Information was elicited through written data requests, and also during one-on-one meetings and follow-up telephone and email correspondence with the individual sponsors. The extent of data and documentation provided by the technology sponsors varied significantly. In addition, the quality of the compost reflected in the data provided is dependent not only on the process, but also on the characteristics of the waste processed. For these reasons, direct, quantitative, inter-comparison of compost data is not practical. Nevertheless, data on compost quality supplied by all the sponsors of anaerobic digestion technologies showed compliance with the New York State standards for pollutants and pathogens, and by a comfortable margin. This is indicative of the ability of the technologies to meet current State standards. Table 7-13 summarizes the data that was available regarding compost quality.

Table 7-13. Summary of Compost Quality

Parameter[1]	New York State Standards[2]		Arrow[3]		WRSI
	Monthly Average Concentration (mg/kg, dry weight)	Maximum Concentration (mg/kg, dry weight)	Acetogenic Digestate[4] (mg/kg)	Methanogenic Digestate[4] (mg/kg)	Finished Compost (mg/kg)
Arsenic (As)	41	75	<5	<3	not reported
Cadmium (Cd)	10	85	1	2	0.73
Chromium (Cr - total)	1,000	1,000	36	140	23.6
Copper (Cu)	1,500	4,300	57	182	44.2
Lead (Pb)	300	840	30	58	62.3
Mercury (Hg)	10	57	2	4	0.30
Molybdenum (Mo)	40	75	not reported	not reported	not reported
Nickel (Ni)	200	420	12	24	16.9
Selenium (Se)	100	100	not reported	not reported	not reported
Zinc (Zn)	2,500	7,500	335	1,122	203
Total Kjeldahl Nitrogen	--	--	0.74	0.90	not reported
Ammonia	--	--	not reported	not reported	894
Nitrate	--	--	not reported	not reported	4
Total Phosporus	--	--	5,888	25,310	1,750
Total Potassium	--	--	2,740	5,119	2,910
pH	--	--	not reported	not reported	7.9
Total Solids	--	--	53.1%	34.1%	59.6%
Total Volatile Solids	--	--	41.4%	19.8%	46.9%
Fecal Coliform or *Salmonella* sp. Bacteria	--	--	not reported	not reported	0

(1) NYSDEC Subpart 360.5.10, Table 8, "Parameters for Analysis - Biosolids/MSW/Sludge Products"
(2) NYSDEC Subpart 360.5.10, Table 7, "Pollutant Limits" (for metals).
(3) Arrow provided multiple sets of data. The larger value is listed in this table.
(4) As described in Section 5, the Arrow process generates two types of digestate (acetogenic and methanogenic), which may be aerobically finished into a compost or delivered to market without further processing.

8.0 CORPORATE AND FINANCIAL INFORMATION

As part of the Phase 2 Study, corporate and financial information provided by the participating companies was reviewed. As previously described, Masada OxyNol (a hydrolysis technology) was a limited participant in the Phase 2 Study, and did not provide corporate and financial information. Therefore, the review was limited to the anaerobic digestion and thermal technology providers.

8.1 Corporate and Financial Information Requests

To better understand the organization, management and financial resources of the companies participating in the Phase 2 Study, the nature of their relationships with the technologies offered, and their postures regarding project risks and guarantees, the City's Supplemental Information Request (SIR) requested completion of SIR Form 10, General Respondent Business Information (see Section 3.3 for additional information on the SIR).

SIR Form 10 requested that the participating companies briefly discuss the following:

- Their business operations, business history and ownership structure, including any long-term contractual relationships, teaming arrangements or other strategic alliances that are pertinent to the City's solid waste program;

- Their relationship with the proposed technology (e.g., years of direct history with the technology; ownership and/or license arrangements; other parties involved in the technology development and ownership);

- Their postures regarding price, schedule, and performance guarantees (either company or via a parent corporation) and the provision of security instruments such as letters of credit and construction and operations performance bonds; and,

- Their postures regarding business risk as to product quality, marketability, sales of and revenues derived from products, and residuals disposal.

The information that was requested by the SIR is important from several perspectives: 1) it indicates the nature and business history of each company in the MSW management business, including its experience with the offered technology; 2) it characterizes the relationship of each company with the technology (e.g., as licensee or developer/owner), which has implications regarding the availability of the technology, the permanency of the relationship and a company's long-term access to technical support; and, 3) it provides an indication of each company's familiarity with and understanding of the U.S. solid waste market's standard industry practices, such as project delivery options (design/build, design/build/operate, design/build/own/operate), construction and operations costs, schedule, performance guarantees, and risk positions.

Corporate and financial information was requested in summary format. It was not requested at the level of detail or comprehensiveness that would be required as a part of a formal competitive procurement for the implementation of a project. The information provided by each company is summarized in Table 8-1, at the end of this section.

Based upon the information provided, several observations can be made. These findings, which are directly applicable only to the participating companies, are as follows:

- *Familiarity and experience with the technology, the proprietary, integrated nature of the technology, and the nature of the relationship of the developer with the technology provider will affect the developer's success in planning, implementing and operating a facility.* All but one of the participating companies offer the advantage of being either the developers/owners, licensees or sole representatives of what can be considered to be proprietary technology. Rigel appears to rely more on the assembly of a system using individual technical components than on a proprietary technology for an overall system.

- *A company's willingness to undertake a variety of project delivery approaches will enhance the implementation flexibility of the City by enabling several options for project financing and development.* Common project delivery approaches include design/build/operate (DBO) and design/build/own/operate (DBOO). Under DBO project delivery, the public sector would own and finance the facility, while the private sector would design, build and operate the facility under specific contractual relationships. Under the DBOO project delivery approach, the private sector would finance and own the facility, design and construct the facility using its own resources, subcontractors and equipment suppliers, and operate the facility and provide service to the public sector for a long-term period. All of the participating companies indicated that they would be willing to undertake project delivery through a DBO approach, and most indicated a willingness to undertake a DBOO approach.

- *Long-term access to technical support, to resolve difficulties that may arise over time or to benefit from technical enhancements that may be developed in later years, is an important consideration.* Dealing directly with the owner of a technology will assure the City of access to technical support over time. The history of the traditional, waste-to-energy industry in the United States, which for the majority of installations in the U.S. is based upon the application of technology licensed from foreign companies, has shown that access through license arrangements can also be effective. Given that the anaerobic digestion and thermal gasification technologies have been developed outside of the United States, the <u>*ease*</u> of access to technical support from non-U.S.-based providers should be addressed prior to the City's commitment to a technology or developer. Techniques such as requiring U.S. resident presence by the technology owner/licensor, combined with a requirement that project teams include experienced U.S. companies in principal capacities (e.g., permitting, engineering design, construction, commissioning, operation, credit support), can be effective in this regard, and may be appropriate for a City project. All of the participating companies recognized the need for this type of support. As indicated on Table 8-1, all companies either have U.S. capabilities in-place or stated that they would develop such, when needed. The U.S.-based companies currently have relationships with other U.S.-based engineering, construction, operation and financial companies; the non-U.S.-based companies all indicated that they would enhance U.S. resident presence, particularly through relationships with U.S.-based partners and team members.

- *In a competitive procurement, the risk postures offered by proposers would be a key evaluative criterion in the selection of a contractor.* The industry standard in the U.S. market is the provision of “single-source” guarantees (through which one entity provides all of the schedule, cost and performance guarantees that are negotiated), often combined with security instruments such as letters of credit and construction and performance bonds. All of the participating companies recognized the importance of their provision of construction, operation, performance and financial guarantees, and all but GEM expressly indicated their willingness to provide single-source guarantees. GEM did indicate that it would provide performance guarantees related to the rated capacity of a plant. With the U.S.-based companies that can be fairly characterized as development groups, and the smaller foreign companies (such as Arrow), the meaningful enforceability of a single-source guarantee (particularly if provided by a foreign company) is diminished. It can be concluded that the participating companies understand the need for project guarantees and acceptable risk postures, but that as the time of a project nears, the City will need to clearly define its guarantee and risk requirements, as well as the security packages that would be required (for example, requiring guarantees or credit support instruments to come from US-based entities, for enforceability).

- *As with construction- and operations-related risk postures for price, schedule and performance, the risk postures of prospective contractors regarding the production and marketing of recovered energy and materials would also be a key evaluation criterion in a procurement.* All of the participating companies recognized the importance of the private entity taking the risk regarding the recovered products (e.g., product quantity and quality, product prices, sales and marketing). Arrow, WRSI, IWT and Rigel expressed their willingness to take all of the commercial risks regarding product marketing. Ebara and GEM indicated that the question of marketing risk would be subject to further discussion and negotiation.

8.2 Financial Resources Information

The City's Supplemental Information Request included SIR Form 11, Financial Resources Data, which requested data for the past three years on financial performance indicators. Financial resources and capabilities are important because they indicate the ability of a company to bear the financial risks associated with project development and operation, and to provide meaningful and enforceable guarantees to the City. Four of the participating companies provided all of the information requested. As privately-owned firms, or teams of privately-owned firms, the other participating companies considered the information requested to be confidential in nature and did not disclose it at this time. Specific arrangements could be made to review such confidential information during procurement for a project.

The following summary of financial resources is based on the information provided by each company:

- **Ebara.** Ebara Corporation, a Japanese company with annual revenues of $4.5 billion, is the most financially substantial direct technology provider that responded, although most of its resources and revenues are off-shore. Six of its 43 non-Japan-based manufacturing and service companies are located in the U.S.

- **IWT.** Interstate Waste Technologies, a development company, is a team composed of experienced, large companies including HDR (a major U.S.-based engineering company) and Montenay (a waste management subsidiary of the international environmental firm Veolia that operates ten waste-to-energy facilities in the U.S.). IWT is the exclusive licensee of the Thermoselect technology in North America.

- **Rigel.** Rigel Resource Recovery, a development company, includes on its team substantial, experienced companies such as Westinghouse, General Electric, Power Engineers, Inc. and Turbosonic Technologies.

- **GEM.** No information was provided on GEM America or its British technology developer and licensor, Graveson Energy Management. Its U.S. associate, Alberici (based in St. Louis, MO), is a $600 million/year construction company.

- **WRSI.** Waste Recovery Systems, Inc. is the exclusive licensee of the Valorga technology in North America. Valorga's parent company, URBASER, is wholly owned by Grupo ACS, a Spanish company with annual revenues in the range of $9 billion.

- **Arrow.** With annual revenues (combined with its affiliate, Northern Estates Ltd. UK) of approximately $900,000, Arrow Ecology is the smallest of the companies that provided financial information. However, it reported that it has established a financial-partnering relationship with IDT Corporation (a U.S. communications and financial services company with annual revenues of $2 billion).

Based on the information summarized above, several findings can be made regarding corporate financial resources of the participating companies and the technology categories those companies represent.

The advanced, innovative technologies market includes both large and small companies, well established and new companies, publicly-traded and privately-held companies, and both U.S. and foreign companies. While very general, this characterization will help indicate which potential proposers, in a procurement, would need to enhance their capabilities and resources in order to meet likely qualifications criteria, as well as which proposers might need to find US-based partners.

Unlike most members of the traditional U.S. waste-to-energy industry, in general the companies offering advanced innovative technologies have not been in business in the U.S. market long enough to have built extensive U.S. project inventories or financial track records. However, as indicated on Table 8-1 at the end of this section, all of the participating companies either have companies on their teams that do have U.S. experience or have indicated their intent to build-up teams that include companies with U.S. experience.

All of the participating companies appear to have invested heavily (and to continue to invest) in the development and/or marketing of their technologies. Irrespective of size, companies such as Arrow and Ebara can be considered direct technology providers, but would probably look to U.S.-based teaming partners for project development assistance and resources. The other companies (GEM, IWT, Rigel and WRSI) can fairly be categorized as technology licensees and team leaders for project development in the U.S. market, who would look to their technology providers and/or other individual team members for project development assistance and resources.

The established, U.S. market for traditional waste-to-energy projects is generally characterized by companies that provide enforceable, single-source corporate guarantees for development and operation of the facility. Although most of the participating companies expressed their willingness to provide single-source guarantees, depending upon their financial resources, such guarantees may not be adequate in and of themselves. Except for the very largest of the technology providers, it might be necessary for the providers to assemble security and credit packages that could include bonds and comprehensive insurance coverages written by rated U.S. companies, letters of credit provided by substantial U.S. financial institutions, and the required participation of substantial, experienced U.S. companies (in guarantee roles) in support of the providers and development companies. The ability of a company to provide such security arrangements would, in itself, be an indicator of financial capability. Even with the largest companies, such as Ebara, security elements provided through U.S.-based companies should be required. The inability of any technology provider to comply with these requirements might disqualify it from further consideration during a procurement, or result in a lower ranking during a competitive evaluation.

The City's planning horizon is long-term; perhaps five to ten years for a demonstration project. The financial information provided in response to the SIR does not enable the projection of the financial conditions of the participating companies that far in the future, although, the long operating history of the larger companies provides some "historic comfort". Corporate financial conditions would need to be revisited in greater depth during procurement for any project.

8.3 Financial Implications

In addition to affecting the City's risk posture on a project, business postures and financial capabilities of the innovative technology companies may also affect the necessary financing approach. Possible financing approaches include general obligation financing for a publicly-owned facility, or revenue-based project financing for a publicly- or privately-owned facility.

Should a general obligation financing of either a demonstration-scale or a commercial-scale facility be required, business postures and financial capabilities of the technology company would not be material considerations regarding the financing, which would be backed by the full faith and credit of the City. Such considerations would, however, still affect the amount of risk assumed by the City. Benefits of general obligation financing typically include a lower interest rate, and a simpler and less costly financing. A disadvantage is that such a financing pledges the full faith and credit of the public entity (e.g., tax base) to pay debt service, and may affect the issuer's future credit capacity.

For a revenue-based project financing, in which project revenues would be used to pay debt service, the financial market would demand that financing include customary elements such as: assured City delivery of an adequate supply of MSW; a technology with demonstrated performance; a company with a track record with the technology and with the financial resources to adequately undergird its performance obligations; an industry-standard contractual structure including a comprehensive, long-term ("life-of-the-bonds") waste disposal agreement between the City and the company; contracts for the purchase of recovered energy and/or products; cash flow projections that indicate adequate debt service coverage; comprehensive insurance coverage; and, credit support such as corporate guarantees on company performance, letters of credit and/or construction and performance bonds. These types of requirements would apply whether a project was publicly financed via revenue bonds (i.e., under a design/build/operate approach) or privately financed via revenue bonds (i.e., under a design/build/own/operate approach).

The advantage of revenue-based project financing is that it uses the project revenues to pay operating costs and debt service (i.e., it does not pledge the full faith and credit of the City to pay debt) and does not diminish the public entity's financing capacity for other public initiatives. The disadvantage is a somewhat higher interest rate and a more complex and costly financing.

Several of the companies participating in the Phase 2 Study have indicated the ability to secure private financing for a project, if revenues are adequate and assured to cover the debt and pay operating costs. It is not certain at this time if all of the participating companies could achieve private financing, particularly without first operating a demonstration project in the U.S. Depending on the technology(ies) for which the City chooses to develop a demonstration project, City financing or financing support for the demonstration facility may be needed.

Table 8-1. General Respondent Business Information (SIR Form 10)

Respondent	Question 1	Question 2	Question 3	Question 4
	Provide a discussion of the Respondent's business and its operations, business history and ownership structure (e.g., corporation, corporate subsidiary of another corporation, joint venture, partnership/LLC, etc.), including a discussion of any long-term contractual relationships, teaming arrangements or other strategic alliances that are pertinent to the City's solid waste program.	Provide a discussion of the Respondent's relationship to the proposed technology (e.g., years of direct history with the technology; ownership and/or license arrangements; other parties involved in technology development and ownership, etc.).	Provide a discussion of the Respondent's views regarding the provision of guarantees (e.g., would it/does it offer cost and performance guarantees (either company or via a parent corporation)? Are any such guarantees provided with financial caps or limits? Would it/does it offer security instruments such as letters of credit and construction and operations performance bonds?	Regarding technologies that may produce marketable products (whether materials, chemicals or energy products), would/does the Respondent take full business risk regarding product quality, marketability, sale and revenues derived from such products, and related risks such as residuals disposal? Generally, under what circumstances, if any, would the Respondent expect the City to bear some product- and market-related risks?
ANAEROBIC DIGESTION TECHNOLOGIES				
Arrow	Arrow is an Israeli company, founded in 1999 as a spin-off of Arrow Ecology Ltd. The company has wastewater experience as well as solid waste experience. Arrow has established a financial-partnering relationship with IDT Corporation (a $2 billion/year communications and financial services company).	Arrow owns the patents (both U.S. and European) to the system. The initial R&D on the technology began in the early 1990s. The Tel Aviv plant has been operating since mid-2003.	Arrow believes that it could provide single-source schedule, cost and performance guarantees, either itself or through its partners. Arrow is willing to undertake design/build/operate (DBO) project delivery.	Arrow indicated that it would take commercial risk regarding product quality, marketing and sales, product prices, and the cost of disposing of non-marketable products.
WRSI	WRSI is a development and management group that represents the Valorga technology in North America (beginning in 1989). WRSI reports significant MSW project experience on the part of its management. It cited project development efforts currently in several states, including its recent selection for a project in Palm Desert, CA. Development teams would include Valorga and its parent, URBASER, as well as U.S.-based engineering and construction firms.	WRSI is the sole representative of Valorga in the U.S., and has represented the technology in North America, the Caribbean and Central America since 1989. Rather than issuing overall licenses in geographic areas, Valorga issues licenses on a project-specific basis.	Project-related guarantees would be provided through Valorga International (process guarantee, with some unspecified limits) and the contractor(s) engaged to design, build and operate a facility (via construction and O&M performance bonds). For the Palm Desert, California project, WRSI and its partner, Shaw Environmental, are jointly responsible for design, construction and start-up, and will provide design, construction, schedule, cost and performance guarantees. WRSI would undertake both design/build/operate (DBO) and design/build/own/operate (DBOO) project delivery.	WRSI stated that it would be willing to assume full business risk with respect to the sale of recyclable materials, energy from biogas, and compost, as well as residuals disposal.

Table 8-1 (Continued). General Respondent Business Information (SIR Form 10)

THERMAL TECHNOLOGIES				
EBARA	Ebara, based in Japan, was founded in 1920, and is publicly traded. Annual revenues are $4.5 billion.	Ebara owns the technology. The first reference plant was started-up in 2000. It would partner with a U.S. company(ies) at the time of project development.	Ebara cited general experience in providing the types of guarantees referenced, and expressed the willingness to negotiate such with the City, including single-source guarantees. Ebara would conduct projects under design/build/operate (DBO) project delivery.	Ebara stated that it is not the norm for it to take business risks on products. However, it is willing to discuss the issue with the City.
GEM	GEM America, Inc, is a Delaware corporation owned by GEM International and GEM America management. The company has been in existence for 2+ years. GEM America has partnered with ICC, Inc. (engineering, construction management, materials processing and handling) and Alberici ($600 million/year construction company), both of St. Louis, MO.	The company has the exclusive patented license 20-year rights for the technology from GEM International.	GEM America would provide a performance guarantee based upon the individual rated capacity of a project. GEM America would secure its guarantee with bank guarantees and/or bonds.	GEM stated that the issue of marketing risks would be a part of negotiations, adding that the revenues from such marketable products could be shared, depending upon the overall final financial arrangement. It stated that, at this stage, the issue cannot be determined.
IWT	IWT, a Delaware corporation with offices in Virginia and Pennsylvania, is a development company, founded in 1990. IWT is 87%-owned by Interstate General Corporation, a publicly traded company in the U.S. The company is a part of an "alliance" that includes the technology supplier (Thermoselect S.A.), designer (HDR, Inc.), builder (H.B. Zachry Company) and operator (Montenay Power Corporation). IWT would serve as the "single point of responsibility" for the development of a project.	IWT reported that it has had a business relationship with Thermoselect (the licensor) since 1995 and has a license for North America for the technology (the license provides for technical support during both construction and operations). Thermoselect S.A., Thermoselect's parent, owns the technology. JFE, Thermoselect's Japanese licensee, also has a technical support arrangement with IWT.	IWT would undertake either design/build/operate (DBO) or design/build/own/operate (DBOO) project delivery. Individual team members would provide guarantees and/or bonds, as appropriate, covering their individual roles and scopes. IWT would form a special purpose company to develop a facility and be the single-source guarantor.	Whether publicly or privately-owned, "IWT and its Alliance partners will guarantee that the Thermoselect technology will produce …. marketable products." Under City ownership and operation, IWT would provide marketing assistance; under IWT operation, IWT would take full responsibility for the sale of products and would negotiate revenue sharing. It suggested a 30-year contract with the City.

Table 8-1 (Continued). General Respondent Business Information (SIR Form 10)

Rigel	Rigel is a fairly new management group. Its principles reportedly have significant energy project development experience. It would develop projects by assembling teams of equipment suppliers, including: Tempico (waste pre-processing); Westinghouse (gasification technology); GE (power generation); Recovered Energy (process design); Power Engineers (detailed engineering). Rigel apparently does not have outside investors, today.	Rigel has neither constructed nor operated a project with the specific combination of technologies cited. It relies on the experience, resources and capabilities of individual team members.	Rigel would undertake either design/build/operate (DBO) or design/build/own/operate (DBOO) project delivery. It would provide a menu of individual guarantees from team members: process guarantees from certain members (with a blanket process guarantee from its team member, Recovered Energy, Inc., albeit "quite limited in amount"); warranties from equipment suppliers; construction bonds from the general contractor. Rigel has not explicity stated it would provide a single-source guarantee.	Rigel stated that it would accept full business risk regarding product marketing. It would expect to operate under a long-term disposal agreement with the City.

9.0 ECONOMIC ANALYSIS

9.1 Introduction

An economic analysis was performed to project the order-of-magnitude costs that could be expected from the conversion technologies for the commercial-scale projects defined by the anaerobic digestion and thermal processing companies participating in the City's Phase 2 Study. The primary purpose of the analysis was to project the first year (2014) tipping fee for each of the technologies, using a model developed specifically for the Phase 2 Study. The model was constructed to also show the net present value (NPV) cost over an assumed 20-year study period (the term of a prospective solid waste disposal contract between the City and a private technology provider).

The analysis was applied to commercial-scale projects, rather than demonstration-scale projects, to determine the cost-competitiveness of such technologies to alternative, commercial disposal methods. The purpose of a demonstration project is not to compete economically with commercially-sized projects, but to provide assurance that a technology can perform successfully and to provide information relative to design, construction and performance that can be used as input to develop commercial scale facilities.

For purposes of the analysis, capital and operating costs provided by the participating companies were used, along with projections for quantities of recovered energy, products, and residues requiring landfill disposal (as previously presented in Sections 5 and 6). It should be emphasized that these are planning-level analyses, not site-specific project analyses based on detailed facility design. Where appropriate, projections made by the participating companies were revised for uniformity in assumptions (e.g., common prices were applied to all technologies for the sale of excess energy and of recovered recyclables of a similar quality, and for residue requiring landfill disposal).

The economic analysis assumed that the facilities would be implemented under a design/build/own/operate (DBOO) project delivery approach, in which a technology provider (either as a company or a team of companies) would privately finance and own the facility, design and construct the facility using its own resources, subcontractors and equipment suppliers, and operate the facility and provide disposal service to the City for a period of 20 years. While not reflected in the economic analysis, such a DBOO arrangement would include customary industry-standard cost, schedule and performance guarantees from the owner/project developer. The assumption of a DBOO project delivery approach is conservative, since the private cost of capital includes a typical requirement for an equity investment (e.g., the "down payment"), with equity being more expensive than debt. This results in the cost of capital being higher than what would be expected through DBO implementation with public ownership and financing. The higher cost of capital results in more conservative (i.e., higher) projections for tipping fees. The economic analysis includes a sensitivity analysis for public ownership and financing of the facility (DBO project delivery).

For illustrative purposes, costs associated with the conversion technologies were compared to the costs that would be experienced by the City over the same 20-year period, if it continued with its current disposal practices (i.e., out-of-City transfer and disposal). Current City costs are on the order of $80/ton (2005 dollars). However, costs for out-of-City transfer and disposal are expected to increase in the future, associated with improvements to the Marine Transfer Stations and implementation of other elements of the City's Solid Waste Plan. The City has estimated a future cost of $107/ton in 2009 for out-of-City transfer and disposal. For purposes of this Phase 2 Study, and in particular to compare costs of the conversion technologies with costs to continue the City's current disposal practices, the 2009 cost of $107/ton has been escalated using the inflation factor assumed for this study (i.e., 3%). As a result, the cost to continue with current disposal practices is projected to be approximately $124/ton in the year 2014, which is assumed (for purposes of the economic model) to be the first year of operation of a conversion technology facility.

9.2 Assumptions and Information for Economic Analysis

The analysis was completed using an economic model developed specifically for the Phase 2 Study. The model required certain assumptions and input information. For purposes of the analysis, participating companies were requested to provide capital and operating cost and recovered-product revenue estimates. The estimates provided were based upon the limited project information and assumptions that were provided in the City's Supplemental Information Request. The participating companies did not have the opportunity to perform the level of design engineering, the type of in-depth due diligence, and the extent of local, site-specific research that would be undertaken during a formal City-sponsored competitive procurement. As such, the costs and revenues provided are planning-level numbers, representing the best estimates of the companies. While the costs and revenues can be considered reasonable order of magnitude estimates for comparative purposes, they should not be considered indicative of a formally proposed price that would result from a City-sponsored competitive procurement.

The economic analysis and cost projections performed for the study were based on the assumptions and inputs summarized below.

9.2.1 General Information. General information required to complete the economic analysis included the processing capacity of each facility (waste throughput), and various modeling assumptions.

Waste Throughput

The participating companies were requested to designate an optimum, technology-specific capacity for a commercial facility for New York City. The proposed throughput for a commercial facility for New York City is presented in Table 9-1, for each technology.

Inflation Rate

Inflation rate is used in the model to escalate costs and prices from current (2005) dollars to future dollars. The inflation rate was assumed to be 3.00%.

Table 9-1. Proposed MSW Throughput for Commercial Facilities for New York City

Technology	Annual Throughput (tpy)	Average Daily Throughput (tpd) (1)
Anaerobic Digestion		
Arrow	214,000	586
WRSI	182,500	500
Thermal Processing		
Ebara	1,080,108	2,959
GEM	1,006,740	2,758
IWT	953,370	2,612
Rigel	996,000	2,729

(1) Calculated based on 365 days per year.

Discount Rate

The discount rate is used in the model to calculate net present value (NPV) costs. NPV can be a useful analytical tool (particularly when comparing alternatives), in that it presents the total costs of a project over the project's life span (in this case, over the 20-year study period) in current dollars, and mitigates the impacts of inflation and debt interest rates. The discount rate for NPV was set at the City's cost of capital for revenue bonds, which was assumed to be 4.65%. The cost of capital is one of the indices commonly applied to NPV analysis.

Cost Basis Year

The cost basis year is 2005. All participating companies presented cost estimates in current (2005) dollars.

Operations Starting Year

The economic model is based on the assumption that waste acceptance and facility operations for all technologies would begin in eight years, i.e., in 2014. While dependent on many factors, a facility could possibly be operational sooner, under a best-case scenario (i.e., with overlap of certain tasks).

The operations start year of 2014 was based on the following activities and time periods:

Year	Task
2006	Develop Implementation Plan for Project • Visit reference facilities • Define project - acceptable technologies, size • Identify and investigate possible sites • Identify facility ownership, financing alternatives • Define environmental regulatory process and requirements • Verify local markets for products • Develop implementation steps and schedule
2006 - 2007	Siting Review
2007 - 2009	Environmental Quality Review (SEQRA/CEQR) and Uniform Land Use Review Procedure (ULURP)
2008 - 2009	Procurement
2010 - 2011	Permitting
2010 - 2013	Design/Construction
2014	Startup/Operations

Study Period

The study period was assumed to be 20 years of waste processing and operations, or a “life of the bonds” term for a service contract between the City and a contractor.

9.2.2 Capital Costs. Capital costs include direct facility design and construction costs as specified by each of the participating companies, as well as costs assumed for site acquisition and financing.

Facility Construction Costs

Participating companies were requested to provide direct facility construction costs, including: development costs; engineering and design; structures; pre-processing equipment; processing equipment; power-generation equipment; storage facilities; environmental control systems; ancillary systems; vehicles, and other technology-specific items. Facility-specific construction costs are summarized in Table 9-2.

Table 9-2. Facility Construction Costs (2005 dollars)

Technology	Construction Cost	Average Daily Throughput (tpd) (1)	Construction Cost per Ton ($/tpd)
Anaerobic Digestion			
Arrow	$43,300,000	586	$73,891
WRSI	$41,048,644	500	$82,097
Thermal Processing			
Ebara	$762,600,000	2,959	$257,722
GEM	$468,211,632	2,758	$169,765
IWT	$405,650,000	2,612	$155,302
Rigel	$876,482,640	2,729	$321,173

(1) Calculated based on 365 days per year.

Site Acquisition Costs.

Under both the design/build/own/operate (DBOO) and design/build/operate (DBO) project delivery approaches applied in the model, it was assumed that new sites would be acquired for the facilities. The analysis applied the site acreage required as specified by each company, as detailed in Sections 5 and 6 and summarized below in Table 9-3, and assumed a per-acre land cost of $150,000.

Table 9-3. Site Acreage Required by Technology

Technology	Annual Throughput (tpy)	Acreage Required	Site Acquisition Cost (1)
Anaerobic Digestion			
Arrow	214,000	8	$1,200,000
WRSI	182,500	14	$2,100,000
Thermal Processing			
Ebara	1,080,108	36	$5,400,000
GEM	1,006,740	11	$1,650,000
IWT	953,380	20	$3,000,000
Rigel	996,000	35	$5,250,000

(1) Based on an assumed cost of $150,000 per acre.

Financing Costs

Under the DBOO project delivery approach applied, the commercial-scale facility would be financed and owned by the private company. The following financing assumptions were applied:

- The facility would be financed with a combination of tax-exempt private activity bonds (similar to municipal revenue bonds) and owner's equity. The financing would be based on an 85% debt and 15% equity ratio.

- The tax-exempt debt portion would carry an interest rate of 4.75%. The owner's equity would have a targeted return of 20% after tax. In order to calculate the combined cost of annual debt service and the equity return, a weighted cost of capital was calculated, yielding 8.04%. This value was applied to the full amount financed in order to project annual capital-related costs (comparable to annual debt service under a publicly-financed approach). A lower-weighted equity rate of return would result in a lower-weighted cost of capital.

- The financing assumed a capitalized interest period of three years, from 2011 through 2013 (i.e., during the design and construction period). Operations were assumed to commence in 2014 (i.e., the assumed starting year of facility operation and waste acceptance and processing).

- The financing included a factor of 20% of construction costs and site acquisition costs to account for customary financing "soft costs" and for a debt service reserve fund, which it is assumed would be required by the financial markets. The 20% factor is based on the assumption that "soft costs" (investment banker fees, bond counsel fees, engineering report, and costs for other advisors) would be roughly 4% of construction and site acquisition costs, and the assumption that the debt service reserve fund would be equal to one year of principal and interest.

- The financing would have a 20-year amortization term with level annual debt service (principal and interest), resulting in a total term of 23 years (three years of capitalized interest during design and construction plus 20 years of principal amortization).

9.2.3 Annual Operating Costs. Annual operating costs include the costs for the annual operations and maintenance of the facility, including facility and equipment repair and replacement, as specified by the participating companies.

The companies were requested to include residue transportation and disposal cost as well as cost to transport recyclables and products to markets, and were requested to disclose the basis of their assumed costs. Information provided was not consistent between the companies. Therefore, for purposes of the analysis, all costs for residue transportation and disposal have been removed from the annual operating costs provided by the companies and applied equally to all technologies on a unit-cost basis using $80/ton (2005 dollars) for transportation and disposal. Costs have not been included for transportation of recyclables and products to markets, because market locations have not been adequately defined. However, as noted below, conservative prices have been applied for recyclables and products, and such prices may be sufficiently conservative to offset transportation costs. If additional costs were to be incurred to transport recyclables and products to markets, such costs would increase the projected waste processing costs.

With the adjustments noted above to the annual operating costs specified by the participating companies, current operating costs for each technology, as input to the model, are summarized in Table 9-4. For comparative purposes, Table 9-4 also shows the O&M cost on a unit-price basis ($/ton). However, it is emphasized that the cost per ton shown on Table 9-4 is *exclusive* of debt service on capital costs and project revenues, and *does not* represent the tipping fee.

Table 9-4. Annual Operating and Maintenance (O&M) Costs ($/year, 2005 dollars)

Technology	Annual Operating Cost	Annual Throughput (tpy)	O&M Cost per Ton ($/ton) (1)
Anaerobic Digestion			
Arrow	$4,225,000	214,000	$19.74
WRSI	$2,902,922	182,500	$15.91
Thermal Processing			
Ebara	$31,461,474	1,080,108	$29.13
GEM	$52,200,000	1,006,740	$51.85
IWT	$51,050,000	953,380	$53.55
Rigel	$166,800,000	996,000	$167.47

(1) Cost per ton for annual operating cost only, i.e., exclusive of debt service on capital costs and project revenues. This cost *does not* represent the tipping fee.

On a unit-price basis, operating costs for the thermal processing facilities are higher than for the anaerobic digestion facilities, which is reflective of the greater technical complexity associated with the thermal technologies. The Rigel technology has the highest operating costs, on an annual basis and unit-price basis. Notably, Rigel's labor costs are significantly higher than all other technologies reviewed (by a factor of 3 to 4). Also, in comparison to the other technologies, Rigel uses a large amount of supplemental fuel. As described in Section 6, approximately 37% of the energy input to Rigel's facility comes from fossil fuel, including coke for the thermal reactor and natural gas for the generation of energy. Approximately 41% of Rigel's operating costs ($69.1 million, annually) are for purchase of natural gas and coke.

9.2.4 Waste-Handling and Processing. Waste-handling and processing assumptions include the quantity of residue requiring landfill disposal, the quantity of recyclables recovered at the front-end of the process, the amount of net electricity generated for sale (i.e., after meeting internal power requirements), and the type and quantity of other products generated. These quantities were specified by the participating companies, and verified and adjusted, where necessary, through a detailed review of the mass and energy balances provided for review. Detailed quantities and discussions are provided in Sections 5 and 6, with the technical evaluations. Those discussions address differences in the technologies, and describe other factors that affect the stated quantities. Model inputs are summarized below, in Tables 9-5 through 9-9.

Table 9-5. Residue Requiring Landfill Disposal
(Percent by Weight of MSW Received for Processing)

Technology	Residue Requiring Landfill Disposal (%)
Anaerobic Digestion	
Arrow	23.36%
WRSI	30.9%
Thermal Processing	
Ebara	6.12%
GEM	28.4%
IWT	0%
Rigel	0%

Table 9-6. Recyclables Recovered and Delivered to Secondary Material Markets (Percent by Weight of MSW Received for Processing)

Technology	Ferrous	Aluminum	Plastic
Anaerobic Digestion			
Arrow	1.86%	0.82%	12.0%
WRSI	3.15%	0.30%	4.9%
Thermal Processing			
Ebara	2.57%	0.64%	0%
GEM	3.5%	0.5%	0%
IWT (1)	0%	0%	0%
Rigel (1)	0%	0%	0%

(1) As quantified elsewhere in this report, IWT and Rigel recovery a mixed metal as a product after the thermal process, rather than segregated ferrous metal and aluminum as recyclables at the front of the process.

Table 9-7. Net Electricity Generated for Sale (kWh/ton of MSW Received for Processing)

Technology	Net Electricity (kWh/ton)
Anaerobic Digestion	
Arrow	215
WRSI	124
Thermal Processing	
Ebara	383
GEM	533
IWT	493
Rigel(1)	2,212

(1) Higher net electricity is due to use of fossil fuel.

Table 9-8. Compost Produced (Percent by Weight of MSW Received for Processing)

Technology (1)	Compost Produced
Anaerobic Digestion	
Arrow	13.72%
WRSI	24.42%

(1) Not applicable to thermal technologies.

Table 9-9. Other Products Generated
(Percent by Weight of MSW Received for Processing)

Technology (1)	Mixed Metals	Glassy Slag/ Vitrified Ash	HCl	Mixed Salts	Sulfur	Zinc
Thermal Processing						
Ebara (2)	0%	6.74%	0%	0%	0%	0%
GEM (2)	0%	0%	0%	0%	0%	0%
IWT	9.13%	6.85%	0%	0.8%	0.15%	1.0%
Rigel (3)	6.29%	13.25%	3.26%	0%	0.17%	0%

(1) Not applicable to anaerobic digestion technologies.
(2) Ebara and GEM recover metal in the form of segregated ferrous and aluminum, which is accounted for as a recyclable material rather than a product. In comparison, IWT and Rigel recover a mixed metal product after the thermal process.
(2) Rigel's quantity of mixed metals includes air pollution control residue marketed for its metal content (2.75%).

9.2.5 Project Revenues. Project revenues are generated from sale of recyclables, electricity, compost (as applicable) and other technology-specific products.

Recyclables

As described previously, different technologies recycle different types and quantities of materials. Some technologies (i.e., IWT and Rigel) do not have any preprocessing for recovery of recyclables, although these technologies recover metal after processing in the form of a marketable product. In addition, the quality of the materials recovered for recycling may differ between technologies, which may impact the value of the material. For example, Arrow has an extensive front-end system that results in recovery of sorted plastic, while WRSI recovers a mixed plastic of lower potential value.

Overall, materials recycled on the front-end of the conversion technologies include, for one or more of the technologies, ferrous metal, aluminum, sorted plastic (PET, HDPE, film), and mixed plastics. As addressed in Sections 5 and 6, some technologies may recover glass and paper, but these materials are considered to be residue requiring disposal. Also, one technology recovers wood, but the recovered material is assumed to be used on-site rather than sold.

Prices suggested by the participating companies for recyclable materials varied widely, from very conservative to optimistic. For purposes of the economic analysis, consistent pricing has been applied for recyclables of similar quality that are recovered from each technology, as applicable. Prices used in the economic analysis are summarized in Table 9-10.

Table 9-10. Recycling Prices by Material ($/ton, 2005 dollars)

Material	Current Reported Price (1)	Price Used in Analysis (2)
Ferrous Metal (Bundled Steel Scrap) ($/ton)	$102.50	$51.00
Aluminum (Baled UBC) ($/lb)	$0.65	
Aluminum (Baled UBC) ($/ton)	$1,300.00	$650.00
Mixed Plastic (Unsorted) ($/lb)	$0.01	
Mixed Plastic (Unsorted) ($/ton) (3)	$20.00	$10.00
PET (Baled Mixed PET Scrap) ($/lb)	$0.16	
PET (Baled Mixed PET Scrap) ($/ton)	$320.00	$160.00
HDPE (Mixed Postconsumer Scrap Baled) ($/lb)	$0.16	
HDPE (Mixed Postconsumer Scrap Baled) ($/ton)	$320.00	$160.00
Film (Mixed Plastic Unsorted) ($/lb)	$0.01	
Film (Mixed Plastic Unsorted) ($/ton)	$20.00	$10.00
Weighted Average Price, Sorted Plastic ($/ton) (4)		$55.00

(1) Value reported by Recycler's World on Nov. 2, 2005 (high price for 20-ton deliveries to market).
(2) Conservatively established as approximately 50% of reported price.
(3) Applies only to WRSI, which recovers mixed plastic.
(4) Applies only to Arrow, which recovers sorted plastic. Based on information provided by Arrow regarding plastic recovery, price is weighted as follows: 15% PET, 15% HDPE, 70% film plastic

Recycling prices summarized in Table 9-10 are conservative estimates, based on current conditions in the U.S. marketplace. The economic analysis assumed no increase in recycling prices over the study period, because prices in secondary material markets have traditionally fluctuated widely and cannot be predicted to increase in an inflationary manner.

Electricity

Participating companies were requested to specify the projected unit price ($ per kilowatt hour) for net electricity sales used in their own revenue projections. The prices identified by the companies ranged from $0.05/kWh to $0.10/kWh in 2005 dollars. For purposes of this study, a sale price of $0.07/kWh (2005 dollars) was uniformly applied to the expected net electricity sales for each technology. This price was assumed to increase annually at the applied inflation rate of 3%.

Various discussions were provided by the companies regarding the expected price for electricity sales. Rigel brought thoughtful and informed facts to the table regarding electric power prices in New York City, which were considered in establishing a uniform power price for the economic modeling work. Based on information provided by Rigel, a power contract could reasonably be established in the range of $0.06 to $0.08 per kWh, with $0.07 per kWh as a middle ground. This is the value selected for use as a uniform power price in the economic modeling.

The pricing structure for electricity sales recognizes that the energy market in the New York City region is deregulated and potentially volatile. The pricing adopted for the economic modeling does not assume that green or renewable premium prices would be available. If such premium prices were available, electricity revenues would increase. The electricity pricing also does not take into account costs for interconnecting a facility to the grid, which have not yet been defined.

Compost

Compost prices are uncertain, since a market is not established in the U.S. for large-scale use of compost generated from mixed MSW. Compost prices will be dependent on compost quality and end-user needs.

Compost prices suggested by the anaerobic digestion companies ranged from $9.00 per ton (Arrow) to $14.50 per ton (WRSI). WRSI did not provide documentation to support their suggested compost price. Arrow indicated uncertainty with their price, but noted it was conservative and based on discussions with people actively engaged in the marketing of organic soil amendments. For purpose of the economic analysis, information provided by the companies was considered and Arrow's price of $9.00 per ton was uniformly applied to compost sales. This common assumption does not address the issue that a specific technology may produce a higher or lower quality compost, which would likely result in variable market value. While compost price may vary by technology, insufficient information was available to establish compost prices specific to individual technologies.

As a "worst-case" sensitivity analysis, the impact on the tipping fee was determined should the compost require disposal due to lack of markets.

Other Products

Thermal technologies generate other products, including: glassy slag or vitrified ash; mixed metals; hydrochloric acid; mixed salts; sulfur, and zinc. Not all thermal technologies generate all of these products.

Based on information reported by the companies, the glassy slag could be marketed as a sand substitute in concrete or bituminous paving material. Metals could be sold to the scrap metal industry, similar to metal recovered by other technologies in the form of recyclables. The other products are commodities that could be marketed to and used in manufacturing industries. For example, industrial salts and elemental sulfur are used by industry as intermediate products in the manufacture of steel and sulfuric acid, respectively.

The prices used in the economic analysis for the products were generally established as the prices reported by the companies. If more than one company reported similar products (e.g., glassy slag/vitrified ash), the lowest reported price was applied to all applicable technologies. Independent review of the prices based on published information, such as prices published in the Chemical Market Reporter, indicate that the prices reported by the companies and used in the analysis are conservative.

The prices used in the analysis for products from the thermal technologies were as follows:

- Glassy Slag/Vitrified Ash: $1/ton
- Mixed Metals: $30/ton
- Air Pollution Control Residue, Marketed for Metal Content: $0/ton
- Hydrochloric Acid: $25/ton
- Mixed Salts: $10/ton
- Elemental Sulfur: $10/ton
- Zinc Hydroxide: $10/ton

9.3 Summary of Results For Commercial Facilities

As previously stated, the primary purpose of the economic analysis was to determine the projected tipping fee for the first year of a commercial project (assumed to be the year 2014). Tipping fees were projected for a DBOO project delivery approach (private ownership and financing) and, as a sensitivity analysis, a DBO project delivery approach (public ownership and financing). As previously described, DBOO project delivery may present the most advantageous risk profile to the City, but it also results in more conservative (higher) projections for tipping fees. The projected tipping fees are summarized in Table 9-11, and discussed below.

Table 9-11. Summary of Projected Tipping Fees for the First Year of a Commercial Project (2014)

Technology	Annual Throughput (tpy)	Projected Tipping Fee ($/ton)(1)	
		DBOO Private Ownership and Financing (Base Case)	**DBO** Public Ownership and Financing (Sensitivity)
Anaerobic Digestion			
Arrow	214,000	$56	$43
WRSI	182,500	$80	$65
Thermal Processing			
Ebara	1,080,108	$141	$96
GEM	1,006,740	$134	$104
IWT	953,380	$103	$76
Rigel	996,000	$165	$129

(1) Planning-level analysis only; project- and site-specific analysis required for more definitive results.

The projected tipping fees (base case, DBOO) for the anaerobic digestion technologies vary from approximately $56/ton to $80/ton. If a market cannot be found for compost, and the compost must be disposed in a landfill, the projected tipping fees would increase. Assuming the cost to transport and dispose of the compost is the same as the cost to transport and dispose of other residue ($80/ton, 2005 dollars), the range of projected tipping fees for the anaerobic digestion technologies increases to approximately $72 to $108/ton. The projected tipping fees (base case, DBOO) for the thermal processing technologies vary from approximately $103/ton to $165/ton.

If the project were developed under public ownership and funding mechanisms (DBO project delivery approach), the projected tipping fees would be $43 to

$65/ton for the anaerobic digestion technologies and $76 to $129/ton for the thermal technologies. The significant difference in the net costs per ton between private ownership (DBOO) and public ownership (DBO) is due entirely to differences in the cost of capital between the two approaches. The DBO approach assumes project financing with 100% tax-exempt revenue bonds at a 4.65% interest rate. The DBOO approach assumes a weighted cost of capital of 8.04%, which reflects a combination of tax-exempt debt at an interest rate of 4.75% (for 85% of the total financing) and private equity at a conservative 20% rate of return for the balance of the financing. The tax-exempt portion of the DBOO financing structure is priced nominally higher than public financing to account for possible alternative minimum tax impacts on bondholders.

In comparison to the projected tipping fees for anaerobic digestion and thermal technologies, the projected cost to continue with current disposal practices (i.e., out-of-City transfer and disposal) is approximately $124/ton (in 2014). This cost is based on escalating the City's projected 2009 price of $107/ton using the 3% escalation factor applied in the economic model. Therefore, based on the results of this planning level analysis, tipping fees for anaerobic digestion technologies are projected to be less costly than continuation of current practices. Tipping fees for thermal processing technologies are projected to be generally comparable to or somewhat more costly than current practices under the base case analysis (DBOO), and comparable to or less costly under the sensitivity analysis (DBO). Based on the projected tipping fees, anaerobic digestion and thermal processing technologies are cost-competitive with current disposal practices in the City.

The detailed results of the economic analysis are provided in Appendix D. The results are presented separately for the anaerobic digestion technologies and thermal technologies. In both cases, the results include a cover page, summary page, input page, and results page (for the 20-year period) for each technology.

9.4 Design, Construction and O&M Costs for Demonstration Facilities

The economic analysis was not applied to demonstration-scale projects, because demonstration projects are not expected or intended to compete economically with commercially-sized projects. As stated previously, the purpose of a demonstration project is to provide assurance that a technology can perform successfully and to provide information relative to design, construction and performance that can be used as input to develop commercial scale facilities.

For informational purposes, the design and construction costs and the operation and maintenance costs for demonstration facilities presented by the participating companies for purposes of this study are summarized in Table 9-12.

Table 9-12. Design and Construction Costs and O&M Costs for Demonstration Facilities for New York City (2005 dollars)

Technology	Annual Throughput (tpy)	Design and Construction Costs	O&M Costs (1)
Anaerobic Digestion			
Arrow	81,000	$19,750,000	$1,940,000
WRSI	182,500	$41,048,644	$2,902,922
Thermal Processing			
Ebara	105,611	$105,000,000	$6,107,547
GEM	167,790	$78,035,272	$8,700,000
IWT	182,500	$151,650,000	$13,440,000
Rigel	166,000	$278,892,195	$55,258,000

(1) Excluding residue transport and disposal costs and transportation costs to deliver products and recyclables to markets.

10.0 REVIEW OF HYDROLYSIS AND OTHER TECHNOLOGY DEVELOPMENTS

10.1 Introduction

Hydrolysis is not yet in commercial operation for MSW. However, at least one company (Masada OxyNol) is advancing the technology to commercial application. Masada was selected to participate in the City's Phase 2 Study, but was unable to provide detailed technical, environmental and economic information required for an independent verification and validation of the technology. A limited review of Masada's technology is provided in Section 10.2, based on permit application materials, permit contents, and other information provided by Masada the City.

Section 10.3 provides an overview of another emerging technology that is nearing commercial application in the United States. The technology is a fiber recovery facility under construction by World Waste Technologies in Anaheim, California. The overview is based on a site visit conducted in September 2005. New York City reviewed two fiber recovery technologies as part of the Phase 1 Study, and determined that fiber recovery was the least developed of all the emerging technology categories, but warranted monitoring.

Development activities with the hydrolysis facility in Middletown, New York, and the fiber recovery technology in Anaheim, California, are indicative of growing interest in the United States to pursue development and application of emerging solid waste conversion technologies. As previously reported in the Phase 1 Study, other cities and public jurisdictions with similar objectives as New York City have been researching and evaluating conversion technologies. As an example, both the City and County of Los Angeles, California, have recently completed studies, and Los Angeles County is currently moving forward with focused verification and validation of selected technologies and evaluation potential sites for purposes of developing a conversion technology demonstration facility.[6]

10.2 Masada OxyNol Hydrolysis Technology

In the early 1990's, Masada began the Masada OxyNol™, LLC business venture, which integrated and piloted existing technologies, and advanced a project for MSW-to-ethanol processing plant in Orange County, New York. In 1996 a feasibility study was conducted and relations were developed with the Orange County municipality of Middletown, and surrounding municipalities. Subsequently, necessary legal, financial and engineering procurement work was completed by Masada, resulting in a contract for waste supply from Middletown and surrounding communities which was signed in the summer of 2004. The New York State Environmental Quality Review Act (SEQR) Environmental Impact Statement (EIS) was completed, and the project was fully permitted by the New York State Department of Environmental Conservation.

[6] The Los Angeles County study identified two thermal technologies not included in the New York City Phase 2 Study, which have reportedly processed mixed MSW: Ntech Environmental and Bioengineering Resources, Inc. (BRI). Ntech Environmental reportedly has commercial facilities in operation overseas, with the largest MSW facility having a capacity of 143 tpd. BRI reportedly has a pilot facility in Fayetteville, Arkansas, with a capacity of 1.5 tpd. BRI was included in New York City's Phase 1 Study, but at the time had not demonstrated it had processed MSW at its pilot facility.

Masada was headed by owner Daryl Harms, who closely managed the OxyNol business venture and the Middletown, NY plant development. He became ill in 2004 and passed away in 2005. At the time he became ill, further development work was suspended while the company sought strategic investors and management support. Recently, ownership issues have been resolved and the project is moving forward. Significantly, the New York State Part 360 Solid Waste Permit and the Title V Air Operating Permit, which were obtained during project development and allow construction of the facility, have been renewed and maintained, and are currently in effect.

10.2.1 Technical Overview. The core concept of the hydrolysis process is conversion of cellulose materials, which are present in MSW, to sugars using a reaction catalyzed by concentrated sulfuric acid. Because it acts as a catalyst, the sulfuric acid is not consumed in the chemical reaction. The sulfuric acid is recycled in the process, with some makeup needed. The hydrolysis reaction involves the breakdown of the large cellulose molecules into smaller sugar molecules, with water produced as a byproduct.

The MSW-to-ethanol process developed by Masada OxyNol consists of many complex and integrated chemical processes. However, the technology can be broken down into four major processes with three significant auxiliary processes. The four major processes are: (1) waste preparation; (2) acid hydrolysis; (3) fermentation, and (4) distillation. Waste preparation involves materials recovery of recyclables, shredding the waste, and drying of the shredded waste to 5% moisture. Acid hydrolysis consists of treatment of the dried, shredded, waste with concentrated sulfuric acid. The sugars resulting from the acid hydrolysis of the waste are then fermented to produce ethanol. The ethanol is then concentrated to fuel grade by distillation (separation of water from the alcohol).

The three significant auxiliary processes are: (1) sewage sludge handling; (2) acid recycle; and (3) fluidized bed gasification. Sewage sludge, in solid and liquid form, are acidified, heated, and dewatered by centrifuge. The dewatered solids from the sewage sludge are used as fuel for the fluidized bed gasifier. The centrate (liquid from the centrifuge) from the sewage sludge is to be used to wash the hydrolyzate (output from the hydrolysis reactors), thus contributing to the water input to the plant.

In order to recycle the sulfuric acid, the sugars produced in the hydrolysis process are separated from the acid in chromatographic columns. The chromatographic separation process involves preferential adsorption one type of chemical on a solid material, such as carbon, silica gel or alumina. For this process to work, the other type of chemical does not adsorb onto the solid and is eventually washed away. As a final step, the chemical that is adsorbed to the solid is removed by a releasing agent.

The fluidized bed gasifier is a two-stage combustor, which generates fuel gas in a starved air first stage. The fuel gas is then completely combusted in the second stage. The term fluidized bed refers to the fact that air is introduced from the bottom of the first stage of the combustor, which lifts, suspends and circulates the solid fuels introduced into the process. Solid fuels fed to the gasifier for the Masada process are residual lignin produced as a by-product of the acid-hydrolysis process and sewage-sludge solids. The steam generated in the gasifier’s boiler is used to transport heat to other processes in the facility. As a backup and/or supplement to the gasifier’s energy output, a smaller package boiler is included.

10.2.2 Reference Facility. Given how far development has gone, the Masada OxyNol reference facility is the Middletown, NY facility, which is under development. The 960-tpd reference facility requires 16 acres for construction. The total site area at the Middletown location is 22 acres, which includes wetlands not accessible for building. A representative of the host community, Mr. Alex Smith, was contacted by telephone regarding project development activities. Mr. Smith confirmed that the project was approved by the town and contracts were signed in the summer of 2004. He also confirmed that in those contracts, Masada took all technical and financial risk. Mr. Smith reported that the town is satisfied with the project progress, given the evolving circumstances of the company ownership.

10.2.3 Mass and Energy Balance. A plantwide mass and energy balance was not available in the information provided by Masada. However, the primary mass inputs, and their relative mass for the reference facility, is as follows:

- 230,000 tpy (wet, as received) of MSW – (34%);
- 422,000 tpy (wet, as received) of sewage sludge – (62%);
- 32,000 tpy waste paper – (4.7%);
- 364 tpy septage and leachate – (0.05%);
- Total plant input 684,364 tpy – (100%).

Other materials added to the process appear to be makeup sulfuric acid, limestone, and aqueous ammonia or urea.

The saleable products from the process are fuel grade ethanol, front-end recyclables, gypsum and carbon dioxide. The fuel grade ethanol is the primary product from the plant and the primary source of revenue. The plant production capacity is stated to be 7.1 million gallons of ethanol per year, given the permitted MSW throughput of 230,000 tpy. Gypsum is derived from the wastewater treatment residues. Carbon dioxide is derived from (separated out of) the off-gassing of the fermentation process.

Residues from the process consist of unrecyclable materials rejected at the MRF, and ash from the fluidized bed gasifier and the gasifier air pollution control train. The quantity of residue was not available.

10.2.4 Environmental Overview. Masada's reference facility, while still under development, has successfully completed permitting activities in New York State. This is a significant accomplishment for a conversion technology not yet in commercial use. This accomplishment may help pave the way for permitting other emerging conversion technologies.

The major air emissions source from the technology is the fluidized bed gasifier. Pollutants of special interest, emitted and regulated by permit from the gasifier, include NOx, CO, acid gases (SO_2 and HCl), dioxin, and mercury. Title V air permit limits for the gasifier are generally equivalent to those for large, traditional, waste-to-energy combustors. The permitted reference facility includes the following air pollution control equipment and measures in conjunction with the gasifier:

- limestone addition in the fluidized bed of the gasifier;
- selective non-catalytic reduction (SNCR);
- a spray dryer absorber; and,
- a fabric filter (baghouse).

10.2.5 Economic Overview. The project delivery approach for the Middletown, NY, reference facility is design/build/own/operate (DBOO) with a guaranteed waste supply and tip fee provided to the Masada facility by contract with Orange County municipalities. The negotiated tipping fee for the contract year 2004 was $65 per ton of MSW supplied. The escalator for the tip fee is 64% of the Consumer Price Index (CPI). Masada has assumed full responsibility for the marketing of the ethanol and its quality.

10.3 World Waste Technologies Fiber Recovery Technology

World Waste Technologies (WWT) is constructing a 500-tpd fiber recovery facility in Anaheim, California. Full commercial operation is expected in the first quarter of 2006. The facility is located in an industrial area, adjacent to an existing material recovery facility (MRF) operated by Taormina Industries (TI), a wholly owned subsidiary of Republic Services, who collects and receives mixed MSW from throughout the Orange County, California, area, and recovers recyclables from the mixed MSW (i.e., in a "dirty" MRF). TI has leased building space to WWT and has signed a ten-year agreement to send 500 tpd (182,000 tpy) of residual MSW remaining after recovering recyclables from the mixed waste, to the WWT facility. WWT is paid a tip fee equivalent to the cost of transfer and disposal of waste to a landfill.

Residual MSW is received on a tipping floor in the WWT building. The waste is loaded on conveyors by a bobcat and sent to one of two (250 tpd each, 350 day per year basis) steam autoclave (vessel) units. The patented autoclaves process the waste, applying steam, pressure and agitation to reduce the volume of waste by approximately 60%. This is a batch process, which takes approximately 2 hours and 10 minutes. The process completely changes the composition of the MSW and coverts it into separable components of sterilized organic and inorganic materials. Odorous air is captured and treated. The sterilized organic component is a biomass containing cellulose material with significant papermaking fiber.

The output from the autoclave is conveyed to a waste storage area, and from that point on, the process is continuous. The waste material from the waste storage reservoir is conveyed to a trommel screen to separate the cellulose material from the oversize inorganic materials. The cellulose falls through the trommel screen and is conveyed to the pulping area where the material is screened and cleaned prior to producing a wetlap product (approximately ¼ of an inch thick) and baled for shipment to paper mills. For reasons of economics and integrity of the wetlap, WWT is currently limiting distribution to within 150 miles of the fiber recovery plant. This process removes the paper and packaging material from the non-cellulose containing fraction, reducing the volume significantly, thereby allowing the organic material to be conveyed past a magnet to capture the ferrous metals and past an eddy current separator to recover the aluminum. At this point the process has captured and recycled approximately 60% of the prepared material. The remaining residual will be landfilled; however, the residual contains a significant amount of plastic and WWT is conducting research and development to identify a market for this residual. WWT estimates that operating and maintenance staff will number 41 to 44. The facility will operate 24/7 except for planned maintenance and emergency maintenance.

WWT has received letters of intent to purchase the wetlap from three mills in the Los Angeles area, all within a 100 mile radius of the fiber recovery plant. Initially, the wetlap will be made into the corrugated filler portion of the cardboard box. Longer term, the objective is to make materials for the entire box; i.e., the liners as well as the corrugated medium. The wetlap is to be sold to the mills at a rate tied to the corrugated medium market rate.

Approximately 40%, by weight, of the incoming waste becomes residue requiring disposal. Ninety percent of the wastewater is recycled within the plant. The only air emissions are the VOCs collected in the autoclave units, which are treated before being sent to the stack.

11.0 CONCLUSIONS

11.1 Study Objectives

In September 2004, the City completed Phase 1 of an evaluation of new and emerging solid waste management conversion technologies. The Phase 1 Study determined that anaerobic digestion and thermal processing are the most advanced of the conversion technologies, with facilities in commercial operation for mixed MSW outside of the United States. The Phase 1 Study also determined that hydrolysis is an advanced conversion technology, with pilot testing completed in the U.S. and a commercial facility under development in Middletown, New York. Based on information provided by technology sponsors, these emerging technologies were represented to be cost-competitive with traditional waste-to-energy (WTE) technology. The technologies were also represented to offer certain other advantages including reduced air emissions (compared with traditional WTE technology), increased beneficial use of waste, and reduced reliance on landfilling. The Phase 1 Study recommended, as a first step for future consideration of conversion technologies by the City, a focused, detailed review to supplement and verify information provided by the technology sponsors during the Phase 1 Study.

Based on the findings of the Phase 1 Study, the City initiated focused, independent verification and validation of information for the most advanced anaerobic digestion, thermal processing, and hydrolysis technologies. The objectives of this Phase 2 Study were (1) to provide a more detailed evaluation of the more advanced technologies and to independently verify and validate information to the extent possible; and (2) to address technical, environmental, and cost issues that would arise during project development, and specifically City application. These analyses were to assist in determining if, as a next step, development of one or more demonstration facilities for New York City may be warranted as part of a long-term plan for commercial application of such technologies to beneficially use waste materials and to reduce reliance on waste export and landfilling.

To complete the Phase 2 Study, eight specific technologies were identified, representative of the advanced technology categories of anaerobic digestion, thermal processing and hydrolysis. Detailed, independent technical and environmental reviews and evaluations were conducted for two anaerobic digestion technologies and four thermal processing technologies. In addition, an independent economic analysis was completed for these six technologies to determine if commercial application could be cost-competitive with current export practices. A third anaerobic digestion technology was selected to participate and was initially reviewed and evaluated, but the technology supplier was unable to provide information pertaining to processing mixed MSW, which was the focus of the Phase 2 Study. One hydrolysis technology was reviewed, but only limited information was available for this technology so detailed, independent verification and validation could not be completed for that technology.

11.2 Summary of Findings

As presented below, the findings of the Phase 2 Study confirm, through independent verification and validation of information, the previous findings of the Phase 1 Study for anaerobic digestion and thermal processing technologies. In addition, although sufficient information was not available for this study, current initiatives in the U.S. for development of hydrolysis and other conversion technologies are underway. Based on these findings, further consideration of development of a demonstration facility(ies) for New York City is warranted to determine if such technologies are viable for commercial application in meeting the City's long-term waste management needs.

The findings of the Phase 2 Study are summarized below:

- **Technical Findings.** Technical findings show that anaerobic digestion and thermal processing technologies are in commercial operation overseas for mixed MSW, and could be successfully applied in New York City. Reference facilities reviewed as part of the Phase 2 Study provide a demonstration of performance of these technologies. With two exceptions, these reference facilities are commercially operating and processing mixed MSW. The reference facility for one anaerobic digestion technology (OWS) demonstrates performance for source-separated organic waste and not mixed MSW. The reference facility for one thermal processing technology (GEM America) is more representative of a successful pilot facility than a commercial facility, having been operated on a limited, rather than continuous, basis.

  Technical information associated with the reference facilities was reviewed, and to the extent possible, owners, operators and/or other parties affiliated with the facilities were contacted as references for facility performance.

  An independent technical review and evaluation of mass and energy balances, including independent calculations of energy generating efficiency of the technologies, was completed. Recovery rates of recyclable materials and process products were confirmed, along with quantities of residue requiring landfill disposal. Equipment configurations and site layouts were reviewed, in consideration of land area required to support project development and operation. Technical information, as verified, is presented in Sections 5 and 6 of this Report.

- **Environmental Findings.** Environmental findings show that in general, anaerobic digestion and thermal processing technologies have the potential to offer better environmental performance than waste-to-energy facilities, including lower air emissions, increased beneficial use of waste, and reduced reliance on landfilling. The environmental findings are based on independent calculation, review and inter-comparison of environmental performance, including air pollutant emissions, water usage and wastewater discharge. The detailed environmental evaluation is presented in Section 7 of this Report.

- **Economic Findings.** Recognizing that the economic analysis performed for this Phase 2 Study is of a planning level only, economic findings indicate that anaerobic digestion and thermal processing technologies (on a commercial scale) are less costly than or comparable to costs for current export practices. These findings are based on application of an economic model that considered capital costs (design and construction, site acquisition, and financing costs), operating and maintenance costs, and project revenues, for a long-term (20-year) operating period. The analysis included two project delivery approaches: implementation under a privately owned and financed design/build/own/operate or "DBOO" project delivery approach, and implementation under a publicly owned and financed design/build/operate or "DBO" project delivery approach. The detailed economic analysis is presented in Section 9 of this Report.

- **Other Initiatives, Including Hydrolysis.** Hydrolysis is not in commercial operation for MSW. However, the technology is advancing to commercial application in the United States, with a waste-to-ethanol hydrolysis facility under development in Middletown, New York. The Middletown facility has been successfully permitted, which is a significant step for advancement to commercial operation. Other initiatives are also underway in the U.S., including construction by World Waste Technologies of a fiber recovery facility in Anaheim, California. These other initiatives are described in Section 10 of this Report.

- **Technology Transfer.** Based on the analyses conducted for this study, no issues have been identified that would prevent transfer of design and operation experience from commercial operation overseas to application of the technologies in the United States. Project-specific and site-specific issues would need to be addressed during development of an Implementation Plan, such as identification of a site, definition of regulatory requirements, verification of markets for products, and (for some technologies) consideration of equipment components and configuration for preprocessing waste of the specific characteristics as generated in New York City. In particular, it should be noted that the more space-intensive processes (those requiring more than 30 acres) may not be practical to site within New York City.

11.3 Potential Next Steps

Should the City agree with the findings of the Phase 2 Study, the first step toward implementing a demonstration facility is development of an Implementation Plan, consisting of the following tasks:

- Visit reference facilities
- Define the specific demonstration project, including acceptable technology(ies) and size
- Identify and investigate possible sites
- Identify facility ownership and financing alternatives
- Define the environmental regulatory process and requirements
- Verify markets for products
- Develop a list of implementation steps and a schedule.

Should the City accept the Implementation Plan, a demonstration project could be implemented for the purpose of providing design, construction, performance and cost information that would be used to develop a commercial-sized facility. Alternately, a demonstration project could be implemented with the intention of continuing its use in commercial application and expanding it to a commercial-sized facility, if the demonstration project was successful. This could be achieved by building the demonstration facility on a site with sufficient acreage available for expansion to a larger, commercial facility, and adding capacity via additional processing units to expand from demonstration-scale to commercial-scale operations.

APPENDIX A

Questionnaire for Selection of Study Participants (April 2005)

New York City Economic Development Corporation
Questionnaire for New and Emerging Solid Waste Management Technologies
April 2005

I. General Information

Company Name: ______________________________

Contact Name: ______________________ Phone: ______________
Address: ______________________ Fax: ______________
______________________ Email: ______________

Technology Name: ______________________________

Technology Category:
- ☐ Anaerobic Digestion
- ☐ Hydrolysis
- ☐ Thermal (e.g., high temperature gasification, plasma gasification, etc.)
- ☐ Other: ______________________

Brief Description of Technology: ______________________________

II. Definition of MSW

For the purposes of the City's focused review of advanced, innovative waste management technologies, the following will serve as the definition of mixed municipal solid waste (MSW). MSW is that fraction of the solid waste stream, generated by residents, institutions and non-industrial businesses, post source-separated recycling programs. In New York City, the Department of Sanitation (DSNY) collects MSW from residents and institutions (public and parochial schools, certain cultural institutions, etc.). DSNY does not collect MSW from any New York City businesses; private haulers collect this waste stream. MSW is by its nature comprised of many different types of materials; MSW *is not* defined as any one of its component fractions. For example, MSW does not mean source-separated organic waste (or bio-waste), or wood waste, or tires, or food waste, etc.

III. Expression of Interest

☐ Willing to participate in the City's focused review process, **and** able to provide detailed technical and financial information.

☐ Unable to effectively participate in the City's focused review process at this time, but interested in future study efforts or consideration for demonstration projects.

IV. Confirmation of Commercial Operation or Pilot/Demonstration Testing with MSW

1. Is the technology identified in Section I currently in commercial operation processing MSW as defined above? ☐ Yes ☐ No

   If Yes, please attach a listing of the facilities in commercial operation, indicating location, design capacity (tpd), quantity of MSW processed in last year, quantity of other materials processed in last year by type (e.g., sludge, wood waste, industrial waste, hazardous waste, etc.), and number of years in operation.

2. Has successful pilot or demonstration testing for MSW been conducted for the technology identified in Section I? ☐ Yes ☐ No

   If Yes, please attach a description of pilot testing, indicating date and duration of testing, location, design capacity (tpd), total quantity of MSW processed, quantity of MSW processed in last year, quantity of other materials processed by type (e.g., sludge, wood waste, industrial waste, hazardous waste, etc.), and number of years in operation.

New York City Economic Development Corporation
Questionnaire for New and Emerging Solid Waste Management Technologies (Page 2)

V. Availability of Technical and Environmental Information

1. Do you have available, and are you willing to disclose, detailed technical and environmental information associated with one or more commercial or pilot facilities that use the technology identified in Section I to process MSW as defined above, including at least the following information:

A.	Process Schematics	☐ Yes	☐ No
B.	Mass and Energy Balance	☐ Yes	☐ No
C.	Facility Site Layout and Equipment Arrangement	☐ Yes	☐ No
D.	Environmental Permits and Emissions Data	☐ Yes	☐ No
E.	Operating Data (e.g., disposal capacity (tpd), annual waste throughput, operating hours, annual availability, and quantity/characteristics of products and residuals)	☐ Yes	☐ No

2. Will you be able to provide references for facilities in commercial operation? ☐ Yes ☐ No

VI. Availability of Financial Information

1. Do you have available, and are you willing to disclose, development, construction, and operation and maintenance costs associated with one or more commercially operated facility(ies) processing MSW as defined above for the technology identified in Section I?

   ☐ Yes
   ☐ No

   If No, please describe the basis on which you would provide development, construction, and operation and maintenance costs for review by the City:

   ____
   ____
   ____

2. Do you have experience successfully marketing products of the technology identified in Section I?

   ☐ Yes
   ☐ No

   If Yes, are you willing and able to disclose the following detailed market information for each product:

List of Materials Marketed	☐ Yes	☐ No
Identification of Purchasers	☐ Yes	☐ No
Unit Sale Prices	☐ Yes	☐ No
Annual Quantities Sold	☐ Yes	☐ No
Annual Revenues Earned	☐ Yes	☐ No

   If Yes, please identify how many facilities this marketing information is available for, and for what time period.

   Number of facilities with marketing data: ____________________
   Time period marketing data is available: ____________________

   If No, please describe the basis on which you would provide marketing information.

   ____
   ____
   ____

APPENDIX B

Representative Supplemental Information Request (SIR) (May 2005)

Alternative Resources, Inc.

Corporate Headquarters

1732 Main Street
Concord, MA 01742
Tel (978) 371-2054
Fax (978) 371-7269

May 27, 2005
1529B

Dr. Melvin S. Finstein
Professor Emeritus of Environmental Science
Rutgers University; Representing:
Arrow Ecology & Engineering
105 Carmel Road
Wheeling, WV 26003

Via email: finstein@envsci.rutgers.edu

Subject: Focused Review of Advanced, Innovative Technologies Supplemental Information Request (SIR)

Dear Dr. Finstein:

We are pleased that Arrow Ecology & Engineering has agreed to participate in New York City's focused review and evaluation of advanced, innovative waste management and recycling technologies. The purpose of this Supplemental Information Request is to describe the fundamental elements of the review process and request detailed information to enable that review. The information you provide will be used by the City to determine if it will take the next step to develop an implementation plan for a demonstration facility, up to 500 tons per day (tpd) in size.

Overview of Focused Review Process

The City's focused review process will be a continuation of initial evaluations conducted by the City and presented in the September 2004 Evaluation Report. The Evaluation Report was attached as an Appendix to the City's Draft Comprehensive Solid Waste Management Plan, submitted to the City Council in October 2004. (The report can be accessed on the Internet at http:www.nyc.gov/html/dos/pdf/pubnrpts/swmp-4oct/appendix-f.pdf)

The focused review will consist of verification and validation of technical, environmental, and cost information and will address technology transfer issues for the more advanced technology categories of gasification, anaerobic digestion, and hydrolysis. The objective of the focused review is to provide assurance that these technology categories can reasonably meet potential expectations for City application. These expectations include, but are not limited to, reliable technical performance, favorable environmental performance (including lower emissions and beneficial use of waste), and competitive economics associated with processing post-recycled, mixed municipal solid waste (MSW).

We wish to emphasize that the review process will be based on information associated with processing MSW, as it is currently set out curbside and collected by the City. The review will not focus on information associated with processing any individual fraction of MSW, such as source separated organics. Attachment 1 to this letter provides information on the definition of MSW for purposes of this study, based on a preliminary waste characterization study conducted by the New York City Department of Sanitation. Information submitted in response to this request should be based on processing MSW consistent with the definition in Attachment 1 and information provided in Attachment 2, Form 5.

Schedule for Submitting Information and Presentations

We are requiring submittal of technical, environmental and cost information requested in this Supplemental Information Request by Wednesday, June 22, 2005. Upon receipt and initial review of the information, technology presentations will be scheduled with each participant. The objective of the presentations will be to further clarify information, address data gaps, and engage in discussions necessary for completing an evaluation of the technologies. These presentations are currently planned for the week of July 25-29, 2005, and if necessary, will continue into the week of August 1-5, 2005. Presentations will be held at ARI's corporate office in Concord, Massachusetts, which is located approximately 20 miles west of downtown Boston. Venetia Lannon, Assistant Vice President for the New York City Economic Development Corporation and EDC's Project Manager for this study, will participate in the presentations.

Requested Information

For purpose of completing the focused review process, we are interested in technical, environmental and cost information for your technology associated with processing MSW as defined in Attachment 1 and Form 5. We are interested in the complete waste processing system; that is, *all* unit operations, including pre-processing, processing (e.g., thermal reactor, anaerobic digester, or other process equipment, as applicable), power generation, management of products and process residuals, and any other unit processes that are integral to the technology (e.g., air pollution control, water treatment and wastewater management).

Technical information submitted in response to this request will be used to independently confirm mass and energy balances, including determination of the overall capability of the technology to beneficially use MSW (in the form of recovered recyclables, energy, and other products). Environmental information will be used to compare environmental performance of different technologies, including comparison to comparable limits promulgated in the United States. Information regarding pricing matters, such as construction costs, operation and maintenance costs, and product revenues will be used to project order-of-magnitude economics for the variety of technologies being reviewed. The City understands that the pricing information provided will reflect good faith estimations based upon the limited information provided in this Supplemental Information Request, and will not be construed in any way by the City to represent proposed or guaranteed pricing, or to comport to the pricing that would result from a formal procurement.

To obtain a consistent set of information from all of the technology vendors participating in the focused review process, we have developed a series of forms. These forms are provided in Attachment 2. To the extent possible, the forms should be completed and supplemented with supporting information to enable verification and validation of the information provided. Supporting information should include, where available, copies of permits and permit applications, air emissions and product test data, records of performance, and other documentation beneficial for the review process. We encourage you to complete the forms to the extent possible, and to submit relevant supporting information to enable a thorough and detailed review.

The information Arrow Ecology & Engineering previously submitted to the City will be considered during the focused review. Supplemental or updated information submitted in response to this request will also be considered. We recognize the effort Arrow Ecology has already made in providing information to the City. ARI will work with you to ensure that while we receive the information that is required for review, we do not unnecessarily require you to resubmit information that was previously provided and that is still current and valid.

Facility Capacity and Location

For purposes of the focused review, and specifically for the purposes of evaluating cost information, two facility capacities will be considered. One facility capacity will be associated with a demonstration facility capable of processing up to 182,500 tons per year (tpy) of MSW (i.e., up to approximately 500 tons per day (tpd) of MSW). The other facility capacity will be associated with a commercial facility capable of processing up to 1,095,000 tpy of MSW (i.e., up to approximately 3,000 tpd of MSW). In both cases, the facility capacity is to be specified by the respondents based on technology-specific, optimum capacity, not exceeding the maximum capacities specified herein.

For purposes of providing information, respondents should assume that the demonstration and commercial facilities would be located in New York City or the New York City Metropolitan Area.

Directions for Submittal of Supplemental Information

Supplemental information requested in this letter should be submitted by June 22, 2005. We welcome electronic submittal of information via email, when practical, but also request three (3) printed copies of information be provided to ARI and one (1) printed copy be provided to the City. Information should be submitted to ARI and the City as follows:

<u>Three (3) printed copies to:</u>
Alternative Resources, Inc.
Attention: Susan Higgins
1732 Main Street
Concord, MA 01742-3837
Tel: (978) 371-2054
email: shiggins@alt-res.com

<u>One (1) printed copy to:</u>
New York City Economic Development Corporation
Attention: Venetia Lannon
110 William Street
New York, NY 10038

Upon your receipt of this letter, and as you compile the information that has been requested, we encourage you to contact ARI if you have any questions or require clarifications. You can contact me, Susan Higgins, as indicated above, or you can contact Kathy Luvisi, Project Engineer and Lead Technical Reviewer, at (978) 371-2054. Kathy's email address is kluvisi@alt-res.com. We look forward to working directly with you to gather, review and evaluate the necessary technical, environmental, and financial data.

Very truly yours,

Susan M. Higgins
Project Manager

Attachments

cc: Venetia Lannon, New York City EDC
Jim Binder, ARI
Kathy Luvisi, ARI
David MacKenzie, ARI

Attachment 1
Definition of Municipal Solid Waste (MSW)

DEFINITION OF MUNICIPAL SOLID WASTE (MSW)

For the purposes of this focused review of advanced, innovative waste management technologies, the following will serve as the definition of mixed municipal solid waste (MSW). MSW is that fraction of the solid waste stream, generated by residents, institutions and non-industrial businesses, post source-separated recycling programs. MSW is by its nature comprised of many different types of materials; MSW *is not* defined as any one of its component fractions. For example, MSW does not mean source-separated organic waste (or bio-waste), or wood waste, or tires, or food waste, etc.

In New York City, the Department of Sanitation (DSNY) collects MSW from residents and institutions (public and parochial schools, certain cultural institutions, etc.). In Fiscal Year 2004, DSNY collected on average 11,722 tons per day of mixed MSW.[1] DSNY does not collect MSW from any New York City businesses; private haulers collect this waste stream.

As part of the Draft Comprehensive Solid Waste Management Plan, DSNY conducted a preliminary waste characterization study (PWCS). This is the first part of a four-season sort and while it is a snapshot, it employs a statistically rigorous sampling protocol and a number of sort categories. Full results can be found on-line at DSNY's website at http://www.nyc.gov/html/dos/pdf/pubnrpts/swmp-4oct/appendix-d.pdf.

The pie chart on the next page summarizes the data from PWCS and shows the percent composition by material group of the MSW collected by DSNY. Although not shown in the figure, the largest material categories are food waste (15.92 percent), compostable/soiled/ waxed corrugated Paper (7.49 percent), and mixed low grade Paper (7.34 percent). The PWCS also found that 22 percent of the materials in the MSW stream are designated recyclables.

Vendors whose technologies are unable to convert certain fractions of MSW, such as glass or metal, must describe how they will handle these components, as MSW would be delivered mixed.

The composition of MSW will vary in the regions where facilities employing advanced innovative technologies are currently located. New York City's data is provided here not with the intention that technology vendors tailor their responses with reference to the particular composition of our waste. Rather the data serves to further define what is meant by MSW. The term MSW means the entirety of materials that comprise the following pie chart.

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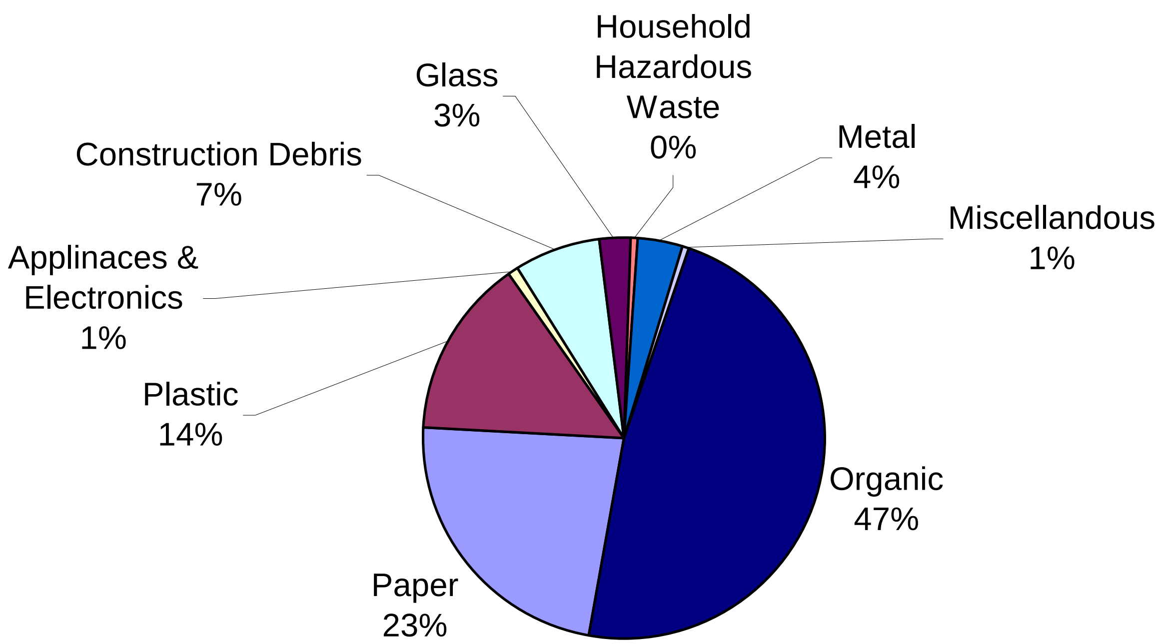
[1] This did not include other miscellaneous waste streams such as bulk waste, street dirt, material cleared from vacant lots, etc. These other DSNY-managed wastes brought the daily total up to 12,489 tons per day. In addition DSNY collected 1,834 tons per day of metal, glass, plastic and mixed paper through its source-separated, curbside recycling program.

DSNY-COLLECTED MIXED MSW COMPOSITION BY MATERIAL GROUP



Source: Final Report Preliminary Waste Characterization Study, DSNY October 2004 (ES-4)

Attachment 2
Supplemental Information Request Forms

Form 1:	Designation of Facility Capacity
Form 2:	Identification and Description of Reference Facility(ies)
Form 3:	Mass & Energy Balance
Form 4:	Land Area Requirements
Form 5:	Assumed Waste Analysis (Basis for Mass Balance)
Form 6:	Biogas Composition for Demonstration and Commercial Facility
Form 7:	Emissions from Combustion of Biogas
Form 8:	Pollution Control Information
Form 9:	Wastewater Characteristics
Form 10:	General Respondent Business Information
Form 11:	Financial Resources Data
Form 12:	Construction Cost Estimate - Demonstration Facility
Form 13:	Construction Cost Estimate - Commercial Facility
Form 14:	Operation and Maintenance Cost Estimate - Demonstration Facility
Form 15:	Operation and Maintenance Cost Estimate - Commercial Facility
Form 16:	Product Revenues - Demonstration Facility
Form 17:	Product Revenues - Commercial Facility

Form 1 - Designation of Facility Capacity

Respondents shall indicate an optimum, technology-specific capacity for a demonstration facility and a commercial facility for New York City, and provide related information requested below.

1. Specify Capacity for a Demonstration Facility

Design Capacity	____________	tpy	___________	tpd
Unit Size	____________	tpy	___________	tpd
Number of Units	____________			
Annual Availability	____________	%		
Annual Facility Capacity at Specified Annual Availability (not greater than 182,500 tpy)	____________	tpy	___________	tpd
Land Area Required for Complete Facility Development at Specified Capacity			___________	acres

2. Specify Capacity for a Commercial Facility

Design Capacity	____________	tpy	___________	tpd
Unit Size	____________	tpy	___________	tpd
Number of Units	____________			
Annual Availability	____________	%		
Annual Facility Capacity at Specified Annual Availability (not greater than 1,095,000 tpy)	____________	tpy	___________	tpd
Land Area Required for Complete Facility Development at Specified Capacity			___________	acres

3. Please describe the proposed technical approach to transition from the demonstration facility to the commercial facility (e.g., scale-up unit size, increase number of units, etc.)

4. Please provide a facility site layout, equipment general arrangement, and schematic process flow diagram for the proposed demonstration and commercial facilities for the capacities specified.

Form 2 - Identification and Description of Reference Facility(ies)

Provide the information listed below, to the extent available, for the commercial or demonstration/pilot facility that serves as the best reference facility for New York City. The reference facility should be processing MSW (as defined in Attachment 1), or should have information available from past processing of MSW. If more than one facility is suitable as a reference facility, please complete this form for each facility. Information regarding operating data should be provided for the longest time period possible, and available supporting information should be provided.

1. Facility name:

2. Facility location:

3. Facility owner (name and contact information):

4. Facility operator (name and contact information):

5. Entity served by facility (name and contact information):

6. Primary regulatory agency for facility (name and contact information):

7. Design capacity (tpy):

8. Demonstrated operating capacity (tpy):

9. Annual availability (%):

10. Annual operating hours:

11. Current quantity of MSW processed (tpy):

12. Other waste currently processed (type and amount in tpy):

13. Operating history of facility (including timeline of development and operation and summary (dates and quantities) of MSW previously processed):

Form 2 - Identification and Description of Reference Facility(ies)

14. Description of waste collection practices for MSW processed at the facility:

15. Description of the major components of the facility (e.g., type and capacity of equipment):

A. Pre-processing:

B. Processing:

C. Power generation:

D. Residual management:

E. Product management (including compost):

F. Air pollution control and wastewater management:

G. Other:

16. Description of quantity and characteristics of residuals requiring disposal:

17. Description of quantity and characteristics of energy and other products generated:

18. Describe the quality standards applicable to the compost produced at the reference facility for purpose of beneficial use. The interest is in regulatory standards for compost quality that limit the permissible levels of contaminants (e.g., metals, organic compounds) as well as pathogens. Provide available test data demonstrating that compost produced from MSW at the reference facility meets such regulatory quality standards.

19. Discussion of end product markets and regulatory requirements for marketing and using such end products, including identification of end users for products identified above:

20. Provide copies of environmental permits, if available.

21. Provide Notices of Non-Compliance or similar regulatory actions or compliance-related correspondence, if any.

22. Provide electronic copies of photographs of the reference facility and/or comparable facilities that may be reproduced for purpose of reporting on the findings of the review process. Please provide, to the extent available, aerial and other external views of the facility and site (or an artists rendering, if photographs are not available), process and materials handling equipment, and products/residuals.

Form 3 - Mass & Energy Balance
Arrow Ecology & Engineering

NOTE: If the Mass & Energy Balance differs for the demonstration facility and the commercial facility proposed for the City, please complete a separate form for each.

Description	Information Previously Submitted	Current Submittal	Units
Incoming MSW	2,000	2,000	Pounds per ton of incoming MSW
Material Separated from the Organic Fraction of the MSW in the Water Bath			
Recyclable Glass	60		Pounds per ton of incoming MSW
Recyclable Plastics	175		Pounds per ton of incoming MSW
Recyclable Ferrous Metal	59		Pounds per ton of incoming MSW
Recyclable Aluminum	21		Pounds per ton of incoming MSW
Material Requiring Landfilling	200		Pounds per ton of incoming MSW
Other (describe):			Pounds per ton of incoming MSW
Material Input to the Biological Element (Acetogenic Bioreactor, UASB Anaerobic Digester)			
Organic Slurry Input (wet solids basis)	1,368		Pounds per ton of incoming MSW
Organic Slurry Input (dry solids basis)			Pounds per ton of incoming MSW
Organic Slurry Input to UASB Anaerobic Digester (percent solids)			Percent
Water Input to UASB Anaerobic Digester (gallons)			Gallons per ton of incoming MSW
Water Input to UASB Anaerobic Digester (pounds)	60% to 80% 1,200 to 1,600		Pounds per ton of incoming MSW
Material Output to the Dewatering Process			
Digested Solids to Dewatering (dry solids basis)			Pounds per ton of incoming MSW
Digested Solids to Dewatering (percent solids)			Percent
Water to Dewatering (gallons)			Gallons per ton of incoming MSW
Water to Dewatering (pounds)			Pounds per ton of incoming MSW
Biogas (pounds)			Pounds per ton of incoming MSW

Form 3 - Mass & Energy Balance
Arrow Ecology & Engineering

Description	Information Previously Submitted	Current Submittal	Units
Water Recycled and Water Discharged			
Water Recycled to Water Bath			Gallons per ton of incoming MSW
Water Discharged to Sewer			Gallons per ton of incoming MSW
Material Output from the Dewatering Process			
Digestate to Composting (dry solids basis)			Pounds per ton of incoming MSW
Water Recycled to Water Bath (gallons)			Gallons per ton of incoming MSW
Water Recycled to Water Bath (pounds)			Pounds per ton of incoming MSW
Material Output from the Composting Process (1)			
Compost (dry solids basis)			Pounds per ton of incoming MSW
Material Requiring Landfilling (pounds)			Pounds per ton of incoming MSW
Water Recycled to Water Bath (pounds)			Pounds per ton of incoming MSW

Energy Use and Energy Generation (2)			
Total Electricity Generated due to Biogas Combustion	340,000		kWh per ton of incoming MSW
Electricity Used for the Arrow Bio Process	50,000		kWh per ton of incoming MSW
Net Electricity Generated for Export (Sale)	290,000		kWh per ton of incoming MSW
Biogas Use for Heating of Anaerobic Digesters			mmCF per ton of incoming MSW

1. Please describe the expected quality and characteristics of the compost produced from MSW as defined in Attachment 1 and Form 5. Describe in detail the standards that will need to be met (e.g., regulatory or end use standards) in order to market the compost in the location(s) in which the compost is expected to be marketed.

2. Please provide supporting documentation, from operation of the reference facility described in Form 2, for biogas generation and electricity generation and use

Form 4 - Land Area Requirements

1. Land Area Requirements for **Demonstration Facility**

Demonstration Facility Size	________	tons per year
Land Area Required for Water Bath	________	acres
Land Area Required for Process Tanks	________	acres
Land Area Required for Process Buildings	________	acres
Land Area Required for Aerobic Finishing Process	________	acres
Land Area Required for Long Term Materials Storage	________	acres
Land Area Suggested for Buffer for Surrounding Land Uses	________	acres
Land Area Required for Other Facility Components	________	acres
Total Land Area Required	________	acres

1. Land Area Requirements for **Commercial Facility**

Commercial Facility Size	________	tons per year
Land Area Required for Water Bath	________	acres
Land Area Required for Process Tanks	________	acres
Land Area Required for Process Buildings	________	acres
Land Area Required for Aerobic Finishing Process	________	acres
Land Area Required for Long Term Materials Storage	________	acres
Land Area Suggested for Buffer for Surrounding Land Uses	________	acres
Land Area Required for Other Facility Components	________	acres
Total Land Area Required	________	acres

Form 5 - Assumed Waste Analysis (Basis for Mass Balance)

For purposes of completing the Mass and Energy Balance for the demonstration and commercial facilities proposed for the City (Form 3), the following waste analysis should be assumed for MSW as received. The analysis for MSW after pre-processing should be specified by the respondent, as applicable.

1. Specified Waste Analysis

Component [1]	MSW as Received [2]	MSW as Processed [3]
Carbon (%)	27.9	
Hydrogen (%)	3.7	
Nitrogen (%)	0.2	
Sulfur (%)	0.1	
Chlorine (%)	0.1	
Ash (%)	16.0	
Oxygen (%)	20.7	
Moisture (%)	31.3	
Ultimate Analysis Total (%)	**100.0**	
Higher Heating Value - HHV (Btu/lb)	5,100	
Lower Heating Value - LHV (Btu/lb)	4,500	

1. As received at the laboratory (including moisture and ash).
2. To be used as the basis for mass and energy balance, as applicable (Source: Babcock & Wilcox, Steam It's Generation and Use, 40th Edition, 1992, with the exception of LHV which was calculated by ARI based on the other specified data).
3. Waste analysis after pre-processing, if applicable. To be specified by respondent.

2. Other Required Assumptions

Please indicate any other assumptions about analysis of waste, as received, if such assumptions are relevant to the quality and characteristics of products and residuals generated, relevant to other elements of the mass and energy balance, or otherwise significant for review and evaluation of the technology (e.g., metals, volatiles, etc.).

Form 6 - Biogas Composition for Demonstration and Commercial Facility

NOTE: If the following information differs for the demonstration facility and the commercial facility proposed for the City, please complete a separate form for each.

1. Composition of Biogas as Produced

Description	Information Previously Submitted	Current Submittal
Methane CH_4	73% to 75%	
Carbon Dioxide CO_2	21% to 26%	
Water Vapor		
Hydrogen Sulfide	Less than 100 ppm	
Other (describe):		
Other (describe):		

2. Disposition of the Biogas

Describe the disposition of the biogas:

How will the biogas be cleaned or otherwise processed prior to combustion or other disposition?

If combustion of the biogas is planned, describe the combustion device (e.g., engine, turbine, boiler, flare)

3. Composition of Processed Biogas Prior to Combustion or Other Disposition

Description	Information Previously Submitted	Current Submittal	Units
Methane CH_4	--		Percent
Carbon Dioxide CO_2	--		Percent
Water Vapor	--		Percent
Hydrogen Sulfide	--		ppm
Other (describe)	--		
Quantity of Processed Biogas	--		Cubic feet per minute at 60^oF
Heating Value of the Processed Biogas HHV not LHV	--		BTU/lb @ 60^oF

4. Attach supporting documentation of the biogas composition based on test data from the reference facility identified in Form 2. Is this data expected to be similar or different from the biogas composition expected to be generated by the NYC waste? Please explain.

Form 7 - Emissions from Combustion of Biogas

NOTE: If the following information differs for the demonstration facility and the commercial facility proposed for the City, please complete a separate form for each.

1. Expected Emissions Generated by the Combustion of the Biogas

Description	Information Previously Submitted	Current Submittal	Units
Particulate Matter			gr/dscf@7%O_2
Particulate Matter			Pounds per ton of incoming MSW
Particulate Matter			Pounds per MMBTU
Carbon Monoxide			ppmdv @ 7% O_2
Carbon Monoxide			Pounds per ton of incoming MSW
Carbon Monoxide			Pounds per MMBTU
Carbon Dioxide			ppmdv @ 7% O_2
Carbon Dioxide			Pounds per ton of incoming MSW
Carbon Dioxide			Pounds per MMBTU
NOx			ppmdv @ 7% O_2
NOx			Pounds per ton of incoming MSW
NOx			Pounds per MMBTU
SOx			ppmdv @ 7% O_2
SOx			Pounds per ton of incoming MSW
SOx			Pounds per MMBTU

2. Attach, as supporting documentation, emissions test data for the reference facility identified in Form 2. Is this emissions data similar to or different from the emissions expected to be generated by processing the NYC waste? Please explain.

3. Is supplemental fuel used when combusting the biogas to generate electricity?
If yes, describe the type (e.g., natural gas) and the quantity (mmBTU/ton of MSW received).

Form 8 - Pollution Control Information

Please describe, for the processes listed below, the proposed air pollution and odor control equipment for the demonstration and commercial facilities proposed for the City. Where applicable, indicate the method of pollution control, air pollutants controlled, and air pollution control equipment removal efficiency for each pollutant.

1. MSW Receiving:

2. MSW Pre-Processing:

3. Process Fugitive Emissions:

4. Biogas Combustion:

5. Compost Management:

6. Residuals Management:

7. Other (Specify):

Form 9 - Wastewater Characteristics

This form is applicable only if wastewater is discharged from the facility. If there is more than one wastewater stream, please complete this form for each wastewater stream. **Also, if the information on this form differs for a demonstration facility and a commercial facility, please complete a separate form for each.**

1. Characteristics of Wastewater Prior to Aerobic Polishing

Description	Information Prev. Submitted	Current Submittal	Units
Wastewater Quantity			Gallons per ton of incoming MSW
BOD	66		mg/L
COD	618		mg/L
TSS 105^{o}	256		mg/L
pH	7.7		mg/L
Total Nitrogen			mg/L
Phosphorus	10		mg/L
Arsenic	<0.1		mg/L
Cadmium	<0.01		mg/L
Copper	<0.05		mg/L
Lead	<0.1		mg/L
Mercury	<0.05		mg/L
Molybdenum	<0.05		mg/L
Nickel	<0.05		mg/L
Selenium	<0.05		mg/L
Zinc	<0.05		mg/L
Chlorides	626		mg/L

2. Characteristics of Wastewater After Aerobic Polishing (1)

Description	Information Prev. Submitted	Current Submittal	Units
Wastewater Quantity			Gallons per ton of incoming MSW
BOD	5		mg/L
COD	28		mg/L
TSS 105^{o}	5		mg/L
pH	8.3		mg/L
Total Nitrogen			mg/L
Phosphorus	<0.5		mg/L
Arsenic	<0.1		mg/L
Cadmium	<0.01		mg/L
Copper	<0.05		mg/L
Lead	<0.1		mg/L
Mercury	<0.05		mg/L
Molybdenum	<0.05		mg/L
Nickel	<0.05		mg/L
Selenium	<0.05		mg/L
Zinc	<0.03		mg/L
Chlorides	286		mg/L

(1) Wastewater discharged to the sewer must meet Federal, State and local requirements

Form 10 - General Respondent Business Information

1. Provide a discussion of the Respondent's business and its operations, business history and ownership structure (e.g., corporation, corporate subsidiary of another corporation, joint venture, partnership/LLC, etc.), including a discussion of any long-term contractual relationships, teaming arrangements or other strategic alliances that are pertinent to the City's solid waste program.

2. Provide a discussion of the Respondent's relationship to the proposed technology (e.g., years of direct history with the technology; ownership and/or license arrangements; other parties involved in technology development and ownership, etc.).

3. Provide a discussion of the Respondent's views regarding the provision of guarantees (e.g., would it/does it offer cost and performance guarantees (either company or via a parent corporation)? Are any such guarantees provided with financial caps or limits? Would it/does it offer security instruments such as letters of credit and construction and operations performance bonds?

4. Regarding technologies that may produce marketable products (whether materials, chemicals or energy products), would/does the Respondent take full business risk regarding product quality, marketability, sale and revenues derived from such products, and related risks such as residuals disposal? Generally, under what circumstances, if any, would the Respondent expect the City to bear some product- and market-related risks?

Form 11 - Financial Resources Data

Please complete this form for respondent and Major Participating Firms, if any. Major Participating Firms, if known or identified for the purposes of this submission, include those whose participation would account for 15% or more of the construction cost or the annual O&M cost.

Name of Company Completing Form	Name and Title of Corporate Officer Certifying Form
Signature:	Date

1. Rating Information

Current ratings on two most recent senior debt issues, if any.

	Issue Description	**Moody's Rating**	**S&P's Rating**
Issue 1			
Issue 2			

2. Financial Indicators

Complete the following table.

Fiscal Year End: ______________

		1	2	3
		2002	2003	2004
A.	Total Revenues	$	$	$
B.	Net Income	$	$	$
C.	Total Assets	$	$	$
D.	Total Liabilities	$	$	$
E.	Net Worth (C-D)	$	$	$

Form 11 - Financial Resources Data

Using the information provided in the Table above, calculate:

A. Revenue Growth Percentages.

2003: (A2-A1)/A1 ___________%

2004: (A3-A2)/A2 ___________%

B. Profitability Measures.

RETURN ON REVENUE

2002: B1/A1 ___________%

2003: B2/A2 ___________%

2004: B3/A3 ___________%

RETURN ON ASSETS

2002: B1/C1 ___________%

2003: B2/C2 ___________%

2004: B3/C3 ___________%

C. Leverage Ratio

2002: D1/E1 ___________%

2003: D2/E2 ___________%

2004: D3/E3 ___________%

3. Additional Financial Information

Provide an annual report and Form 10-K for the most recent fiscal year of the Respondent and, if appropriate, its parent corporation and other Major Participating Firms.

Form 12 - Construction Cost Estimate for a Demonstration Facility

Please provide the estimated construction cost for a **demonstration facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below. Construction costs shall be all inclusive of design and engineering, permitting, testing, contractor development fees and costs, structures, equipment, storage facilities, environmental control systems, ancillary systems, vehicles, etc., but *excluding* currently undeterminable costs such as site acquisition, abnormal site conditions and site remediation. Please include assumptions for any financing-related costs, including length of "typical" design and construction period. Please provide, to the extent available, supporting documentation associated with the reference facility identified in Form 2.

1. Demonstration Facility Capacity (tpy): ______________________
   (not to exceed 182,500 tpy)

2. Estimated Construction Cost (June 2005 dollars):

Item	Cost
Development (Fees, Permits, etc.)	$____________________
Engineering & Design	$____________________
Structures	$____________________
Pre-Processing Equipment	$____________________
Processing Equipment [1]	$____________________
Power Generation Equipment	$____________________
Storage Facilities	$____________________
Environmental Control Systems	$____________________
Ancillary Systems	$____________________
Vehicles	$____________________
Other (Specify)	$____________________
Total Estimated Construction Cost	$____________________

1. Including any processing/material handling associated with products and process residuals.

3. Description of "Other" cost items:

4. Assumptions:

Form 13 - Construction Cost Estimate for a Commercial Facility

Please provide the estimated construction cost for a **commercial facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below. Construction costs shall be all inclusive of design and engineering, permitting, testing, contractor development fees and costs, structures, equipment, storage facilities, environmental control systems, ancillary systems, vehicles, etc., but *excluding* currently undeterminable costs such as site acquisition, abnormal site conditions and site remediation. Please include assumptions for any financing-related costs, including length of "typical" design and construction period. Please provide, to the extent available, supporting documentation associated with the reference facility identified in Form 2.

1. Commercial Facility Capacity (tpy): ______________________
   (not to exceed 1,095,000 tpy)

2. Estimated Construction Cost (June 2005 dollars):

Item	Cost
Development (Fees, Permits, etc.)	$____________________
Engineering & Design	$____________________
Structures	$____________________
Pre-Processing Equipment	$____________________
Processing Equipment [1]	$____________________
Power Generation Equipment	$____________________
Storage Facilities	$____________________
Environmental Control Systems	$____________________
Ancillary Systems	$____________________
Vehicles	$____________________
Other (Specify)	$____________________
Total Estimated Construction Cost	$____________________

1. Including any processing/material handling associated with products and process residuals.

3. Description of "Other" cost items:

4. Assumptions:

Form 14 - Operation & Maintenance Cost Estimate for a Demonstration Facility

Please provide the estimated operation and maintenance cost for a **demonstration facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below. Please provide, to the extent available, supporting documentation associated with the reference facility identified in Form 2.

1. Demonstration Facility Capacity (tpy): ______________________
   (not to exceed 182,500 tpy)

2. Estimated Operation and Maintenance Cost (June 2005 dollars):

Item	Annual Cost ($/Year)
Labor (e.g., Salary & Benefits) (1)	$ ________________
Residuals Disposal (2)	$ ________________
Utilities	
Water	$ ________________
Wastewater	$ ________________
Natural Gas	
Fossil Fuel	$ ________________
Imported Electricity (3)	$ ________________
Other (4)	$ ________________
Chemicals (5)	
Air Pollution Control (carbon, lime, etc.)	$ ________________
Water/Wastewater Treatment	$ ________________
Process Operations	$ ________________
Other	$ ________________
Maintenance & Repair	$ ________________
Capital Repair & Replacement	$ ________________
Wheeling Charges for Electricity, if applicable	$ ________________
Transportation/Haul Costs (6)	
Residuals to Disposal	$ ________________
Front-end Recyclables to Markets	$ ________________
Process Products (including Compost) to Markets	$ ________________
Miscellaneous and Other Costs (7)	$ ________________
Total O&M Costs	$ ________________

(1) Provide an organization chart showing staffing resources
(2) Specify annual quantity (tpy and % of incoming MSW) requiring disposal
(3) Specify quantity of imported electricity
(4) Specify other utilities, if any
(5) Specify types of chemicals required
(6) Specify assumed distance to markets and disposal locations
(7) Specify or describe miscellaneous/other costs

3. Please attach the details requested in the footnotes to the O&M cost table.

Form 15 - Operation & Maintenance Cost Estimate for a Commercial Facility

Please provide the estimated operation and maintenance cost for a **commercial facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below. Please provide, to the extent available, supporting documentation associated with the reference facility identified in Form 2.

1. Commercial Facility Capacity (tpy): ______________________
   (not to exceed 1,095,000 tpy)

2. Estimated Operation and Maintenance Cost (June 2005 dollars):

Item	Annual Cost ($/Year)
Labor (e.g., Salary & Benefits) (1)	$ ________________
Residuals Disposal (2)	$ ________________
Utilities	
Water	$ ________________
Wastewater	$ ________________
Natural Gas	
Fossil Fuel	$ ________________
Imported Electricity (3)	$ ________________
Other (4)	$ ________________
Chemicals (5)	
Air Pollution Control (carbon, lime, etc.)	$ ________________
Water/Wastewater Treatment	$ ________________
Process Operations	$ ________________
Other	$ ________________
Maintenance & Repair	$ ________________
Capital Repair & Replacement	$ ________________
Wheeling Charges for Electricity, if applicable	$ ________________
Transportation/Haul Costs (6)	
Residuals to Disposal	$ ________________
Front-end Recyclables to Markets	$ ________________
Process Products (including Compost) to Markets	$ ________________
Miscellaneous and Other Costs (7)	$ ________________
Total O&M Costs	$ ________________

(1) Provide an organization chart showing staffing resources
(2) Specify annual quantity (tpy and % of incoming MSW) requiring disposal
(3) Specify quantity of imported electricity
(4) Specify other utilities, if any
(5) Specify types of chemicals required
(6) Specify assumed distance to markets and disposal locations
(7) Specify or describe miscellaneous/other costs

3. Please attach the details requested in the footnotes to the O&M cost table.

Form 16 - Product Revenues for a Demonstration Facility

Please provide the estimated quantity, unit value, and annual revenues associated with products and recovered materials for a **demonstration facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below.

1. Demonstration Facility Capacity (tpy): ______________________
   (not to exceed 182,500 tpy)

2. Estimated Products, Unit Value or Price, and Annual Revenues (June 2005 dollars):

Products and/or Recovered Materials	Amount (Percent of Incoming Waste Stream)	Annual Amount		Per Unit Value or Price		Annual Revenue
		Quantity	Unit	Price	Unit	
Electricity (1)			kWh/yr		$/kWh	
Digester Gas			mmCF		$/mmCF	
Front-end Recyclables						
Ferrous Metal			tons		$/ton	
Aluminum			tons		$/ton	
Other Non-Ferrous Metal			tons		$/ton	
Plastics			tons		$/ton	
Glass			tons		$/ton	
Paper			tons		$/ton	
Other:______________			tons		$/ton	
Other:______________			tons		$/ton	
Compost			tons		$/ton	
Other Products (2)						
1.						
2.						
3.						
4.						
5.						
6.						
					Total Annual Revenue:	

(1) For electricity sales, specify if price assumes a capacity credit.
(2) For other products, list products by type and provide a description; indicate units as appropriate.

3. Please identify the likely markets for products (i.e., end users and location of those end users), describe the quality necessary to market the products at the assumed unit values, and discuss how the products would meet the necessary quality standards. Provide a discussion of marketing risks and uncertainties (i.e., market volatility) and disclosure of financial consequences (i.e., cost impacts) of market fall-off or market rejection of products.

Form 17 - Product Revenues for a Commercial Facility

Please provide the estimated quantity, unit value, and annual revenues associated with products and recovered materials for a **commercial facility** located in New York City or the New York City Metropolitan Area, at the size specified in Form 1 and restated below.

1. Commercial Facility Capacity (tpy): ______________________
   (not to exceed 1,095,000 tpy)

2. Estimated Products, Unit Value or Price, and Annual Revenues (June 2005 dollars):

Products and/or Recovered Materials	Amount (Percent of Incoming Waste Stream)	Annual Amount		Per Unit Value or Price		Annual Revenue
		Quantity	Unit	Price	Unit	
Electricity (1)			kWh/yr		$/kWh	
Digester Gas			mmCF		$/mmCF	
Front-end Recyclables						
Ferrous Metal			tons		$/ton	
Aluminum			tons		$/ton	
Other Non-Ferrous Metal			tons		$/ton	
Plastics			tons		$/ton	
Glass			tons		$/ton	
Paper			tons		$/ton	
Other:______________			tons		$/ton	
Other:______________			tons		$/ton	
Compost			tons		$/ton	
Other Products (2)						
1.						
2.						
3.						
4.						
5.						
6.						
Total Annual Revenue:						

(1) For electricity sales, specify if price assumes a capacity credit.
(2) For other products, list products by type and provide a description; indicate units as appropriate.

3. Please identify the likely markets for products (i.e., end users and location of those end users), describe the quality necessary to market the products at the assumed unit values, and discuss how the products would meet the necessary quality standards. Provide a discussion of marketing risks and uncertainties (i.e., market volatility) and disclosure of financial consequences (i.e., cost impacts) of market fall-off or market rejection of products.

APPENDIX C

ORGANIC WASTE SYSTEMS
DRANCO, DRY ANAEROBIC DIGESTION TECHNOLOGY

APPENDIX C

ORGANIC WASTE SYSTEMS
DRANCO, DRY ANAEROBIC DIGESTION TECHNOLOGY

Organic Waste Systems (OWS), a Belgian company, offers the patented DRANCO dry anaerobic digestion technology. The DRANCO technology has been applied most often with source-separated organic waste, but is also used for mixed MSW and can be used to process sewage sludge and other organic waste. The DRANCO process is considered a "dry" anaerobic digestion process; in other words, the solids content of the material in the digester is 30% or greater. Specifically, the DRANCO process operates within a range of 35% to 40% solids. The operating temperature within the DRANCO anaerobic digester is typically 50° to 55°C (approximately 120° to 130°F), making it a thermophilic digestion process (i.e., provides the ideal conditions for thermophilic bacteria).

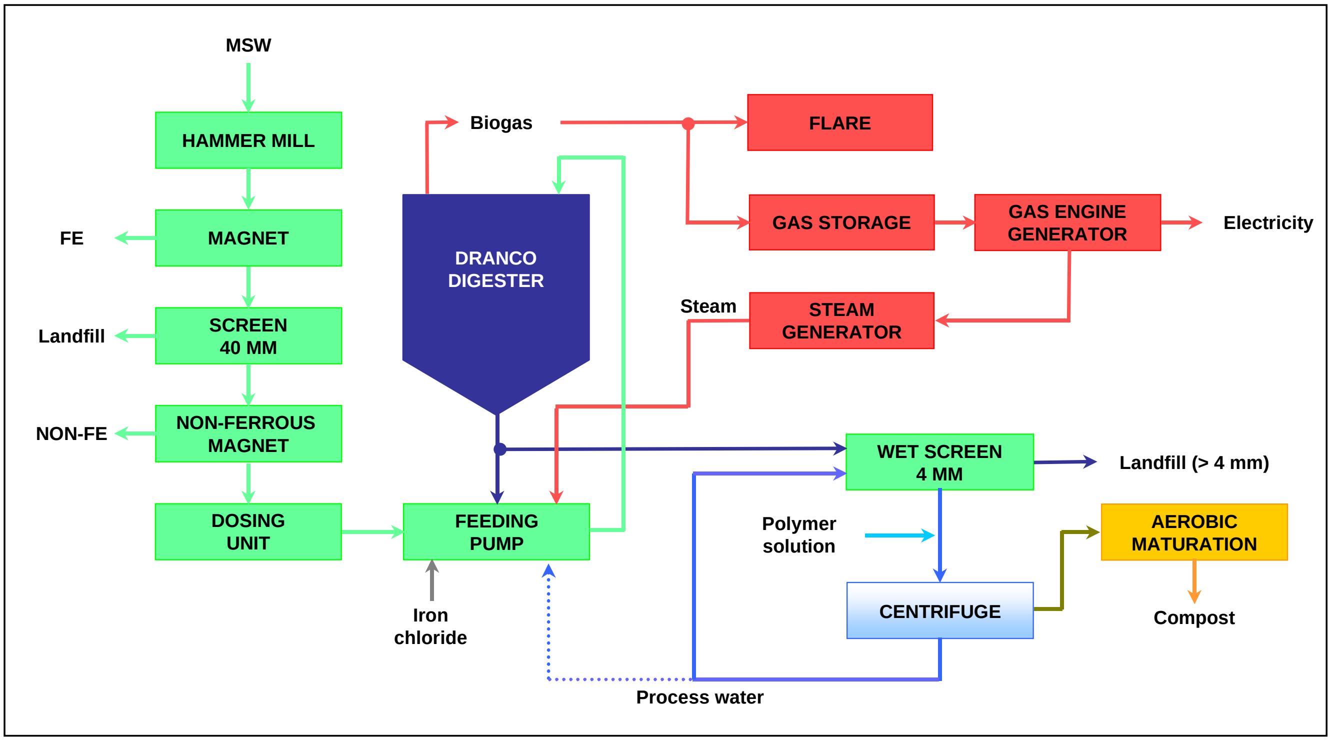
For purposes of the Phase 2 Study, OWS identified the 55,000-tpy Brecht II facility as its reference facility. The Brecht II facility, which has been in commercial operation since January 2000, is owned and operated by IGEAN, an association of municipalities around the City of Antwerp, Belgium. At the onset of the Phase 2 Study, it was represented by OWS that Brecht II was processing, or had previously processed, mixed MSW. However, in later correspondence with OWS it was disclosed that Brecht II processes biowaste only (source-separated organics including food waste and yard waste, diapers, and non-recyclable paper) and has never processed mixed MSW. OWS disclosed that several facilities using the DRANCO technology do so with mixed MSW, including Bassum, Kaiserslautern, Munster and Hille, all of which are located in Germany. However, OWS was not able to provide detailed information for these facilities, either because the facilities have just recently started up, or because OWS is not involved in the operation of these plants. Therefore, the intent of verifying and validating data associated with processing mixed MSW was not achieved for the OWS DRANCO technology. However, the information in this Appendix C is provided for reference, and to generally share information that was learned during the Phase 2 Study.

OWS DRANCO Reference Facility	
Name:	Brecht II
Location:	Brecht, Belgium (near Antwerp)
Capacity:	55,000 tpy
Type of Waste:	Source-Separated Organic Waste
Owner:	IGEAN (association of municipalities)
Operator:	IGEAN
Commercial Operation:	January, 2000

<u>Description of the OWS DRANCO Technology</u>

Figure C-1 shows a process flow diagram for the DRANCO technology. The figure, provided by OWS, uses the terminology MSW for source-separated waste. MSW as referred to by OWS is not the same as mixed MSW as defined by the City for the Phase 2 Study.

Figure C-1. Schematic Diagram of DRANCO Technology



Waste is received and stored on a tipping floor in an enclosed area. Mobile equipment such as front-end loaders are used to remove bulky waste and feed MSW onto conveyors. The conveyors feed a hammer mill, which size-reduces the MSW. Following the hammer mill, ferrous metal is removed using a magnet. After ferrous recovery, the material passes through a rotating screen. Materials that are larger than the 40-millimeter screen openings, typically inorganic materials such as plastics, textiles, etc., pass over rather than through the screen. These "overs" are then passed by an eddy current separator for recovery of nonferrous metal. The remaining "overs" are disposed of as residue. Materials smaller than the screen openings pass through the screen and make up the feedstock for digestion. Most of the biodegradable organic material in the MSW will be small enough to pass through the screen openings, although some organics may remain on the screen and be disposed of as residue. Inorganic materials that are smaller than the screen openings (e.g., broken glass, stones, etc.) will be present in the prepared feedstock.

OWS reports that the purpose of the pretreatment of MSW (i.e., size reduction and recovery of metals) is to concentrate biodegradable organics for digestion. A material recovery facility (MRF) could be coupled with the DRANCO technology to remove more recyclables from the MSW. If economically attractive, OWS would team with a partner to provide such a MRF. At this time, OWS is not proposing to do so.

The DRANCO digestion process is single-step, with the complete anaerobic process taking place in the same digester volume. The prepared waste is mixed with previously digested material, at a ratio of one part prepared waste to approximately seven parts digested material, to inoculate the prepared waste with the anaerobic microorganisms (shown on

Figure C-1 as the "dosing unit". Steam is injected into the inoculated mixture to increase the temperature to the thermophilic range of 48°C to 55°C, and the heated mixture is pumped into the top of the digester. The material in the digester moves from top to bottom by gravity, over approximately a three-day period. With the recycling of digested material with prepared waste at a ratio of approximately 7:1, the average retention time in the digester is about 25 days. As new material is fed into the top of the digester, digested material is extracted through the bottom.

As described above, a portion of the digestate is mixed with prepared waste and recirculated through the digester, while a portion is extracted for post-processing. Post-processing consists of removal of residue using a wet screen, dewatering with a centrifuge, and aerobic finishing (composting). The post-processing screen has smaller openings than the pre-processing screen (4 mm compared to 40 mm). Therefore, inorganic material, including plastic, broken glass, textiles, and other foreign material that passed through the pre-processing screen and entered the digestion process as part of the prepared waste is removed in the post-processing screening process as residue requiring landfilling.

After screening, the material passes through a centrifuge to separate solids from liquids. Water removed with the centrifuge is used as process water, both to operate the wet screen and for achieving the proper consistency of the prepared feedstock to the digester (i.e., 35-40% solids). OWS originally reported that it did not expected there would be any excess of wastewater, or that such quantities would be very limited. During due diligence, OWS disclosed an estimate of approximately 2,000,000 gallons per year (5,500 gallons per day) of wastewater would be discharged.

After dewatering, the digestate requires aerobic finishing before it is considered a mature, stable compost. OWS uses an unspecified, in-vessel technology. Recycled air from building enclosures is used to supply oxygen to the composting process, which takes approximately two weeks.

Proposed Facility Capacity for New York City

As part of the study, OWS was requested to designate a capacity for a demonstration facility and a commercial facility for New York City. The capacity was to be specific to the DRANCO technology, with size guidelines established by the City.

As summarized below, OWS designated a demonstration facility with an annual capacity (at 365 days per year) of 182,500 tpy and an availability of 100%, resulting in an annual waste throughput of 182,500 tpy. This is equivalent to an average daily throughput of 500 tpd, calculated based on 365 days per year. The facility would consist of one digester. OWS would achieve 100% availability by operating 16 hours per day, 365 days per year, and performing maintenance during off-hours.

OWS designated a commercial facility with an annual capacity of 1,095,000 tpy (i.e., the maximum capacity allowed for any technology, for purposes of the study). This capacity is equivalent to an average daily throughput of 3,000 tpd, calculated based on 365 days per year. In discussions with OWS, it was determined that a 3,000-tpd facility is not currently practical, considering land availability required for this size facility (at least 50 acres). Also, this size facility is significantly larger than the DRANCO reference facility. Therefore, for purposes of this study and in discussion with OWS, the capacity for the commercial facility is considered to be 182,500 tpy (500 tpd), which is the same as the proposed demonstration facility.

OWS	**Demonstration Facility**	**Commercial Facility**
Annual Capacity (at 365 days/yr):	182,500 tpy	182,500 tpy
Annual Availability:	100%	100%
Annual Throughput:	182,500 tpy	182,500 tpy
Avg. Daily Throughput (at 365 days/yr):	500 tpd	500 tpd
Land Area Required:	20 acres	20 acres

Site Layout / Size Requirements for New York City

OWS originally reported that the total land area required for a 182,500-tpy facility would be 10 acres. OWS did not provide a breakdown of land area requirements for the facility sub-systems, such as pre-processing, process tanks, process buildings, and long-term materials storage. The reported acreage specifically *excluded* area required for long-term materials storage, buffer, and other facility components (e.g., roadways, administrative buildings, etc.). Following independent due diligence, OWS reported that site acreage would approximately double with all the required facility components, including a recommended four-month outdoor storage area for compost. Therefore, the land area required for a complete facility is assumed to be 20 acres. OWS did not provide a facility site layout or general equipment arrangement to confirm site requirements.

Mass Balance

Based on information provided by OWS and an independent review of the data, the mass facility balance appears reasonable. Specific elements of the mass balance are further discussed below.

Recyclables. The OWS system recovers only metal (ferrous and aluminum) as recyclables:

Material	**Amount (%)(1)**	**Amount (tpy)(2)**
Ferrous Metal	2.2%	4,000
Aluminum	0.5%	1,000
Total	2.7%	5,000

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 182,500 tpy.

Based on information provided to OWS regarding the composition of the City's wastestream (see Section 3.3 of this Report), OWS recovers approximately 68% of the metal present in the City's waste; this is a reasonable recovery rate. However, with recovery of only 2.7% by weight of the MSW processed, OWS has the lowest amount of recovered recyclables of the three anaerobic digestion technologies reviewed.

Residue Requiring Landfill Disposal. In the up-front processing step, approximately 22.2% of the MSW received for processing does not pass through the 40-mm screen and is landfilled as residue. In the post-digestion processing step, material that does not pass through the 4-mm screen is also landfilled. This additional residue is approximately 21.4% by weight of incoming MSW. As summarized below, the percentage of incoming MSW removed as residue and requiring landfill disposal is 43.6% by weight. The DRANCO process generates a higher amount of residue than the other anaerobic digestion technologies evaluated as part of this study, because of the reduced amount of materials recovered in the front-end as recyclables.

Material	Amount (%)[1]	Amount (tpy)[2]
Pretreatment Residue	22.2%	40,515
Post-Digestion Residue	21.4%	39,055
Total	43.6%	79,570

(1) Percent by weight of MSW received for processing.
(2) For a commercial facility with a throughput of 182,500 tpy.

Organic Material Input to Anaerobic Digestion. Approximately 75% by weight of the incoming MSW is input to the anaerobic digester. However, not all of this material is biodegradable organic matter, as evidenced by the need to screen the digestate to remove foreign materials (e.g., glass, plastic and other inorganics) prior to composting.

Compost Produced. The compost production rate is approximately 33% of the incoming MSW (on a wet weight basis), which is the highest rate of all anaerobic digestion technologies reviewed for this study. OWS reported that the compost could be produced to be visually "clean", due to the post-digestion wet screening through the very fine, 4-mm screen. This screening removes foreign material such as plastics, glass and stones from the compost. OWS provided a summary of the Flemish (Belgian) compost standards, along with an analysis of compost produced at the Brecht II plant. However, because the Brecht II plant processes source-separated organic waste, the analysis is not an indication of the characteristics of the compost produced from mixed MSW. As previously stated, the intent of the Phase 2 Study was to review data associated with processing MSW, and this data was requested from OWS. OWS was unable to provide such data.

Energy Balance. Based on information provided by OWS, an independent energy analysis was completed for the DRANCO technology. Relevant information regarding the biogas characteristics and energy generation for the DRANCO process is as follows:

Parameter	Performance	
Quantity of Biogas Generated:	15.8%	(% by weight of MSW received)
Biogas Composition		
Methane Content:	55%	
Carbon Dioxide Content:	45%	
Hydrogen Sulfide Content:	800 ppm	
Heating Value of Biogas:	7,000	Btu/lb
Gross Electricity Generated:	189	kWh/ton of waste received
Net Electricity Generated for Sale:	94	kWh/ton of waste received
Energy Conversion Efficiency:	28.9%	

The DRANCO anaerobic digestion technology produces biogas at a rate approximately equal to 15.8% of the incoming MSW by weight. The biogas produced consists of methane, typically at a concentration of 55%, and carbon dioxide at a concentration of approximately 45%. Independent calculations indicate the biogas has a heating value of approximately 7,000 Btu/lb. In comparison, natural gas has a heating value of approximately 23,600 Btu/lb.

OWS reported that the biogas would be combusted in a reciprocating engine to generate electricity. No air pollution control devices are specified for use on the engine. Supplemental fuel (e.g., natural gas) is not used. The energy production rate is reported to be 189 kWh per ton of incoming MSW. The technology requires approximately 95 kWh for internal use, resulting in net electricity generated for export (sale) of approximately 94 kWh per ton of incoming MSW.

An independent analysis was completed of the energy conversion efficiency for the DRANCO process. Assuming a biogas generation rate of 316 pounds of biogas generated per ton of incoming mixed MSW, a biogas methane content of 55% by weight, and gross generation of 189 kWh of electricity per ton of MSW through combustion of the biogas in a reciprocating engine, the energy conversion efficiency of the engine is estimated to be 28.9%. This calculated energy conversion efficiency is at the low end of efficiencies achievable with reciprocating engines combusting biogas, which may reflect conservative assumptions by OWS regarding electricity generation rates.

Technology References. OWS provided contact information for the Brecht II plant, as a reference for the DRANCO technology. Mr. Peter Magielse, operator of the Brecht II plant, was independently contacted by telephone. Mr. Magielse provided an overview of the plant, reporting favorable operations and no problems associated with noise or dust. He reported that the compost meets the standards of VLACO, the Flemish compost organization, as well as the standards of the ministry of agriculture. He also reported that all compost is sold, for use in gardens and parks. While this reference check provides an indication that the OWS reference facility is running well, the information is of limited use since the plant processes source separated organic waste and not MSW.

Corporate and Financial Information

OWS provided corporate and financial information in response to four specific questions asked on Form 10 of the City's Supplemental Information Request. Information provided by OWS is summarized below.

Question 1. Provide a discussion of the Respondent's business and its operations, business history and ownership structure (e.g., corporation, corporate subsidiary of another corporation, joint venture, partnership/LLC, etc.), including a discussion of any long-term contractual relationships, teaming arrangements or other strategic alliances that are pertinent to the City's solid waste program. The parent company, OWS NV is Belgian, formed in 1988. In addition to selling the DRANCO process, the company operates a laboratory in Belgium, maintains a limited U.S. presence through OWS, Inc, and owns an operations company which provides plant start-up and operations services. OWS reportedly has relationships with U.S. construction, finance and operations firms, the details of which were not disclosed. OWS would build-out OWS, Inc. to support projects in the U.S.

Question 2. Provide a discussion of the Respondent's relationship to the proposed technology (e.g., years of direct history with the technology; ownership and/or license arrangements; other parties involved in technology development and ownership, etc.). OWS developed, owns and continues to control the proprietary DRANCO technology.

Question 3. Provide a discussion of the Respondent's views regarding the provision of guarantees (e.g., would it/does it offer cost and performance guarantees (either company or via a parent corporation)? Are any such guarantees provided with financial caps or limits? Would it/does it offer security instruments such as letters of credit and construction and operations performance bonds? OWS would undertake either design/build/operate (DBO) or design/build/own/operate (DBOO) project delivery (it did one design/build/own/operate/ transfer project in Europe). While it offers bank guarantees such as letters of credit, it has also provided single-source guarantees on projects (in the range of $15 million).

Question 4. Regarding technologies that may produce marketable products (whether materials, chemicals or energy products), would/does the Respondent take full business risk regarding product quality, marketability, sale and revenues derived from such products, and related risks such as residuals disposal? Generally, under what circumstances, if any, would the Respondent expect the City to bear some product- and market-related risks? In the case of a DBO or DBOO contract, OWS would be willing to take full commercial risks on product quality, marketing and pricing.

Economic Analysis

OWS and the DRANCO technology were included in the economic analysis conducted for the Phase 2 Study, for a 500-tpd (182,500 tpy) commercial facility. Model inputs and results for OWS are as follows:

Parameter	OWS Commercial Facility (182,500 tpy)
Construction Cost	$80,000,000
Construction Cost per Ton ($/tpd)	$160,000
Site Acreage Required	20 acres
Site Acquistion Cost ($150,000/acre)	$3,000,000
Annual Operating Cost	$4,770,000
O&M Cost pet Ton ($/tpy)	$26.14
Projected Tipping Fee ($/ton)	
Base Case - Private Ownership and Financing (DBOO)	$141/ton
Sensitivity - Public Ownership and Financing (DBO)	$112/ton

APPENDIX D

ECONOMIC EVALUATIONS AND PROJECTIONS

City of New York, New York
Advanced, Conversion Technologies

Economic Evaluations and Projections

<u>Anaerobic Digestion Technologies</u>
Commercial Scale Facilities/DBOO Implementation

Alternative Resources, Inc.

March 2006

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

Anaerobic Digestion Technologies
Commercial Scale Facilities/DBOO Implementation

Summary of Projections

	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
Facility			
Waste Processed (Average Tons/Day 365 Days/Year)	586	500	500
Waste Processed (Tons/Year)	214,000	182,500	182,500
Development & Capital Costs			
Development, Design & Construction Costs	52,902,464	51,114,228	98,524,184
Financing-Related Costs	30,751,573	29,712,092	57,270,935
Total Capital Cost	83,654,037	80,826,319	155,795,118
Annual Costs			
Annual Debt Service	8,544,139	8,255,326	15,912,384
Year 1 O&M Costs	10,731,750	9,674,009	14,529,432
Total Year 1 Costs	19,275,890	17,929,334	30,441,816
Annual Revenues			
Total Year 1 Revenues	7,298,518	3,326,977	4,709,612
Net Year 1 Costs	11,977,371	14,602,357	25,732,204
Year 1 (2014) Tipping Fee Required	**$55.97**	**$80.01**	**$141.00**

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

	Inputs & Assumptions	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
	General Information			
1	Throughput (average tons/day 365 days/year)	586	500	500
2	MSW Processed in Beginning Year (tons/year)	214,000	182,500	182,500
3	Discount Rate (Tax-Exempt Cost of Capital)	4.65%	4.65%	4.65%
4	Inflation Rate / General Escalation	3.00%	3.00%	3.00%
5	Start Year	1	1	1
6	Operations Starting Year ("Year 1")	2014	2014	2014
7	Construction Starting Year	2011	2011	2011
8	Cost Basis Year	2005	2005	2005
9	O&M Term (Years)	20	20	20
10	End Year	2033	2033	2033
	Waste Handling & Processing			
11	Total Tonnage Processed (Year 1)	214,000	182,500	182,500
12	Residuals/Ash for Disposal (%)	23.36%	30.90%	43.60%
13	Residuals/Ash for Disposal (tons)	50,000	56,393	79,570
14	Ferrous Recovered (%)	1.86%	3.15%	2.19%
15	Ferrous Recovered (tons/year)	3,970	5,749	4,000
16	Aluminum Recovered (%)	0.82%	0.30%	0.55%
17	Aluminum Recovered (tons/year)	1,750	548	1,000
18	Other Non-Ferrous Recovered (%)	0.00%	0.00%	0.00%
19	Other Non-Ferrous Recovered (tons/year)	0	0	0
20	Plastics Recovered (%)	12.00%	4.90%	0.00%
21	Plastics Recovered (tons/year)	25,680	8,943	0
22	Glass Recovered (%)	0.00%	0.00%	0.00%
23	Glass Recovered (tons/year)	0	0	0
24	Paper Recovered (%)	0.00%	0.00%	0.00%
25	Paper Recovered (tons/year)	0	0	0
26	Other Materials (Wood) Recovered (%)	0.00%	0.70%	0.00%
27	Other Materials (Wood) Recovered (tons/year)	0	1,278	0
28	Other Materials Recovered (%)	0.00%	0.00%	0.00%
29	Other Materials Recovered (tons/year)	0	0	0
30	Other Materials Recovered (%)	0.00%	0.00%	0.00%
31	Other Materials Recovered (tons/year)	0	0	0
32	Other Materials Recovered (%)	0.00%	0.00%	0.00%
33	Other Materials Recovered (tons/year)	0	0	0
34	Compost Produced (%)	13.72%	24.42%	32.88%
35	Compost Produced (tons/year)	29,361	44,565	60,000
	Year 1 Project Costs (As Provided)			
36	Annual O&M (2005)			
37	Labor	1,500,000	1,395,050	1,500,000
38	Residuals Disposal			
39	Utilities			
40	Water		12,000	20,000
41	Wastewater	25,000		
42	Natural Gas			
43	Fossil Fuel	25,000	24,000	100,000
44	Imported Electricity		12,000	
45	Other			
46	Chemicals			
47	Air Pollution Control			
48	Water/Wastewater Treatment			
49	Process Operations			
50	Other	25,000		750,000
51	Maintenance & Repair	1,000,000	500,000	2,400,000
52	Capital Repair & Replacement	1,400,000	425,000	
53	Transportation Costs			
54	Front-End Recycling to Markets			
55	Process Products (inc. Compost) to Markets			
56	Miscellaneous & Other Costs	250,000	534,872	
57	Total Annual Plant O&M (2005)	4,225,000	2,902,922	4,770,000
58	Annual Plant O&M (Year 1)	5,512,667	3,787,655	6,223,768
59	Residue Transportation & Disposal ($/ton) (2005)	80.00	80.00	80.00
60	Residue Transportation & Disposal ($/ton) (Year 1)	104.38	104.38	104.38

	Inputs & Assumptions	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
	Recovered Products Prices			
61	Net Power Output (kWh/ton)	215	124	189
62	Annual Net Power Output (kwh)	46,000,000	22,611,057	34,500,000
63	Power Price ($/kWh) (2005)	0.0700	0.0700	0.0700
64	Power Price ($/kWh) (Year 1)	0.0913	0.0913	0.0913
65	Net Digester Gas Output (mmCF/ton)	0.0000	0.0000	0.00
66	Annual Net Gas Output (mmCF)	0	0	0
67	Gas Price ($/mmCF) (2005)	0.00	0.00	0.00
68	Gas Price ($/mmCF) (Year 1)	0.00	0.00	0.00
69	Ferrous Price ($/ton) (2005)	51.00	51.00	51.00
70	Ferrous Price ($/ton) (Year 1)	51.00	51.00	51.00
71	Aluminum Price ($/ton) (2005)	650.00	650.00	650.00
72	Aluminum Price ($/ton) (Year 1)	650.00	650.00	650.00
73	Other Non-Ferrous Price ($/ton)(2005)	0.00	0.00	100.00
74	Other Non-Ferrous Price ($/ton)(Year 1)	0.00	0.00	100.00
75	Plastics Price ($/ton) (2005) (1)	55.00	10.00	0.00
76	Plastics Price ($/ton) (Year 1)	55.00	10.00	0.00
77	Glass Price ($/ton) (2005)	0.00	0.00	0.00
78	Glass Price ($/ton) (Year 1)	0.00	0.00	0.00
79	Paper Price ($/ton) (2005)	0.00	0.00	0.00
80	Paper Price ($/ton) (Year 1)	0.00	0.00	0.00
81	Other Materials (Wood) Price ($/ton)(2005)	0.00	0.00	0.00
82	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
83	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
84	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
85	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
86	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
87	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
88	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
89	Finished Compost Product ($/ton)(2005)	9.00	9.00	9.00
90	Finished Compost Product ($/ton)(Year1)	11.74	11.74	11.74
	Capital Costs (2005) (As Provided)			
91	Central Facility			
92	Development (Fees, Permits, etc.)	1,000,000	500,000	
93	Engineering & Design	2,500,000	2,750,000	
94	Structures	10,000,000	7,379,755	
95	Pre-Processing Equipment	1,000,000	1,311,000	
96	Processing Equipment	18,500,000	20,707,889	
97	Power Generation Equipment	5,000,000	4,550,000	
98	Storage Facilities	1,000,000	650,000	
99	Environmental Control Systems	800,000	2,000,000	
100	Ancillary Systems	1,400,000	250,000	
101	Vehicles	600,000	950,000	
102	Other	1,500,000	0	80,000,000
103	Total Development/Construction Costs	43,300,000	41,048,644	80,000,000
104	Construction Cost (2011)	51,702,464	49,014,228	95,524,184
105	Site Acquisition			
106	Acreage Required	8.0	14	20
107	Cost/Acre	150,000	150,000	150,000
108	Site Acquisition Cost	1,200,000	2,100,000	3,000,000
109	City Implementation Costs	0	0	0
110	Total Capital Cost	52,902,464	51,114,228	98,524,184
111	Financing Costs & Reserve Fund Factor	20%	20%	20%
112	Financing Costs & Reserve Fund	10,580,493	10,222,846	19,704,837
113	Total Construction Financing	63,482,957	61,337,073	118,229,020
114	Capitalized Interest (2)	20,171,080	19,489,246	37,566,098
115	Total Financing	83,654,037	80,826,319	155,795,118
116	Debt Amortization Term (years)	20	20	20
117	Debt Interest Rate	4.75%	4.75%	4.75%
118	Weighted Cost of Capital - Private Ownership/Financing (DBOO)	8.04%	8.04%	8.04%
119	Private Equity Return (%)	26.67%	26.67%	26.67%

(1) The plastics price for Arrow represents sorted plastics; for WRSI, mixed plastics.
(2) Capitalized Interest calculations are performed on individual proformas

Arrow Ecology

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000
Residuals/Ash for Disposal	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Operating Costs ($/year)																				
Facility O&M ($/year)	5,512,667	5,678,047	5,848,388	6,023,840	6,204,555	6,390,692	6,582,412	6,779,885	6,983,281	7,192,780	7,408,563	7,630,820	7,859,745	8,095,537	8,338,403	8,588,555	8,846,212	9,111,598	9,384,946	9,666,494
Residuals/Ash Disposal (if separately calculated)	5,219,084	5,375,656	5,536,926	5,703,034	5,874,125	6,050,348	6,231,859	6,418,815	6,611,379	6,809,720	7,014,012	7,224,432	7,441,165	7,664,400	7,894,332	8,131,162	8,375,097	8,626,350	8,885,141	9,151,695
Total Annual Operating Costs ($																				
Total Operating Costs	10,731,750	11,053,703	11,385,314	11,726,873	12,078,680	12,441,040	12,814,271	13,198,699	13,594,660	14,002,500	14,422,575	14,855,252	15,300,910	15,759,937	16,232,735	16,719,717	17,221,309	17,737,948	18,270,087	18,818,189
O&M Cost/Ton - - All Tonnage	50.15	51.65	53.20	54.80	56.44	58.14	59.88	61.68	63.53	65.43	67.40	69.42	71.50	73.64	75.85	78.13	80.47	82.89	85.37	87.94
NPV of Total Annual Costs	*177,098,265*																			
Debt Service ($)																				
Total Annual Debt Service	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139
Debt Service Cost/Ton - - All Tonnage	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93
NPV Total Annual Debt Service	*109,711,015*																			
Total Project Costs	19,275,890	19,597,842	19,929,453	20,271,013	20,622,819	20,985,179	21,358,410	21,742,839	22,138,799	22,546,639	22,966,714	23,399,392	23,845,049	24,304,076	24,776,875	25,263,857	25,765,448	26,282,087	26,814,226	27,362,328
Total Cost/Ton - - All Tonnage	90.07	91.58	93.13	94.72	96.37	98.06	99.81	101.60	103.45	105.36	107.32	109.34	111.43	113.57	115.78	118.06	120.40	122.81	125.30	127.86
NPV All Project Costs	*286,809,280.54*																			
Revenues ($)																				
Power Revenue	4,201,370	4,327,411	4,457,233	4,590,950	4,728,679	4,870,539	5,016,655	5,167,155	5,322,169	5,481,834	5,646,289	5,815,678	5,990,149	6,169,853	6,354,949	6,545,597	6,741,965	6,944,224	7,152,551	7,367,127
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470
Aluminum Revenue	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	344,782	355,125	365,779	376,752	388,055	399,697	411,688	424,038	436,759	449,862	463,358	477,259	491,576	506,324	521,513	537,159	553,274	569,872	586,968	604,577
Total Annual Revenues ($																				
Total Annual Revenues ($)	7,298,518	7,434,903	7,575,379	7,720,069	7,869,100	8,022,602	8,180,709	8,343,560	8,511,295	8,684,063	8,862,014	9,045,304	9,234,092	9,428,543	9,628,829	9,835,123	10,047,605	10,266,462	10,491,885	10,724,071
Total Revenues/Ton - - All Tonnage	34.11	34.74	35.40	36.08	36.77	37.49	38.23	38.99	39.77	40.58	41.41	42.27	43.15	44.06	44.99	45.96	46.95	47.97	49.03	50.11
NPV Total Annual Revenues	*110,363,593*																			
Net Annual Cost	(11,977,371)	(12,162,939)	(12,354,074)	(12,550,943)	(12,753,719)	(12,962,577)	(13,177,701)	(13,399,279)	(13,627,504)	(13,862,576)	(14,104,700)	(14,354,088)	(14,610,957)	(14,875,533)	(15,148,046)	(15,428,734)	(15,717,843)	(16,015,625)	(16,322,341)	(16,638,258)
NPV Net Annual Cost	*(176,445,688)*																			
Required Tipping Fee	**$55.97**	**$56.84**	**$57.73**	**$58.65**	**$59.60**	**$60.57**	**$61.58**	**$62.61**	**$63.68**	**$64.78**	**$65.91**	**$67.08**	**$68.28**	**$69.51**	**$70.79**	**$72.10**	**$73.45**	**$74.84**	**$76.27**	**$77.75**
Average Tipping Fee Required	**$65.90**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	83,654,037	83,654,037	83,654,037	83,654,037	81,833,591	79,866,827	77,741,984	75,446,356	72,966,218	70,286,739	67,391,896	64,264,381	60,885,491	57,235,023	53,291,149	49,030,286	44,426,956	39,453,633	34,080,580	28,275,667	22,004,185	15,228,632	7,908,494
Interest	6,723,693	6,723,693	6,723,693	6,723,693	6,577,375	6,419,296	6,248,512	6,064,001	5,864,660	5,649,297	5,416,624	5,165,250	4,893,671	4,600,265	4,283,276	3,940,809	3,570,817	3,171,086	2,739,227	2,272,657	1,768,586	1,224,001	635,645
Principal	0	0	0	1,820,446	1,966,764	2,124,843	2,295,627	2,480,138	2,679,479	2,894,843	3,127,516	3,378,890	3,650,468	3,943,874	4,260,863	4,603,330	4,973,323	5,373,053	5,804,913	6,271,482	6,775,553	7,320,138	7,908,494
Annual Debt Service	6,723,693	6,723,693	6,723,693	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139	8,544,139
Ending Balance	6,723,693	13,447,386	20,171,080	81,833,591	79,866,827	77,741,984	75,446,356	72,966,218	70,286,739	67,391,896	64,264,381	60,885,491	57,235,023	53,291,149	49,030,286	44,426,956	39,453,633	34,080,580	28,275,667	22,004,185	15,228,632	7,908,494	0

Waste Recovery Systems

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Residuals/Ash for Disposal	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393
Operating Costs ($/year)																				
Facility O&M ($/year)	3,787,655	3,901,284	4,018,323	4,138,873	4,263,039	4,390,930	4,522,658	4,658,338	4,798,088	4,942,030	5,090,291	5,243,000	5,400,290	5,562,299	5,729,168	5,901,043	6,078,074	6,260,416	6,448,229	6,641,676
Residuals/Ash Disposal (if separately calculated)	5,886,354	6,062,944	6,244,833	6,432,178	6,625,143	6,823,897	7,028,614	7,239,473	7,456,657	7,680,357	7,910,767	8,148,090	8,392,533	8,644,309	8,903,638	9,170,747	9,445,870	9,729,246	10,021,123	10,321,757
Total Annual Operating Costs ($																				
Total Operating Costs	9,674,009	9,964,229	10,263,156	10,571,050	10,888,182	11,214,827	11,551,272	11,897,810	12,254,745	12,622,387	13,001,059	13,391,090	13,792,823	14,206,608	14,632,806	15,071,790	15,523,944	15,989,662	16,469,352	16,963,433
O&M Cost/Ton - - All Tonnage	53.01	54.60	56.24	57.92	59.66	61.45	63.29	65.19	67.15	69.16	71.24	73.38	75.58	77.84	80.18	82.59	85.06	87.61	90.24	92.95
NPV of Total Annual Costs	*159,643,121*																			
Debt Service ($)																				
Total Annual Debt Service	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326
Debt Service Cost/Ton - - All Tonnage	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23	45.23
NPV Total Annual Debt Service	*106,002,506*																			
Total Project Costs	17,929,334	18,219,555	18,518,481	18,826,376	19,143,508	19,470,153	19,806,598	20,153,136	20,510,070	20,877,713	21,256,384	21,646,416	22,048,149	22,461,933	22,888,132	23,327,116	23,779,269	24,244,988	24,724,678	25,218,758
Total Cost/Ton - - All Tonnage	98.24	99.83	101.47	103.16	104.90	106.69	108.53	110.43	112.38	114.40	116.47	118.61	120.81	123.08	125.41	127.82	130.30	132.85	135.48	138.18
NPV All Project Costs	*265,645,627.45*																			
Revenues ($)																				
Power Revenue	2,065,161	2,127,116	2,190,929	2,256,657	2,324,357	2,394,088	2,465,910	2,539,888	2,616,084	2,694,567	2,775,404	2,858,666	2,944,426	3,032,759	3,123,741	3,217,454	3,313,977	3,413,397	3,515,798	3,621,272
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191
Aluminum Revenue	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	523,325	539,025	555,195	571,851	589,007	606,677	624,877	643,624	662,932	682,820	703,305	724,404	746,136	768,520	791,576	815,323	839,783	864,976	890,926	917,653
Total Annual Revenues ($																				
Total Annual Revenues ($)	3,326,977	3,404,631	3,484,616	3,566,999	3,651,855	3,739,256	3,829,279	3,922,002	4,017,508	4,115,878	4,217,200	4,321,561	4,429,053	4,539,770	4,653,808	4,771,268	4,892,251	5,016,864	5,145,215	5,277,417
Total Revenues/Ton - - All Tonnage	18.23	18.66	19.09	19.55	20.01	20.49	20.98	21.49	22.01	22.55	23.11	23.68	24.27	24.88	25.50	26.14	26.81	27.49	28.19	28.92
NPV Total Annual Revenues	*52,198,493*																			
Net Annual Cost	(14,602,357)	(14,814,923)	(15,033,866)	(15,259,377)	(15,491,653)	(15,730,897)	(15,977,319)	(16,231,134)	(16,492,563)	(16,761,835)	(17,039,185)	(17,324,855)	(17,619,096)	(17,922,164)	(18,234,323)	(18,555,848)	(18,887,018)	(19,228,124)	(19,579,463)	(19,941,341)
NPV Net Annual Cost	*(213,447,135)*																			
Required Tipping Fee	**$80.01**	**$81.18**	**$82.38**	**$83.61**	**$84.89**	**$86.20**	**$87.55**	**$88.94**	**$90.37**	**$91.85**	**$93.37**	**$94.93**	**$96.54**	**$98.20**	**$99.91**	**$101.68**	**$103.49**	**$105.36**	**$107.28**	**$109.27**
Average Tipping Fee Required	**$93.35**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	80,826,319	80,826,319	80,826,319	80,826,319	79,067,409	77,167,126	75,114,108	72,896,079	70,499,776	67,910,870	65,113,880	62,092,082	58,827,408	55,300,335	51,489,774	47,372,938	42,925,213	38,120,001	32,928,570	27,319,878	21,260,388	14,713,866	7,641,167
Interest	6,496,415	6,496,415	6,496,415	6,496,415	6,355,043	6,202,308	6,037,296	5,859,022	5,666,419	5,458,336	5,233,528	4,990,651	4,728,253	4,444,764	4,138,491	3,807,600	3,450,114	3,063,895	2,646,634	2,195,835	1,708,804	1,182,627	614,159
Principal	0	0	0	1,758,910	1,900,283	2,053,018	2,218,029	2,396,303	2,588,906	2,796,990	3,021,798	3,264,675	3,527,073	3,810,561	4,116,835	4,447,726	4,805,212	5,191,431	5,608,692	6,059,491	6,546,522	7,072,699	7,641,167
Annual Debt Service	6,496,415	6,496,415	6,496,415	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326	8,255,326
Ending Balance	6,496,415	12,992,831	19,489,246	79,067,409	77,167,126	75,114,108	72,896,079	70,499,776	67,910,870	65,113,880	62,092,082	58,827,408	55,300,335	51,489,774	47,372,938	42,925,213	38,120,001	32,928,570	27,319,878	21,260,388	14,713,866	7,641,167	0

Organic Waste Systems

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Residuals/Ash for Disposal	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570
Operating Costs ($/year)																				
Facility O&M ($/year)	6,223,768	6,410,481	6,602,796	6,800,879	7,004,906	7,215,053	7,431,505	7,654,450	7,884,083	8,120,606	8,364,224	8,615,151	8,873,605	9,139,813	9,414,008	9,696,428	9,987,321	10,286,940	10,595,549	10,913,415
Residuals/Ash for Disposal	8,305,664	8,554,834	8,811,479	9,075,824	9,348,098	9,628,541	9,917,397	10,214,919	10,521,367	10,837,008	11,162,118	11,496,982	11,841,891	12,197,148	12,563,062	12,939,954	13,328,153	13,727,997	14,139,837	14,564,032
Total Annual Operating Costs ($																				
Total Operating Costs	14,529,432	14,965,315	15,414,275	15,876,703	16,353,004	16,843,594	17,348,902	17,869,369	18,405,450	18,957,614	19,526,342	20,112,132	20,715,496	21,336,961	21,977,070	22,636,382	23,315,474	24,014,938	24,735,386	25,477,447
O&M Cost/Ton - - All Tonnage	79.61	82.00	84.46	87.00	89.61	92.29	95.06	97.91	100.85	103.88	106.99	110.20	113.51	116.91	120.42	124.03	127.76	131.59	135.54	139.60
NPV of Total Annual Costs	*239,768,645*																			
Debt Service ($)																				
Total Annual Debt Service	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384
Debt Service Cost/Ton - - All Tonnage	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19	87.19
NPV Total Annual Debt Service	*204,322,962*																			
Total Project Costs	30,441,816	30,877,699	31,326,659	31,789,087	32,265,388	32,755,978	33,261,286	33,781,753	34,317,834	34,869,998	35,438,726	36,024,516	36,627,880	37,249,345	37,889,454	38,548,766	39,227,858	39,927,322	40,647,770	41,389,832
Total Cost/Ton - - All Tonnage	166.80	169.19	171.65	174.19	176.80	179.48	182.25	185.11	188.04	191.07	194.18	197.39	200.70	204.11	207.61	211.23	214.95	218.78	222.73	226.79
NPV All Project Costs	*444,091,607.23*																			
Revenues ($)																				
Power Revenue	3,151,027	3,245,558	3,342,925	3,443,213	3,546,509	3,652,904	3,762,491	3,875,366	3,991,627	4,111,376	4,234,717	4,361,759	4,492,611	4,627,390	4,766,211	4,909,198	5,056,474	5,208,168	5,364,413	5,525,345
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002
Aluminum Revenue	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	704,577	725,715	747,486	769,911	793,008	816,798	841,302	866,541	892,538	919,314	946,893	975,300	1,004,559	1,034,696	1,065,737	1,097,709	1,130,640	1,164,559	1,199,496	1,235,481
Total Annual Revenues ($																				
Total Annual Revenues ($)	4,709,612	4,825,280	4,944,419	5,067,131	5,193,525	5,323,710	5,457,801	5,595,915	5,738,172	5,884,697	6,035,618	6,191,066	6,351,178	6,516,093	6,685,956	6,860,914	7,041,121	7,226,735	7,417,916	7,614,834
Total Revenues/Ton - - All Tonnage	25.81	26.44	27.09	27.77	28.46	29.17	29.91	30.66	31.44	32.24	33.07	33.92	34.80	35.70	36.64	37.59	38.58	39.60	40.65	41.73
NPV Total Annual Revenues	*74,592,121*																			
Net Annual Cost	(25,732,204)	(26,052,419)	(26,382,240)	(26,721,956)	(27,071,864)	(27,432,268)	(27,803,485)	(28,185,838)	(28,579,662)	(28,985,301)	(29,403,108)	(29,833,450)	(30,276,703)	(30,733,252)	(31,203,499)	(31,687,852)	(32,186,737)	(32,700,587)	(33,229,854)	(33,774,998)
NPV Net Annual Cost	*(369,499,486)*																			
Required Tipping Fee	**$141.00**	**$142.75**	**$144.56**	**$146.42**	**$148.34**	**$150.31**	**$152.35**	**$154.44**	**$156.60**	**$158.82**	**$161.11**	**$163.47**	**$165.90**	**$168.40**	**$170.98**	**$173.63**	**$176.37**	**$179.18**	**$182.08**	**$185.07**
Average Tipping Fee Required	**$161.09**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	155,795,118	155,795,118	155,795,118	155,795,118	152,404,767	148,741,916	144,784,663	140,509,346	135,890,401	130,900,207	125,508,927	119,684,323	113,391,566	106,593,029	99,248,060	91,312,738	82,739,615	73,477,428	63,470,792	52,659,872	40,980,025	28,361,411	14,728,575
Interest	12,522,033	12,522,033	12,522,033	12,522,033	12,249,533	11,955,131	11,637,067	11,293,439	10,922,191	10,521,104	10,087,780	9,619,627	9,113,847	8,567,415	7,977,063	7,339,261	6,650,197	5,905,748	5,101,465	4,232,537	3,293,770	2,279,548	1,183,809
Principal	0	0	0	3,390,352	3,662,851	3,957,253	4,275,317	4,618,946	4,990,193	5,391,280	5,824,604	6,292,757	6,798,537	7,344,969	7,935,321	8,573,123	9,262,188	10,006,636	10,810,919	11,679,847	12,618,615	13,632,836	14,728,575
Annual Debt Service	12,522,033	12,522,033	12,522,033	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384	15,912,384
Ending Balance	12,522,033	25,044,065	37,566,098	152,404,767	148,741,916	144,784,663	140,509,346	135,890,401	130,900,207	125,508,927	119,684,323	113,391,566	106,593,029	99,248,060	91,312,738	82,739,615	73,477,428	63,470,792	52,659,872	40,980,025	28,361,411	14,728,575	0

City of New York, New York
Advanced, Conversion Technologies

Economic Evaluations and Projections

<u>Anaerobic Digestion Technologies</u>
Commercial Scale Facilities/DBO Implementation

Alternative Resources, Inc.

March 2006

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

Anaerobic Digestion Technologies
Commercial Scale Facilities/DBO Implementation

Summary of Projections

	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
Facility			
Waste Processed (Average Tons/Day 365 Days/Year)	586	500	500
Waste Processed (Tons/Year)	214,000	182,500	182,500
Development & Capital Costs			
Development, Design & Construction Costs	52,902,464	51,114,228	98,524,184
Financing-Related Costs	20,872,036	20,166,508	38,871,540
Total Capital Cost	73,774,500	71,280,736	137,395,724
Annual Costs			
Annual Debt Service	5,745,454	5,551,243	10,700,185
Year 1 O&M Costs	10,731,750	9,674,009	14,529,432
Total Year 1 Costs	16,477,204	15,225,252	25,229,618
Annual Revenues			
Total Year 1 Revenues	7,298,518	3,326,977	4,709,612
Net Year 1 Costs	9,178,686	11,898,275	20,520,005
Year 1 (2014) Tipping Fee Required	**$42.89**	**$65.20**	**$112.44**

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

	Inputs & Assumptions	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
	General Information			
1	Throughput (average tons/day 365 days/year)	586	500	500
2	MSW Processed in Beginning Year (tons/year)	214,000	182,500	182,500
3	Discount Rate (Tax-Exempt Cost of Capital)	4.65%	4.65%	4.65%
4	Inflation Rate / General Escalation	3.00%	3.00%	3.00%
5	Start Year	1	1	1
6	Operations Starting Year ("Year 1")	2014	2014	2014
7	Construction Starting Year	2011	2011	2011
8	Cost Basis Year	2005	2005	2005
9	O&M Term (Years)	20	20	20
10	End Year	2033	2033	2033
	Waste Handling & Processing			
11	Total Tonnage Processed (Year 1)	214,000	182,500	182,500
12	Residuals/Ash for Disposal (%)	23.36%	30.90%	43.60%
13	Residuals/Ash for Disposal (tons)	50,000	56,393	79,570
14	Ferrous Recovered (%)	1.86%	3.15%	2.19%
15	Ferrous Recovered (tons/year)	3,970	5,749	4,000
16	Aluminum Recovered (%)	0.82%	0.30%	0.55%
17	Aluminum Recovered (tons/year)	1,750	548	1,000
18	Other Non-Ferrous Recovered (%)	0.00%	0.00%	0.00%
19	Other Non-Ferrous Recovered (tons/year)	0	0	0
20	Plastics Recovered (%)	12.00%	4.90%	0.00%
21	Plastics Recovered (tons/year)	25,680	8,943	0
22	Glass Recovered (%)	0.00%	0.00%	0.00%
23	Glass Recovered (tons/year)	0	0	0
24	Paper Recovered (%)	0.00%	0.00%	0.00%
25	Paper Recovered (tons/year)	0	0	0
26	Other Materials (Wood) Recovered (%)	0.00%	0.70%	0.00%
27	Other Materials (Wood) Recovered (tons/year)	0	1,278	0
28	Other Materials Recovered (%)	0.00%	0.00%	0.00%
29	Other Materials Recovered (tons/year)	0	0	0
30	Other Materials Recovered (%)	0.00%	0.00%	0.00%
31	Other Materials Recovered (tons/year)	0	0	0
32	Other Materials Recovered (%)	0.00%	0.00%	0.00%
33	Other Materials Recovered (tons/year)	0	0	0
34	Compost Produced (%)	13.72%	24.42%	32.88%
35	Compost Produced (tons/year)	29,361	44,565	60,000
	Year 1 Project Costs (As Provided)			
36	Annual O&M (2005)			
37	Labor	1,500,000	1,395,050	1,500,000
38	Residuals Disposal			
39	Utilities			
40	Water		12,000	20,000
41	Wastewater	25,000		
42	Natural Gas			
43	Fossil Fuel	25,000	24,000	100,000
44	Imported Electricity		12,000	
45	Other			
46	Chemicals			
47	Air Pollution Control			
48	Water/Wastewater Treatment			
49	Process Operations			
50	Other	25,000		750,000
51	Maintenance & Repair	1,000,000	500,000	2,400,000
52	Capital Repair & Replacement	1,400,000	425,000	
53	Transportation Costs			
54	Front-End Recycling to Markets			
55	Process Products (inc. Compost) to Markets			
56	Miscellaneous & Other Costs	250,000	534,872	
57	Total Annual Plant O&M (2005)	4,225,000	2,902,922	4,770,000
58	Annual Plant O&M (Year 1)	5,512,667	3,787,655	6,223,768
59	Residue Transportation & Disposal ($/ton) (2005)	80.00	80.00	80.00
60	Residue Transportation & Disposal ($/ton) (Year 1)	104.38	104.38	104.38

	Inputs & Assumptions	Arrow Ecology	Waste Recovery Systems	Organic Waste Systems
	Recovered Products Prices			
61	Net Power Output (kWh/ton)	215	124	189
62	Annual Net Power Output (kwh)	46,000,000	22,611,057	34,500,000
63	Power Price ($/kWh) (2005)	0.0700	0.0700	0.0700
64	Power Price ($/kWh) (Year 1)	0.0913	0.0913	0.0913
65	Net Digester Gas Output (mmCF/ton)	0.0000	0.0000	0.00
66	Annual Net Gas Output (mmCF)	0	0	0
67	Gas Price ($/mmCF) (2005)	0.00	0.00	0.00
68	Gas Price ($/mmCF) (Year 1)	0.00	0.00	0.00
69	Ferrous Price ($/ton) (2005)	51.00	51.00	51.00
70	Ferrous Price ($/ton) (Year 1)	51.00	51.00	51.00
71	Aluminum Price ($/ton) (2005)	650.00	650.00	650.00
72	Aluminum Price ($/ton) (Year 1)	650.00	650.00	650.00
73	Other Non-Ferrous Price ($/ton)(2005)	0.00	0.00	100.00
74	Other Non-Ferrous Price ($/ton)(Year 1)	0.00	0.00	100.00
75	Plastics Price ($/ton) (2005) (1)	55.00	10.00	0.00
76	Plastics Price ($/ton) (Year 1)	55.00	10.00	0.00
77	Glass Price ($/ton) (2005)	0.00	0.00	0.00
78	Glass Price ($/ton) (Year 1)	0.00	0.00	0.00
79	Paper Price ($/ton) (2005)	0.00	0.00	0.00
80	Paper Price ($/ton) (Year 1)	0.00	0.00	0.00
81	Other Materials (Wood) Price ($/ton)(2005)	0.00	0.00	0.00
82	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
83	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
84	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
85	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
86	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
87	Other Materials Price ($/ton)(2005)	0.00	0.00	0.00
88	Other Materials Price ($/ton)(Year 1)	0.00	0.00	0.00
89	Finished Compost Product ($/ton)(2005)	9.00	9.00	9.00
90	Finished Compost Product ($/ton)(Year1)	11.74	11.74	11.74
	Capital Costs (2005) (As Provided)			
91	Central Facility			
92	Development (Fees, Permits, etc.)	1,000,000	500,000	
93	Engineering & Design	2,500,000	2,750,000	
94	Structures	10,000,000	7,379,755	
95	Pre-Processing Equipment	1,000,000	1,311,000	
96	Processing Equipment	18,500,000	20,707,889	
97	Power Generation Equipment	5,000,000	4,550,000	
98	Storage Facilities	1,000,000	650,000	
99	Environmental Control Systems	800,000	2,000,000	
100	Ancillary Systems	1,400,000	250,000	
101	Vehicles	600,000	950,000	
102	Other	1,500,000	0	80,000,000
103	Total Development/Construction Costs	43,300,000	41,048,644	80,000,000
104	Construction Cost (2011)	51,702,464	49,014,228	95,524,184
105	Site Acquisition			
106	Acreage Required	8.0	14	20
107	Cost/Acre	150,000	150,000	150,000
108	Site Acquisition Cost	1,200,000	2,100,000	3,000,000
109	City Implementation Costs	0	0	0
110	Total Capital Cost	52,902,464	51,114,228	98,524,184
111	Financing Costs & Reserve Fund Factor	20%	20%	20%
112	Financing Costs & Reserve Fund	10,580,493	10,222,846	19,704,837
113	Total Construction Financing	63,482,957	61,337,073	118,229,020
114	Capitalized Interest (2)	10,291,543	9,943,663	19,166,703
115	Total Financing	73,774,500	71,280,736	137,395,724
116	Debt Amortization Term (years)	20	20	20
117	Debt Interest Rate - Public Ownership/Financing (DBO)	4.65%	4.65%	4.65%
118	Debt Interest Rate Applied	4.65%	4.65%	4.65%

(1) The plastics price for Arrow represents sorted plastics; for WRSI, mixed plastics.
(2) Capitalized Interest calculations are performed on individual proformas

Arrow Ecology

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000	214,000
Residuals/Ash for Disposal	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Operating Costs ($/year)																				
Facility O&M ($/year)	5,512,667	5,678,047	5,848,388	6,023,840	6,204,555	6,390,692	6,582,412	6,779,885	6,983,281	7,192,780	7,408,563	7,630,820	7,859,745	8,095,537	8,338,403	8,588,555	8,846,212	9,111,598	9,384,946	9,666,494
Residuals/Ash Disposal (if separately calculated)	5,219,084	5,375,656	5,536,926	5,703,034	5,874,125	6,050,348	6,231,859	6,418,815	6,611,379	6,809,720	7,014,012	7,224,432	7,441,165	7,664,400	7,894,332	8,131,162	8,375,097	8,626,350	8,885,141	9,151,695
Total Annual Operating Costs ($																				
Total Operating Costs	10,731,750	11,053,703	11,385,314	11,726,873	12,078,680	12,441,040	12,814,271	13,198,699	13,594,660	14,002,500	14,422,575	14,855,252	15,300,910	15,759,937	16,232,735	16,719,717	17,221,309	17,737,948	18,270,087	18,818,189
O&M Cost/Ton - - All Tonnage	50.15	51.65	53.20	54.80	56.44	58.14	59.88	61.68	63.53	65.43	67.40	69.42	71.50	73.64	75.85	78.13	80.47	82.89	85.37	87.94
NPV of Total Annual Costs	*177,098,265*																			
Debt Service ($)																				
Total Annual Debt Service	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454
Debt Service Cost/Ton - - All Tonnage	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85	26.85
NPV Total Annual Debt Service	*73,774,500*																			
Total Project Costs	16,477,204	16,799,157	17,130,768	17,472,327	17,824,134	18,186,494	18,559,725	18,944,153	19,340,114	19,747,954	20,168,029	20,600,706	21,046,364	21,505,391	21,978,189	22,465,171	22,966,763	23,483,402	24,015,541	24,563,643
Total Cost/Ton - - All Tonnage	77.00	78.50	80.05	81.65	83.29	84.98	86.73	88.52	90.37	92.28	94.24	96.27	98.35	100.49	102.70	104.98	107.32	109.74	112.22	114.78
NPV All Project Costs	*250,872,765.40*																			
Revenues ($)																				
Power Revenue	4,201,370	4,327,411	4,457,233	4,590,950	4,728,679	4,870,539	5,016,655	5,167,155	5,322,169	5,481,834	5,646,289	5,815,678	5,990,149	6,169,853	6,354,949	6,545,597	6,741,965	6,944,224	7,152,551	7,367,127
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470	202,470
Aluminum Revenue	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500	1,137,500
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397	1,412,397
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	344,782	355,125	365,779	376,752	388,055	399,697	411,688	424,038	436,759	449,862	463,358	477,259	491,576	506,324	521,513	537,159	553,274	569,872	586,968	604,577
Total Annual Revenues ($																				
Total Annual Revenues ($)	7,298,518	7,434,903	7,575,379	7,720,069	7,869,100	8,022,602	8,180,709	8,343,560	8,511,295	8,684,063	8,862,014	9,045,304	9,234,092	9,428,543	9,628,829	9,835,123	10,047,605	10,266,462	10,491,885	10,724,071
Total Revenues/Ton - - All Tonnage	34.11	34.74	35.40	36.08	36.77	37.49	38.23	38.99	39.77	40.58	41.41	42.27	43.15	44.06	44.99	45.96	46.95	47.97	49.03	50.11
NPV Total Annual Revenues	*110,363,593*																			
Net Annual Cost	(9,178,686)	(9,364,254)	(9,555,389)	(9,752,258)	(9,955,033)	(10,163,892)	(10,379,016)	(10,600,594)	(10,828,819)	(11,063,891)	(11,306,015)	(11,555,403)	(11,812,272)	(12,076,848)	(12,349,361)	(12,630,049)	(12,919,158)	(13,216,940)	(13,523,655)	(13,839,572)
NPV Net Annual Cost	*(140,509,173)*																			
Required Tipping Fee	**$42.89**	**$43.76**	**$44.65**	**$45.57**	**$46.52**	**$47.49**	**$48.50**	**$49.54**	**$50.60**	**$51.70**	**$52.83**	**$54.00**	**$55.20**	**$56.43**	**$57.71**	**$59.02**	**$60.37**	**$61.76**	**$63.19**	**$64.67**
Average Tipping Fee Required	**$52.82**																			

Debt Service Calculation

	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	73,774,500	73,774,500	73,774,500	73,774,500	71,459,560	69,036,976	66,501,741	63,848,618	61,072,125	58,166,524	55,125,814	51,943,710	48,613,638	45,128,719	41,481,750	37,665,197	33,671,175	29,491,430	25,117,328	20,539,830	15,749,478	10,736,374	5,490,162
Interest	3,430,514	3,430,514	3,430,514	3,430,514	3,322,870	3,210,219	3,092,331	2,968,961	2,839,854	2,704,743	2,563,350	2,415,383	2,260,534	2,098,485	1,928,901	1,751,432	1,565,710	1,371,352	1,167,956	955,102	732,351	499,241	255,293
Principal	0	0	0	2,314,940	2,422,585	2,535,235	2,653,123	2,776,493	2,905,600	3,040,711	3,182,104	3,330,072	3,484,920	3,646,969	3,816,553	3,994,022	4,179,744	4,374,103	4,577,498	4,790,352	5,013,103	5,246,213	5,490,162
Annual Debt Service	3,430,514	3,430,514	3,430,514	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454	5,745,454
Ending Balance	3,430,514	6,861,029	10,291,543	71,459,560	69,036,976	66,501,741	63,848,618	61,072,125	58,166,524	55,125,814	51,943,710	48,613,638	45,128,719	41,481,750	37,665,197	33,671,175	29,491,430	25,117,328	20,539,830	15,749,478	10,736,374	5,490,162	0

Waste Recovery Systems

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Residuals/Ash for Disposal	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393	56,393
Operating Costs ($/year)																				
Facility O&M ($/year)	3,787,655	3,901,284	4,018,323	4,138,873	4,263,039	4,390,930	4,522,658	4,658,338	4,798,088	4,942,030	5,090,291	5,243,000	5,400,290	5,562,299	5,729,168	5,901,043	6,078,074	6,260,416	6,448,229	6,641,676
Residuals/Ash Disposal (if separately calculated)	5,886,354	6,062,944	6,244,833	6,432,178	6,625,143	6,823,897	7,028,614	7,239,473	7,456,657	7,680,357	7,910,767	8,148,090	8,392,533	8,644,309	8,903,638	9,170,747	9,445,870	9,729,246	10,021,123	10,321,757
Total Annual Operating Costs ($																				
Total Operating Costs	9,674,009	9,964,229	10,263,156	10,571,050	10,888,182	11,214,827	11,551,272	11,897,810	12,254,745	12,622,387	13,001,059	13,391,090	13,792,823	14,206,608	14,632,806	15,071,790	15,523,944	15,989,662	16,469,352	16,963,433
O&M Cost/Ton - - All Tonnage	53.01	54.60	56.24	57.92	59.66	61.45	63.29	65.19	67.15	69.16	71.24	73.38	75.58	77.84	80.18	82.59	85.06	87.61	90.24	92.95
NPV of Total Annual Costs	*159,643,121*																			
Debt Service ($)																				
Total Annual Debt Service	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243
Debt Service Cost/Ton - - All Tonnage	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42	30.42
NPV Total Annual Debt Service	*71,280,736*																			
Total Project Costs	15,225,252	15,515,472	15,814,399	16,122,294	16,439,425	16,766,070	17,102,515	17,449,053	17,805,988	18,173,630	18,552,302	18,942,333	19,344,066	19,757,851	20,184,049	20,623,033	21,075,187	21,540,905	22,020,595	22,514,676
Total Cost/Ton - - All Tonnage	83.43	85.02	86.65	88.34	90.08	91.87	93.71	95.61	97.57	99.58	101.66	103.79	105.99	108.26	110.60	113.00	115.48	118.03	120.66	123.37
NPV All Project Costs	*230,923,857.21*																			
Revenues ($)																				
Power Revenue	2,065,161	2,127,116	2,190,929	2,256,657	2,324,357	2,394,088	2,465,910	2,539,888	2,616,084	2,694,567	2,775,404	2,858,666	2,944,426	3,032,759	3,123,741	3,217,454	3,313,977	3,413,397	3,515,798	3,621,272
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191	293,191
Aluminum Revenue	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875	355,875
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425	89,425
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	523,325	539,025	555,195	571,851	589,007	606,677	624,877	643,624	662,932	682,820	703,305	724,404	746,136	768,520	791,576	815,323	839,783	864,976	890,926	917,653
Total Annual Revenues ($																				
Total Annual Revenues ($)	3,326,977	3,404,631	3,484,616	3,566,999	3,651,855	3,739,256	3,829,279	3,922,002	4,017,508	4,115,878	4,217,200	4,321,561	4,429,053	4,539,770	4,653,808	4,771,268	4,892,251	5,016,864	5,145,215	5,277,417
Total Revenues/Ton - - All Tonnage	18.23	18.66	19.09	19.55	20.01	20.49	20.98	21.49	22.01	22.55	23.11	23.68	24.27	24.88	25.50	26.14	26.81	27.49	28.19	28.92
NPV Total Annual Revenues	*52,198,493*																			
Net Annual Cost	(11,898,275)	(12,110,840)	(12,329,783)	(12,555,294)	(12,787,570)	(13,026,815)	(13,273,237)	(13,527,051)	(13,788,480)	(14,057,752)	(14,335,102)	(14,620,773)	(14,915,013)	(15,218,081)	(15,530,241)	(15,851,766)	(16,182,936)	(16,524,041)	(16,875,380)	(17,237,259)
NPV Net Annual Cost	*(178,725,365)*																			
Required Tipping Fee	**$65.20**	**$66.36**	**$67.56**	**$68.80**	**$70.07**	**$71.38**	**$72.73**	**$74.12**	**$75.55**	**$77.03**	**$78.55**	**$80.11**	**$81.73**	**$83.39**	**$85.10**	**$86.86**	**$88.67**	**$90.54**	**$92.47**	**$94.45**
Average Tipping Fee Required	**$78.53**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	71,280,736	71,280,736	71,280,736	71,280,736	69,044,047	66,703,352	64,253,814	61,690,374	59,007,733	56,200,349	53,262,422	50,187,882	46,970,375	43,603,254	40,079,562	36,392,019	32,533,004	28,494,546	24,268,299	19,845,531	15,217,105	10,373,458	5,304,580
Interest	3,314,554	3,314,554	3,314,554	3,314,554	3,210,548	3,101,706	2,987,802	2,868,602	2,743,860	2,613,316	2,476,703	2,333,736	2,184,122	2,027,551	1,863,700	1,692,229	1,512,785	1,324,996	1,128,476	922,817	707,595	482,366	246,663
Principal	0	0	0	2,236,689	2,340,695	2,449,537	2,563,441	2,682,641	2,807,384	2,937,927	3,074,541	3,217,507	3,367,121	3,523,692	3,687,544	3,859,014	4,038,459	4,226,247	4,422,767	4,628,426	4,843,648	5,068,877	5,304,580
Annual Debt Service	3,314,554	3,314,554	3,314,554	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243	5,551,243
Ending Balance	3,314,554	6,629,108	9,943,663	69,044,047	66,703,352	64,253,814	61,690,374	59,007,733	56,200,349	53,262,422	50,187,882	46,970,375	43,603,254	40,079,562	36,392,019	32,533,004	28,494,546	24,268,299	19,845,531	15,217,105	10,373,458	5,304,580	0

Organic Waste Systems

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Pro Forma																				
Throughput (Tons/Year																				
Tons MSW to Facility (tons/year)	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500	182,500
Residuals/Ash for Disposal	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570	79,570
Operating Costs ($/year)																				
Facility O&M ($/year)	6,223,768	6,410,481	6,602,796	6,800,879	7,004,906	7,215,053	7,431,505	7,654,450	7,884,083	8,120,606	8,364,224	8,615,151	8,873,605	9,139,813	9,414,008	9,696,428	9,987,321	10,286,940	10,595,549	10,913,415
Residuals/Ash for Disposal	8,305,664	8,554,834	8,811,479	9,075,824	9,348,098	9,628,541	9,917,397	10,214,919	10,521,367	10,837,008	11,162,118	11,496,982	11,841,891	12,197,148	12,563,062	12,939,954	13,328,153	13,727,997	14,139,837	14,564,032
Total Annual Operating Costs ($																				
Total Operating Costs	14,529,432	14,965,315	15,414,275	15,876,703	16,353,004	16,843,594	17,348,902	17,869,369	18,405,450	18,957,614	19,526,342	20,112,132	20,715,496	21,336,961	21,977,070	22,636,382	23,315,474	24,014,938	24,735,386	25,477,447
O&M Cost/Ton - - All Tonnage	79.61	82.00	84.46	87.00	89.61	92.29	95.06	97.91	100.85	103.88	106.99	110.20	113.51	116.91	120.42	124.03	127.76	131.59	135.54	139.60
NPV of Total Annual Costs	*239,768,645*																			
Debt Service ($)																				
Total Annual Debt Service	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185
Debt Service Cost/Ton - - All Tonnage	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63	58.63
NPV Total Annual Debt Service	*137,395,724*																			
Total Project Costs	25,229,618	25,665,501	26,114,460	26,576,888	27,053,189	27,543,779	28,049,087	28,569,554	29,105,635	29,657,799	30,226,527	30,812,318	31,415,682	32,037,146	32,677,255	33,336,567	34,015,659	34,715,123	35,435,571	36,177,633
Total Cost/Ton - - All Tonnage	138.24	140.63	143.09	145.63	148.24	150.92	153.69	156.55	159.48	162.51	165.62	168.83	172.14	175.55	179.05	182.67	186.39	190.22	194.17	198.23
NPV All Project Costs	*377,164,369.37*																			
Revenues ($)																				
Power Revenue	3,151,027	3,245,558	3,342,925	3,443,213	3,546,509	3,652,904	3,762,491	3,875,366	3,991,627	4,111,376	4,234,717	4,361,759	4,492,611	4,627,390	4,766,211	4,909,198	5,056,474	5,208,168	5,364,413	5,525,345
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002	204,002
Aluminum Revenue	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006	650,006
Other Non-Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost Revenue	704,577	725,715	747,486	769,911	793,008	816,798	841,302	866,541	892,538	919,314	946,893	975,300	1,004,559	1,034,696	1,065,737	1,097,709	1,130,640	1,164,559	1,199,496	1,235,481
Total Annual Revenues ($																				
Total Annual Revenues ($)	4,709,612	4,825,280	4,944,419	5,067,131	5,193,525	5,323,710	5,457,801	5,595,915	5,738,172	5,884,697	6,035,618	6,191,066	6,351,178	6,516,093	6,685,956	6,860,914	7,041,121	7,226,735	7,417,916	7,614,834
Total Revenues/Ton - - All Tonnage	25.81	26.44	27.09	27.77	28.46	29.17	29.91	30.66	31.44	32.24	33.07	33.92	34.80	35.70	36.64	37.59	38.58	39.60	40.65	41.73
NPV Total Annual Revenues	*74,592,121*																			
Net Annual Cost	(20,520,005)	(20,840,220)	(21,170,041)	(21,509,757)	(21,859,665)	(22,220,069)	(22,591,286)	(22,973,639)	(23,367,463)	(23,773,102)	(24,190,909)	(24,621,251)	(25,064,504)	(25,521,053)	(25,991,300)	(26,475,653)	(26,974,538)	(27,488,388)	(28,017,655)	(28,562,799)
NPV Net Annual Cost	*(302,572,249)*																			
Required Tipping Fee	**$112.44**	**$114.19**	**$116.00**	**$117.86**	**$119.78**	**$121.75**	**$123.79**	**$125.88**	**$128.04**	**$130.26**	**$132.55**	**$134.91**	**$137.34**	**$139.84**	**$142.42**	**$145.07**	**$147.81**	**$150.62**	**$153.52**	**$156.51**
Average Tipping Fee Required	**$132.53**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	137,395,724	137,395,724	137,395,724	137,395,724	133,084,440	128,572,681	123,851,125	118,910,017	113,739,148	108,327,833	102,664,892	96,738,624	90,536,785	84,046,560	77,254,540	70,146,691	62,708,327	54,924,078	46,777,863	38,252,848	29,331,420	19,995,146	10,224,735
Interest	6,388,901	6,388,901	6,388,901	6,388,901	6,188,426	5,978,630	5,759,077	5,529,316	5,288,870	5,037,244	4,773,917	4,498,346	4,209,960	3,908,165	3,592,336	3,261,821	2,915,937	2,553,970	2,175,171	1,778,757	1,363,911	929,774	475,450
Principal	0	0	0	4,311,284	4,511,759	4,721,556	4,941,108	5,170,869	5,411,315	5,662,941	5,926,268	6,201,839	6,490,225	6,792,020	7,107,849	7,438,364	7,784,248	8,146,216	8,525,015	8,921,428	9,336,274	9,770,411	10,224,735
Annual Debt Service	6,388,901	6,388,901	6,388,901	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185	10,700,185
Ending Balance	6,388,901	12,777,802	19,166,703	133,084,440	128,572,681	123,851,125	118,910,017	113,739,148	108,327,833	102,664,892	96,738,624	90,536,785	84,046,560	77,254,540	70,146,691	62,708,327	54,924,078	46,777,863	38,252,848	29,331,420	19,995,146	10,224,735	0

City of New York, New York
Advanced, Conversion Technologies

Economic Evaluations and Projections

Thermal Technologies
Commercial Scale Facilities/DBOO Implementation

Alternative Resources, Inc.

March 2006

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

Thermal Technologies
Commercial Scale Facilities/DBOO Implementation

Summary of Projections

	Interstate Waste Technologies	Rigel Resource Recovery	GEM America	Ebara
Facility				
Waste Processed (Average Tons/Day 365 Days/Year)	2,612	2,729	2,758	2,959
Waste Processed (Tons/Year)	953,380	996,000	1,006,740	1,080,108
Development & Capital Costs				
Development, Design & Construction Costs	487,367,314	1,051,816,109	560,719,174	915,984,281
Financing-Related Costs	283,300,816	420,113,140	325,939,378	532,450,754
Total Capital Cost	770,668,130	1,471,929,249	886,658,553	1,448,435,036
Annual Costs				
Annual Debt Service	78,713,425	150,337,854	90,560,293	147,938,235
Year 1 O&M Costs	66,608,671	217,636,167	97,953,424	47,950,001
Total Year 1 Costs	145,322,096	367,974,021	188,513,717	195,888,235
Annual Revenues				
Total Year 1 Revenues	46,691,955	203,812,487	54,078,158	43,798,357
Net Year 1 Costs	98,630,142	164,161,534	134,435,559	152,089,878
Year 1 (2014) Tipping Fee Required	**$103.45**	**$164.82**	**$133.54**	**$140.81**

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

	Inputs & Assumptions	Interstate Waste Technologies	Rigel Resource Recovery	GEM America (see footnote 1)	Ebara
	General Information				
1	Throughput (average tons/day 365 days/year)	2,612	2,729	2,758	2,959
2	MSW Processed in Beginning Year (tons/year)	953,380	996,000	1,006,740	1,080,108
3	Discount Rate (Tax-Exempt Cost of Capital)	4.65%	4.65%	4.65%	4.65%
4	Inflation Rate / General Escalation	3.00%	3.00%	3.00%	3.00%
5	Start Year	1	1	1	1
6	Operations Starting Year ("Year 1")	2014	2014	2014	2014
7	Construction Starting Year	2011	2011	2011	2011
8	Cost Basis Year	2005	2005	2005	2005
9	O&M Term (Years)	20	20	20	20
10	End Year	2033	2033	2033	2033
	Waste Handling & Processing				
11	Total Tonnage Processed (Year 1)	953,380	996,000	1,006,740	1,080,108
12	Residuals/Ash for Disposal (%)	0.00%	0.00%	28.40%	6.12%
13	Residuals/Ash for Disposal (tonsyear)	0	0	285,914	66,103
14	Ferrous Recovered (%)	0.00%	0.00%	3.50%	2.57%
15	Ferrous Recovered (tons/year)	0	0	35,236	27,742
16	Aluminum Recovered (%)	0.00%	0.00%	0.50%	0.64%
17	Aluminum Recovered (tons/year)	0	0	5,034	6,947
18	Plastics Recovered (%)	0.00%	0.00%	0.00%	0.00%
19	Plastics Recovered (tons/year)	0	0	0	0
20	Paper Recovered (%)	0.00%	0.00%	0.00%	0.00%
21	Paper Recovered (tons/year)	0	0	0	0
22	Mixed Metals Produced (%)	9.13%	3.54%	0.00%	0.00%
23	Mixed Metals Produced (tons/year)	87,063	35,278	0	0
24	Glassy Slag or Vitrifed Ash Produced (%)	6.85%	13.25%	0.00%	6.74%
25	Glassy Slag or Vitrified Ash Produced (tons/year)	65,297	131,970	0	72,755
26	Hydrochloric Acid Produced (%)	0.00%	3.26%	0.00%	0.00%
27	Hydrochloric Acid Produced (tons/year)	0	32,499	0	0
28	Mixed Salts Produced (%)	0.80%	0.00%	0.00%	0.00%
29	Mixed Salts Produced (tons/year)	7,656	0	0	0
30	Elemental Sulfur Produced (%)	0.15%	0.17%	0.00%	0.00%
31	Elemental Sulfur Produced (tons/year)	1,471	1,650	0	0
32	Zinc Hydroxide Produced (%)	1.00%	0.00%	0.00%	0.00%
33	Zinc Hydroxide Produced (tons/year)	9,534	0	0	0
34	APC Metals Produced (%)	0.00%	2.75%	0.00%	0.00%
35	APC Metals Produced (tons/year)	0	27,390	0	0
	Year 1 Project Costs (As Provided)				
36	Annual O&M (2005)				
37	Labor	5,500,000	24,000,000	7,200,000	6,830,000
38	Residuals Disposal				
39	Utilities				
40	Water	1,600,000			4,761,468
41	Wastewater	100,000			261,168
42	Natural Gas	8,100,000	47,700,000		849,364
43	Fossil Fuel	3,600,000			
44	Imported Electricity				30,191
45	Other		21,400,000		
46	Chemicals				
47	Air Pollution Control	100,000	6,200,000		2,035,649
48	Water/Wastewater Treatment		2,400,000		1,003,152
49	Process Operations	7,000,000			1,633,021
50	Other				2,624,097
51	Maintenance & Repair	15,250,000	35,100,000	27,000,000	11,433,364
52	Capital Repair & Replacement	6,600,000			
53	Transportation Costs				
54	Front-End Recycling to Markets				
55	Process Products (inc. Compost) to Markets				
56	Miscellaneous & Other Costs	3,200,000	30,000,000	18,000,000	
57	Total Annual Plant O&M (2005)	51,050,000	166,800,000	52,200,000	31,461,474
58	Annual Plant O&M (Year 1)	66,608,671	217,636,167	68,109,160	41,050,088
59	Residue Transportation & Disposal ($/ton) (2005)	80.00	80.00	80.00	80.00
60	Residue Transportation & Disposal ($/ton) (Year 1)	104.38	104.38	104.38	104.38

	Inputs & Assumptions	Interstate Waste Technologies	Rigel Resource Recovery	GEM America	Ebara
	Recovered Products Prices				
61	Net Power Output (kWh/ton)	493	2212	533	383
62	Annual Net Power Output (kwh)	470,310,190	2,202,657,000	536,592,657	413,568,000
63	Power Price ($/kWh) (2005)	0.0700	0.0700	0.0700	0.0700
64	Power Price ($/kWh) (Year 1)	0.0913	0.0913	0.0913	0.0913
65	Net Digester Gas Output (mmCF/ton)	0.0000	0.0000	0.00	0.00
66	Annual Net Gas Output (mmCF)	0	0	0	0
67	Gas Price ($/mmCF) (2005)	0.00	0.00	0.00	0.00
68	Gas Price ($/mmCF) (Year 1)	0.00	0.00	0.00	0.00
69	Ferrous Price ($/ton) (2005)	0.00	0.00	51.00	51.00
70	Ferrous Price ($/ton) (Year 1)	0.00	0.00	51.00	51.00
71	Aluminum Price ($/ton) (2005)	0.00	0.00	650.00	650.00
72	Aluminum Price ($/ton) (Year 1)	0.00	0.00	650.00	650.00
73	Mixed Metals Price ($/ton)(2005)	30.00	30.00	0.00	0.00
74	Mixed Metals Price ($/ton)(Year 1)	39.14	39.14	0.00	0.00
75	Plastics Price ($/ton) (2005)	0.00	0.00	0.00	0.00
76	Plastics Price ($/ton) (Year 1)	0.00	0.00	0.00	0.00
77	Glassy Slag/Vitrified Ash Price ($/ton) (2005)	1.00	1.00	0.00	1.00
78	Glassy Slag/Vitrified Ash Price ($/ton) (Year 1)	1.30	1.30	0.00	1.30
79	Paper Price ($/ton) (2005)	0.00	0.00	0.00	0.00
80	Paper Price ($/ton) (Year 1)	0.00	0.00	0.00	0.00
81	Hydrochloric Acid Produced (%)	25.00	25.00	0.00	0.00
82	Hydrochloric Acid Produced (tons/year)	32.62	32.62	0.00	0.00
83	Mixed Salts Produced (%)	10.00	10.00	0.00	0.00
84	Mixed Salts Produced (tons/year)	13.05	13.05	0.00	0.00
85	Elemental Sulfur Produced (%)	10.00	10.00	0.00	0.00
86	Elemental Sulfur Produced (tons/year)	13.05	13.05	0.00	0.00
87	Zinc Hydroxide Produced (%)	10.00	10.00	0.00	0.00
88	Zinc Hydroxide Produced (tons/year)	13.05	13.05	0.00	0.00
89	APC Metals Product ($/ton)(2005)	0.00	0.00	0.00	0.00
90	APC Metals Product ($/ton)(Year1)	0.00	0.00	0.00	0.00
	Capital Costs (2005) (As Provided)				
91	Central Facility				
92	Development (Fees, Permits, etc.)	6,000,000	9,360,000		
93	Engineering & Design	5,000,000	49,608,720	84,000,000	
94	Structures	70,000,000	147,001,200	15,000,000	
95	Pre-Processing Equipment		10,920,000	116,461,500	
96	Processing Equipment	96,000,000	208,729,864	183,000,132	
97	Power Generation Equipment	115,000,000	350,124,360	63,900,000	
98	Storage Facilities	3,000,000	4,680,000	4,500,000	
99	Environmental Control Systems	50,000,000	46,819,248		
100	Ancillary Systems	55,000,000	46,939,248		
101	Vehicles	150,000	2,300,000		
102	Other	5,500,000		1,350,000	
103	Total Development/Construction Costs	405,650,000	876,482,640	468,211,632	762,600,000
104	Construction Cost (2011)	484,367,314	1,046,566,109	559,069,174	910,584,281
105	Site Acquisition				
106	Acreage Required	20	35	11	36
107	Cost/Acre	150,000	150,000	150,000	150,000
108	Site Acquisition Cost	3,000,000	5,250,000	1,650,000	5,400,000
109	City Implementation Costs	0	0	0	0
110	Total Capital Cost	487,367,314	1,051,816,109	560,719,174	915,984,281
111	Financing Costs & Reserve Fund Factor	20%	20%	20%	20%
112	Financing Costs & Reserve Fund	97,473,463	210,363,222	112,143,835	183,196,856
113	Total Capital	584,840,777	1,262,179,331	672,863,009	1,099,181,138
114	Capitalized Interest[1]	185,827,353	209,749,918	213,795,544	349,253,898
115	Total Financing	770,668,130	1,471,929,249	886,658,553	1,448,435,036
116	Debt Amortization Term (years)	20	20	20	20
117	Debt Interest Rate	4.75%	4.75%	4.75%	4.75%
118	Weighted Cost of Capital - Private Ownership/Financing (BDOO)	8.04%	8.04%	8.04%	8.04%
119	Private Equity Return (%)	26.67%	26.67%	26.67%	26.67%

(1) As per GEM America's submittal, all costs for the demonstration-scale facility have been escalated by a factor of 6
to arrive a comparable costs for the commercial-scale facility
(2) Capitalized Interest calculations are performed on individual proformas

Interstate Waste Technologies

Model Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																					
Amount of MSW (tons/year)		953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380
Pro Forma																					
Throughput (Tons/Year)																					
Tons MSW to Facility (tons/year)		953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380
Residuals/Ash for Disposal		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Costs ($/year)																					
Facility O&M ($/year)		66,608,671	68,606,931	70,665,139	72,785,093	74,968,646	77,217,705	79,534,237	81,920,264	84,377,872	86,909,208	89,516,484	92,201,979	94,968,038	97,817,079	100,751,591	103,774,139	106,887,363	110,093,984	113,396,804	116,798,708
Residuals/Ash Disposal		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Operating Costs ($)																					
Total Operating Costs		66,608,671	68,606,931	70,665,139	72,785,093	74,968,646	77,217,705	79,534,237	81,920,264	84,377,872	86,909,208	89,516,484	92,201,979	94,968,038	97,817,079	100,751,591	103,774,139	106,887,363	110,093,984	113,396,804	116,798,708
O&M Cost/Ton - - All Tonnage		69.87	71.96	74.12	76.34	78.63	80.99	83.42	85.93	88.50	91.16	93.89	96.71	99.61	102.60	105.68	108.85	112.11	115.48	118.94	122.51
NPV of Total Annual Costs	*1,099,194,417*																				
Debt Service ($)																					
Total Annual Debt Service		78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425
Debt Service Cost/Ton - - All Tonnage		82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56	82.56
NPV Total Annual Debt Service	*1,010,719,697*																				
Total Project Costs		145,322,096	147,320,356	149,378,564	151,498,518	153,682,071	155,931,131	158,247,662	160,633,689	163,091,297	165,622,633	168,229,909	170,915,404	173,681,463	176,530,504	179,465,016	182,487,564	185,600,788	188,807,409	192,110,229	195,512,133
Total Cost/Ton - - All Tonnage		152.43	154.52	156.68	158.91	161.20	163.56	165.99	168.49	171.07	173.72	176.46	179.27	182.17	185.16	188.24	191.41	194.68	198.04	201.50	205.07
NPV All Project Costs	*2,109,914,114*																				
Revenues ($)																					
Power Revenue		42,955,369	44,244,030	45,571,351	46,938,491	48,346,646	49,797,045	51,290,957	52,829,685	54,414,576	56,047,013	57,728,424	59,460,276	61,244,085	63,081,407	64,973,849	66,923,065	68,930,757	70,998,679	73,128,640	75,322,499
Gas Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminum Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue		3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911
Glass Revenue		85,198	87,754	90,386	93,098	95,891	98,768	101,731	104,783	107,926	111,164	114,499	117,934	121,472	125,116	128,869	132,735	136,717	140,819	145,043	149,395
Other Materials Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue		99,889	102,885	105,972	109,151	112,426	115,798	119,272	122,851	126,536	130,332	134,242	138,269	142,417	146,690	151,091	155,623	160,292	165,101	170,054	175,156
Other Materials Revenue		19,194	19,770	20,363	20,974	21,603	22,251	22,919	23,606	24,314	25,044	25,795	26,569	27,366	28,187	29,033	29,904	30,801	31,725	32,677	33,657
Other Materials Revenue		124,394	128,126	131,970	135,929	140,007	144,207	148,533	152,990	157,579	162,307	167,176	172,191	177,357	182,677	188,158	193,803	199,617	205,605	211,773	218,126
APC Metals Revenue		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																					
Total Annual Revenues ($)		46,691,955	47,990,476	49,327,953	50,705,554	52,124,483	53,585,981	55,091,323	56,641,825	58,238,842	59,883,770	61,578,046	63,323,150	65,120,607	66,971,988	68,878,911	70,843,041	72,866,094	74,949,840	77,096,098	79,306,743
Total Revenues/Ton - - All Tonnage		48.98	50.34	51.74	53.19	54.67	56.21	57.79	59.41	61.09	62.81	64.59	66.42	68.30	70.25	72.25	74.31	76.43	78.61	80.87	83.18
NPV Total Annual Revenues	*758,044,346*																				
Net Annual Cost		(98,630,142)	(99,329,880)	(100,050,611)	(100,792,964)	(101,557,588)	(102,345,150)	(103,156,339)	(103,991,864)	(104,852,454)	(105,738,863)	(106,651,863)	(107,592,253)	(108,560,856)	(109,558,516)	(110,586,106)	(111,644,524)	(112,734,694)	(113,857,569)	(115,014,131)	(116,205,389)
NPV Net Annual Cost	*(1,351,869,768)*																				
Required Tipping Fee		**$103.45**	**$104.19**	**$104.94**	**$105.72**	**$106.52**	**$107.35**	**$108.20**	**$109.08**	**$109.98**	**$110.91**	**$111.87**	**$112.85**	**$113.87**	**$114.92**	**$115.99**	**$117.10**	**$118.25**	**$119.43**	**$120.64**	**$121.89**
Average Tipping Fee Required	**$111.86**																				

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	770,668,130	770,668,130	770,668,130	770,668,130	753,897,155	735,778,214	716,202,963	695,054,351	672,205,920	647,521,045	620,852,124	592,039,689	560,911,453	527,281,286	490,948,095	451,694,623	409,286,153	363,469,102	313,969,506	260,491,380	202,714,950	140,294,739	72,857,503
Interest	61,942,451	61,942,451	61,942,451	61,942,451	60,594,484	59,138,174	57,564,813	55,864,993	54,028,551	52,044,504	49,900,989	47,585,190	45,083,258	42,380,233	39,459,953	36,304,955	32,896,375	29,213,829	25,235,299	20,936,995	16,293,214	11,276,190	5,855,922
Principal	0	0	0	16,770,974	18,118,941	19,575,251	21,148,612	22,848,432	24,684,874	26,668,921	28,812,436	31,128,235	33,630,167	36,333,192	39,253,472	42,408,470	45,817,051	49,499,596	53,478,126	57,776,430	62,420,211	67,437,235	72,857,503
Annual Debt Service	61,942,451	61,942,451	61,942,451	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425	78,713,425
Ending Balance	61,942,451	123,884,902	185,827,353	753,897,155	735,778,214	716,202,963	695,054,351	672,205,920	647,521,045	620,852,124	592,039,689	560,911,453	527,281,286	490,948,095	451,694,623	409,286,153	363,469,102	313,969,506	260,491,380	202,714,950	140,294,739	72,857,503	0

Rigel Resource Recovery

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000
Residuals/Ash for Disposal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Costs ($/year)																				
Facility O&M ($/year)	217,636,167	224,165,252	230,890,210	237,816,916	244,951,423	252,299,966	259,868,965	267,665,034	275,694,985	283,965,835	292,484,810	301,259,354	310,297,135	319,606,049	329,194,230	339,070,057	349,242,159	359,719,423	370,511,006	381,626,336
Residuals/Ash Disposal (if separately calculated)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Operating Costs ($)																				
Total Operating Costs	217,636,167	224,165,252	230,890,210	237,816,916	244,951,423	252,299,966	259,868,965	267,665,034	275,694,985	283,965,835	292,484,810	301,259,354	310,297,135	319,606,049	329,194,230	339,070,057	349,242,159	359,719,423	370,511,006	381,626,336
O&M Cost/Ton - - All Tonnage	218.51	225.07	231.82	238.77	245.94	253.31	260.91	268.74	276.80	285.11	293.66	302.47	311.54	320.89	330.52	340.43	350.64	361.16	372.00	383.16
NPV of Total Annual Costs	*3,591,491,258*																			
Debt Service ($)																				
Total Annual Debt Service	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854
Debt Service Cost/Ton - - All Tonnage	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94	150.94
NPV Total Annual Debt Service	*1,930,413,140*																			
Total Project Costs	367,974,021	374,503,106	381,228,064	388,154,770	395,289,277	402,637,820	410,206,819	418,002,888	426,032,839	434,303,689	442,822,664	451,597,208	460,634,988	469,943,903	479,532,084	489,407,911	499,580,013	510,057,277	520,848,860	531,964,190
Total Cost/Ton - - All Tonnage	369.45	376.01	382.76	389.71	396.88	404.25	411.85	419.68	427.74	436.05	444.60	453.41	462.48	471.83	481.46	491.37	501.59	512.11	522.94	534.10
NPV All Project Costs	*5,521,904,399*																			
Revenues ($)																				
Power Revenue	201,177,745	207,213,077	213,429,470	219,832,354	226,427,324	233,220,144	240,216,748	247,423,251	254,845,948	262,491,327	270,366,067	278,477,049	286,831,360	295,436,301	304,299,390	313,428,372	322,831,223	332,516,160	342,491,644	352,766,394
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminum Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906
Glass Revenue	172,191	177,357	182,677	188,158	193,802	199,616	205,605	211,773	218,126	224,670	231,410	238,352	245,503	252,868	260,454	268,268	276,316	284,605	293,144	301,938
Other Materials Revenue	1,060,111	1,091,915	1,124,672	1,158,412	1,193,165	1,228,959	1,265,828	1,303,803	1,342,917	1,383,205	1,424,701	1,467,442	1,511,465	1,556,809	1,603,513	1,651,619	1,701,167	1,752,202	1,804,768	1,858,911
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	21,534	22,180	22,845	23,530	24,236	24,963	25,712	26,484	27,278	28,096	28,939	29,808	30,702	31,623	32,572	33,549	34,555	35,592	36,660	37,759
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487
Total Revenues/Ton - - All Tonnage	204.63	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
NPV Total Annual Revenues	*2,617,054,141*																			
Net Annual Cost	(164,161,534)	(170,690,619)	(177,415,577)	(184,342,283)	(191,476,790)	(198,825,333)	(206,394,332)	(214,190,401)	(222,220,352)	(230,491,202)	(239,010,177)	(247,784,721)	(256,822,501)	(266,131,416)	(275,719,597)	(285,595,424)	(295,767,526)	(306,244,790)	(317,036,373)	(328,151,703)
NPV Net Annual Cost	*(2,904,850,258)*																			
Required Tipping Fee	**$164.82**	**$171.38**	**$178.13**	**$185.08**	**$192.25**	**$199.62**	**$207.22**	**$215.05**	**$223.11**	**$231.42**	**$239.97**	**$248.78**	**$257.85**	**$267.20**	**$276.83**	**$286.74**	**$296.96**	**$307.47**	**$318.31**	**$329.47**
Average Tipping Fee Required	**$239.88**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	1,471,929,249	1,471,929,249	1,471,929,249	1,471,929,249	1,439,897,708	1,405,291,633	1,367,904,094	1,327,511,532	1,283,872,417	1,236,725,809	1,185,789,792	1,130,759,792	1,071,306,756	1,007,075,183	937,680,997	862,709,253	781,711,656	694,203,876	599,662,659	497,522,691	387,173,223	267,954,417	139,153,399
Interest	69,916,639	69,916,639	69,916,639	118,306,313	115,731,778	112,950,315	109,945,292	106,698,739	103,191,246	99,401,837	95,307,854	90,884,818	86,106,281	80,943,668	75,366,110	69,340,256	62,830,074	55,796,637	48,197,886	39,988,386	31,119,048	21,536,836	11,184,454
Principal	0	0	0	32,031,541	34,606,076	37,387,539	40,392,562	43,639,115	47,146,608	50,936,017	55,029,999	59,453,036	64,231,573	69,394,186	74,971,744	80,997,598	87,507,780	94,541,217	102,139,968	110,349,468	119,218,806	128,801,018	139,153,399
Annual Debt Service	69,916,639	69,916,639	69,916,639	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854	150,337,854
Ending Balance	69,916,639	139,833,279	209,749,918	1,439,897,708	1,405,291,633	1,367,904,094	1,327,511,532	1,283,872,417	1,236,725,809	1,185,789,792	1,130,759,792	1,071,306,756	1,007,075,183	937,680,997	862,709,253	781,711,656	694,203,876	599,662,659	497,522,691	387,173,223	267,954,417	139,153,399	0

GEM America

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740
Residuals/Ash for Disposal	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914
Operating Costs ($/year)																				
Facility O&M ($/year)	68,109,160	70,152,435	72,257,008	74,424,718	76,657,460	78,957,184	81,325,899	83,765,676	86,278,646	88,867,006	91,533,016	94,279,006	97,107,377	100,020,598	103,021,216	106,111,852	109,295,208	112,574,064	115,951,286	119,429,825
Residuals/Ash for Disposal	29,844,263	30,739,591	31,661,779	32,611,633	33,589,981	34,597,681	35,635,611	36,704,680	37,805,820	38,939,995	40,108,195	41,311,440	42,550,784	43,827,307	45,142,126	46,496,390	47,891,282	49,328,020	50,807,861	52,332,097
Total Annual Operating Costs ($)																				
Total Operating Costs	97,953,424	100,892,026	103,918,787	107,036,351	110,247,441	113,554,865	116,961,511	120,470,356	124,084,467	127,807,001	131,641,211	135,590,447	139,658,160	143,847,905	148,163,342	152,608,242	157,186,490	161,902,084	166,759,147	171,761,921
O&M Cost/Ton - - All Tonnage	97.30	100.22	103.22	106.32	109.51	112.79	116.18	119.66	123.25	126.95	130.76	134.68	138.72	142.88	147.17	151.59	156.13	160.82	165.64	170.61
NPV of Total Annual Costs	*1,616,454,056*																			
Debt Service ($)																				
Total Annual Debt Service	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293
Debt Service Cost/Ton - - All Tonnage	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95	89.95
NPV Total Annual Debt Service	*1,162,839,398*																			
Total Project Costs	188,513,717	191,452,319	194,479,080	197,596,644	200,807,734	204,115,158	207,521,803	211,030,649	214,644,759	218,367,293	222,201,503	226,150,740	230,218,453	234,408,198	238,723,635	243,168,535	247,746,783	252,462,377	257,319,440	262,322,214
Total Cost/Ton - - All Tonnage	187.25	190.17	193.18	196.27	199.46	202.75	206.13	209.62	213.21	216.91	220.71	224.64	228.68	232.84	237.13	241.54	246.09	250.77	255.60	260.57
NPV All Project Costs	*2,779,293,454*																			
Revenues ($)																				
Power Revenue	49,009,220	50,479,496	51,993,881	53,553,698	55,160,309	56,815,118	58,519,571	60,275,158	62,083,413	63,945,916	65,864,293	67,840,222	69,875,429	71,971,691	74,130,842	76,354,767	78,645,410	81,004,773	83,434,916	85,937,963
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032
Aluminum Revenue	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																				
Total Annual Revenues ($)	54,078,158	55,548,434	57,062,819	58,622,636	60,229,247	61,884,056	63,588,509	65,344,097	67,152,351	69,014,854	70,933,231	72,909,160	74,944,367	77,040,630	79,199,780	81,423,706	83,714,349	86,073,711	88,503,854	91,006,902
Total Revenues/Ton - - All Tonnage	53.72	55.18	56.68	58.23	59.83	61.47	63.16	64.91	66.70	68.55	70.46	72.42	74.44	76.52	78.67	80.88	83.15	85.50	87.91	90.40
NPV Total Annual Revenues	*873,851,179*																			
Net Annual Cost	(134,435,559)	(135,903,885)	(137,416,261)	(138,974,008)	(140,578,488)	(142,231,102)	(143,933,294)	(145,686,552)	(147,492,408)	(149,352,440)	(151,268,272)	(153,241,580)	(155,274,087)	(157,367,568)	(159,523,855)	(161,744,830)	(164,032,434)	(166,388,667)	(168,815,586)	(171,315,313)
NPV Net Annual Cost	*(1,905,442,275)*																			
Required Tipping Fee	**$133.54**	**$134.99**	**$136.50**	**$138.04**	**$139.64**	**$141.28**	**$142.97**	**$144.71**	**$146.50**	**$148.35**	**$150.26**	**$152.22**	**$154.23**	**$156.31**	**$158.46**	**$160.66**	**$162.93**	**$165.27**	**$167.69**	**$170.17**
Average Tipping Fee Required	**$150.24**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	886,658,553	886,658,553	886,658,553	886,658,553	867,363,441	846,517,485	823,996,035	799,664,423	773,377,158	744,977,054	714,294,292	681,145,403	645,332,171	606,640,452	564,838,885	519,677,518	470,886,305	418,173,499	361,223,901	299,696,979	233,224,831	161,409,983	83,823,018
Interest	71,265,181	71,265,181	71,265,181	71,265,181	69,714,337	68,038,843	66,228,681	64,273,028	62,160,189	59,877,531	57,411,404	54,747,062	51,868,573	48,758,726	45,398,925	41,769,080	37,847,487	33,610,695	29,033,371	24,088,145	18,745,446	12,973,327	6,737,275
Principal	0	0	0	19,295,112	20,845,956	22,521,450	24,331,612	26,287,265	28,400,104	30,682,762	33,148,889	35,813,231	38,691,720	41,801,567	45,161,368	48,791,212	52,712,806	56,949,598	61,526,922	66,472,148	71,814,847	77,586,966	83,823,018
Annual Debt Service	71,265,181	71,265,181	71,265,181	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293	90,560,293
Ending Balance	71,265,181	142,530,362	213,795,544	867,363,441	846,517,485	823,996,035	799,664,423	773,377,158	744,977,054	714,294,292	681,145,403	645,332,171	606,640,452	564,838,885	519,677,518	470,886,305	418,173,499	361,223,901	299,696,979	233,224,831	161,409,983	83,823,018	0

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Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108
Residuals/Ash for Disposal	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103
Operating Costs ($/year)																				
Facility O&M ($/year)	41,050,088	42,281,590	43,550,038	44,856,539	46,202,235	47,588,302	49,015,951	50,486,430	52,001,023	53,561,053	55,167,885	56,822,922	58,527,609	60,283,438	62,091,941	63,954,699	65,873,340	67,849,540	69,885,026	71,981,577
Residuals/Ash for Disposal	6,899,913	7,106,910	7,320,118	7,539,721	7,765,913	7,998,890	8,238,857	8,486,023	8,740,603	9,002,821	9,272,906	9,551,093	9,837,626	10,132,755	10,436,737	10,749,840	11,072,335	11,404,505	11,746,640	12,099,039
Total Annual Operating Costs ($)																				
Total Operating Costs	47,950,001	49,388,501	50,870,156	52,396,260	53,968,148	55,587,193	57,254,808	58,972,453	60,741,626	62,563,875	64,440,791	66,374,015	68,365,235	70,416,192	72,528,678	74,704,539	76,945,675	79,254,045	81,631,666	84,080,616
O&M Cost/Ton - - All Tonnage	44.39	45.73	47.10	48.51	49.97	51.46	53.01	54.60	56.24	57.92	59.66	61.45	63.29	65.19	67.15	69.16	71.24	73.38	75.58	77.84
NPV of Total Annual Costs	*791,283,959*																			
Debt Service ($)																				
Total Annual Debt Service	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	-
Debt Service Cost/Ton - - All Tonnage	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	136.97	0.00
NPV Total Annual Debt Service	*1,839,994,036*																			
Total Project Costs	195,888,235	197,326,735	198,808,390	200,334,495	201,906,383	203,525,427	205,193,043	206,910,687	208,679,861	210,502,110	212,379,026	214,312,250	216,303,470	218,354,427	220,466,913	222,642,773	224,883,909	227,192,280	229,569,901	84,080,616
Total Cost/Ton - - All Tonnage	181.36	182.69	184.06	185.48	186.93	188.43	189.97	191.56	193.20	194.89	196.63	198.42	200.26	202.16	204.12	206.13	208.21	210.34	212.54	77.84
NPV All Project Costs	*2,631,277,995*																			
Revenues ($)																				
Power Revenue	37,772,871	38,906,057	40,073,238	41,275,436	42,513,699	43,789,110	45,102,783	46,455,866	47,849,542	49,285,029	50,763,579	52,286,487	53,855,081	55,470,734	57,134,856	58,848,902	60,614,369	62,432,800	64,305,784	66,234,957
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842
Aluminum Revenue	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	94,929	97,777	100,710	103,731	106,843	110,048	113,350	116,750	120,253	123,861	127,576	131,404	135,346	139,406	143,588	147,896	152,333	156,903	161,610	166,458
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																				
Total Annual Revenues ($)	43,798,357	44,934,391	46,104,506	47,309,724	48,551,099	49,829,716	51,146,690	52,503,174	53,900,353	55,339,447	56,821,713	58,348,448	59,920,985	61,540,698	63,209,002	64,927,355	66,697,259	68,520,260	70,397,951	72,331,973
Total Revenues/Ton - - All Tonnage	40.55	41.60	42.69	43.80	44.95	46.13	47.35	48.61	49.90	51.24	52.61	54.02	55.48	56.98	58.52	60.11	61.75	63.44	65.18	66.97
NPV Total Annual Revenues	*701,056,052*																			
Net Annual Cost	(152,089,878)	(152,392,344)	(152,703,884)	(153,024,771)	(153,355,284)	(153,695,712)	(154,046,353)	(154,407,513)	(154,779,508)	(155,162,663)	(155,557,313)	(155,963,802)	(156,382,485)	(156,813,730)	(157,257,911)	(157,715,418)	(158,186,650)	(158,672,020)	(159,171,950)	(11,748,643)
NPV Net Annual Cost	*(1,930,221,943)*																			
Required Tipping Fee	**$140.81**	**$141.09**	**$141.38**	**$141.68**	**$141.98**	**$142.30**	**$142.62**	**$142.96**	**$143.30**	**$143.65**	**$144.02**	**$144.40**	**$144.78**	**$145.18**	**$145.59**	**$146.02**	**$146.45**	**$146.90**	**$147.37**	**$10.88**
Average Tipping Fee Required	**$137.17**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	1,448,435,036	1,448,435,036	1,448,435,036	1,448,435,036	1,416,914,767	1,382,861,056	1,346,070,279	1,306,322,443	1,263,379,875	1,216,985,797	1,166,862,796	1,112,711,158	1,054,207,083	991,000,742	922,714,192	848,939,111	769,234,357	683,123,334	590,091,137	489,581,477	380,993,354	263,677,460	136,932,301
Interest	116,417,966	116,417,966	116,417,966	116,417,966	113,884,524	111,147,457	108,190,399	104,995,666	101,544,157	97,815,233	93,786,597	89,434,159	84,731,894	79,651,685	74,163,153	68,233,481	61,827,211	54,906,038	47,428,575	39,350,111	30,622,341	21,193,076	11,005,934
Principal	0	0	0	31,520,269	34,053,710	36,790,777	39,747,836	42,942,568	46,394,077	50,123,001	54,151,638	58,504,075	63,206,340	68,286,550	73,775,082	79,704,754	86,111,023	93,032,197	100,509,660	108,588,124	117,315,894	126,745,159	136,932,301
Annual Debt Service	116,417,966	116,417,966	116,417,966	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235	147,938,235
Ending Balance	116,417,966	232,835,932	349,253,898	1,416,914,767	1,382,861,056	1,346,070,279	1,306,322,443	1,263,379,875	1,216,985,797	1,166,862,796	1,112,711,158	1,054,207,083	991,000,742	922,714,192	848,939,111	769,234,357	683,123,334	590,091,137	489,581,477	380,993,354	263,677,460	136,932,301	0

City of New York, New York
Advanced, Conversion Technologies

Economic Evaluations and Projections

<u>Thermal Technologies</u>
Commercial Scale Facilities/DBO Implementation

Alternative Resources, Inc.

March 2006

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

Thermal Technologies
Commercial Scale Facilities/DBO Implementation

Summary of Projections

	Interstate Waste Technologies	Rigel Resource Recovery	GEM America	Ebara
Facility				
Waste Processed (Average Tons/Day 365 Days/Year)	2,612	2,729	2,758	2,959
Waste Processed (Tons/Year)	953,380	996,000	1,006,740	1,080,108
Development & Capital Costs				
Development, Design & Construction Costs	487,367,314	1,051,816,109	560,719,174	915,984,281
Financing-Related Costs	192,284,954	414,981,486	221,225,055	361,390,661
Total Capital Cost	679,652,268	1,466,797,596	781,944,229	1,277,374,942
Annual Costs				
Annual Debt Service	52,930,361	114,232,129	60,896,714	99,480,160
Year 1 O&M Costs	66,608,671	217,636,167	97,953,424	47,950,001
Total Year 1 Costs	119,539,032	331,868,296	158,850,138	147,430,160
Annual Revenues				
Total Year 1 Revenues	46,691,955	203,812,487	54,078,158	43,798,357
Net Year 1 Costs	72,847,077	128,055,809	104,771,980	103,631,803
Year 1 (2014) Tipping Fee Required	**$76.41**	**$128.57**	**$104.07**	**$95.95**

City of New York, New York
Advanced, Conversion Technologies
Economic Evaluations and Projections

#	Inputs & Assumptions	Interstate Waste Technologies	Rigel Resource Recovery	GEM America (see footnote 1)	Ebara
	General Information				
1	Throughput (average tons/day 365 days/year)	2,612	2,729	2,758	2,959
2	MSW Processed in Beginning Year (tons/year)	953,380	996,000	1,006,740	1,080,108
3	Discount Rate (Tax-Exempt Cost of Capital)	4.65%	4.65%	4.65%	4.65%
4	Inflation Rate / General Escalation	3.00%	3.00%	3.00%	3.00%
5	Start Year	1	1	1	1
6	Operations Starting Year ("Year 1")	2014	2014	2014	2014
7	Construction Starting Year	2011	2011	2011	2011
8	Cost Basis Year	2005	2005	2005	2005
9	O&M Term (Years)	20	20	20	20
10	End Year	2033	2033	2033	2033
	Waste Handling & Processing				
11	Total Tonnage Processed (Year 1)	953,380	996,000	1,006,740	1,080,108
12	Residuals/Ash for Disposal (%)	0.00%	0.00%	28.40%	6.12%
13	Residuals/Ash for Disposal (tonsyear)	0	0	285,914	66,103
14	Ferrous Recovered (%)	0.00%	0.00%	3.50%	2.57%
15	Ferrous Recovered (tons/year)	0	0	35,236	27,742
16	Aluminum Recovered (%)	0.00%	0.00%	0.50%	0.64%
17	Aluminum Recovered (tons/year)	0	0	5,034	6,947
18	Plastics Recovered (%)	0.00%	0.00%	0.00%	0.00%
19	Plastics Recovered (tons/year)	0	0	0	0
20	Paper Recovered (%)	0.00%	0.00%	0.00%	0.00%
21	Paper Recovered (tons/year)	0	0	0	0
22	Mixed Metals Produced (%)	9.13%	3.54%	0.00%	0.00%
23	Mixed Metals Produced (tons/year)	87,063	35,278	0	0
24	Glassy Slag or Vitrifed Ash Produced (%)	6.85%	13.25%	0.00%	6.74%
25	Glassy Slag or Vitrified Ash Produced (tons/year)	65,297	131,970	0	72,755
26	Hydrochloric Acid Produced (%)	0.00%	3.26%	0.00%	0.00%
27	Hydrochloric Acid Produced (tons/year)	0	32,499	0	0
28	Mixed Salts Produced (%)	0.80%	0.00%	0.00%	0.00%
29	Mixed Salts Produced (tons/year)	7,656	0	0	0
30	Elemental Sulfur Produced (%)	0.15%	0.17%	0.00%	0.00%
31	Elemental Sulfur Produced (tons/year)	1,471	1,650	0	0
32	Zinc Hydroxide Produced (%)	1.00%	0.00%	0.00%	0.00%
33	Zinc Hydroxide Produced (tons/year)	9,534	0	0	0
34	APC Metals Produced (%)	0.00%	2.75%	0.00%	0.00%
35	APC Metals Produced (tons/year)	0	27,390	0	0
	Year 1 Project Costs (As Provided)				
36	Annual O&M (2005)				
37	Labor	5,500,000	24,000,000	7,200,000	6,830,000
38	Residuals Disposal				
39	Utilities				
40	Water	1,600,000			4,761,468
41	Wastewater	100,000			261,168
42	Natural Gas	8,100,000	47,700,000		849,364
43	Fossil Fuel	3,600,000			
44	Imported Electricity				30,191
45	Other		21,400,000		
46	Chemicals				
47	Air Pollution Control	100,000	6,200,000		2,035,649
48	Water/Wastewater Treatment		2,400,000		1,003,152
49	Process Operations	7,000,000			1,633,021
50	Other				2,624,097
51	Maintenance & Repair	15,250,000	35,100,000	27,000,000	11,433,364
52	Capital Repair & Replacement	6,600,000			
53	Transportation Costs				
54	Front-End Recycling to Markets				
55	Process Products (inc. Compost) to Markets				
56	Miscellaneous & Other Costs	3,200,000	30,000,000	18,000,000	
57	Total Annual Plant O&M (2005)	51,050,000	166,800,000	52,200,000	31,461,474
58	Annual Plant O&M (Year 1)	66,608,671	217,636,167	68,109,160	41,050,088
59	Residue Transportation & Disposal ($/ton) (2005)	80.00	80.00	80.00	80.00
60	Residue Transportation & Disposal ($/ton) (Year 1)	104.38	104.38	104.38	104.38

	Inputs & Assumptions	Interstate Waste Technologies	Rigel Resource Recovery	GEM America	Ebara
	Recovered Products Prices				
61	Net Power Output (kWh/ton)	493	2212	533	383
62	Annual Net Power Output (kwh)	470,310,190	2,202,657,000	536,592,657	413,568,000
63	Power Price ($/kWh) (2005)	0.0700	0.0700	0.0700	0.0700
64	Power Price ($/kWh) (Year 1)	0.0913	0.0913	0.0913	0.0913
65	Net Digester Gas Output (mmCF/ton)	0.0000	0.0000	0.00	0.00
66	Annual Net Gas Output (mmCF)	0	0	0	0
67	Gas Price ($/mmCF) (2005)	0.00	0.00	0.00	0.00
68	Gas Price ($/mmCF) (Year 1)	0.00	0.00	0.00	0.00
69	Ferrous Price ($/ton) (2005)	0.00	0.00	51.00	51.00
70	Ferrous Price ($/ton) (Year 1)	0.00	0.00	51.00	51.00
71	Aluminum Price ($/ton) (2005)	0.00	0.00	650.00	650.00
72	Aluminum Price ($/ton) (Year 1)	0.00	0.00	650.00	650.00
73	Mixed Metals Price ($/ton)(2005)	30.00	30.00	0.00	0.00
74	Mixed Metals Price ($/ton)(Year 1)	39.14	39.14	0.00	0.00
75	Plastics Price ($/ton) (2005)	0.00	0.00	0.00	0.00
76	Plastics Price ($/ton) (Year 1)	0.00	0.00	0.00	0.00
77	Glassy Slag/Vitrified Ash Price ($/ton) (2005)	1.00	1.00	0.00	1.00
78	Glassy Slag/Vitrified Ash Price ($/ton) (Year 1)	1.30	1.30	0.00	1.30
79	Paper Price ($/ton) (2005)	0.00	0.00	0.00	0.00
80	Paper Price ($/ton) (Year 1)	0.00	0.00	0.00	0.00
81	Hydrochloric Acid Produced (%)	25.00	25.00	0.00	0.00
82	Hydrochloric Acid Produced (tons/year)	32.62	32.62	0.00	0.00
83	Mixed Salts Produced (%)	10.00	10.00	0.00	0.00
84	Mixed Salts Produced (tons/year)	13.05	13.05	0.00	0.00
85	Elemental Sulfur Produced (%)	10.00	10.00	0.00	0.00
86	Elemental Sulfur Produced (tons/year)	13.05	13.05	0.00	0.00
87	Zinc Hydroxide Produced (%)	10.00	10.00	0.00	0.00
88	Zinc Hydroxide Produced (tons/year)	13.05	13.05	0.00	0.00
89	APC Metals Product ($/ton)(2005)	0.00	0.00	0.00	0.00
90	APC Metals Product ($/ton)(Year1)	0.00	0.00	0.00	0.00
	Capital Costs (2005) (As Provided)				
91	Central Facility				
92	Development (Fees, Permits, etc.)	6,000,000	9,360,000		
93	Engineering & Design	5,000,000	49,608,720	84,000,000	
94	Structures	70,000,000	147,001,200	15,000,000	
95	Pre-Processing Equipment		10,920,000	116,461,500	
96	Processing Equipment	96,000,000	208,729,864	183,000,132	
97	Power Generation Equipment	115,000,000	350,124,360	63,900,000	
98	Storage Facilities	3,000,000	4,680,000	4,500,000	
99	Environmental Control Systems	50,000,000	46,819,248		
100	Ancillary Systems	55,000,000	46,939,248		
101	Vehicles	150,000	2,300,000		
102	Other	5,500,000		1,350,000	
103	Total Development/Construction Costs	405,650,000	876,482,640	468,211,632	762,600,000
104	Construction Cost (2011)	484,367,314	1,046,566,109	559,069,174	910,584,281
105	Site Acquisition				
106	Acreage Required	20	35	11	36
107	Cost/Acre	150,000	150,000	150,000	150,000
108	Site Acquisition Cost	3,000,000	5,250,000	1,650,000	5,400,000
109	City Implementation Costs	0	0	0	0
110	Total Capital Cost	487,367,314	1,051,816,109	560,719,174	915,984,281
111	Financing Costs & Reserve Fund Factor	20%	20%	20%	20%
112	Financing Costs & Reserve Fund	97,473,463	210,363,222	112,143,835	183,196,856
113	Total Capital	584,840,777	1,262,179,331	672,863,009	1,099,181,138
114	Capitalized Interest(1)	94,811,491	204,618,265	109,081,220	178,193,804
115	Total Financing	679,652,268	1,466,797,596	781,944,229	1,277,374,942
116	Debt Amortization Term (years)	20	20	20	20
117	Debt Interest Rate - Public Ownership/Financing (DBO)	4.65%	4.65%	4.65%	4.65%
118	Debt Interest Rate Applied	4.65%	4.65%	4.65%	4.65%

(1) As per GEM America's submittal, all costs for the demonstration-scale facility have been escalated by a factor of 6
to arrive a comparable costs for the commercial-scale facility
(2) Capitalized Interest calculations are performed on individual proformas

Interstate Waste Technologies

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380	953,380
Residuals/Ash for Disposal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Costs ($/year)																				
Facility O&M ($/year)	66,608,671	68,606,931	70,665,139	72,785,093	74,968,646	77,217,705	79,534,237	81,920,264	84,377,872	86,909,208	89,516,484	92,201,979	94,968,038	97,817,079	100,751,591	103,774,139	106,887,363	110,093,984	113,396,804	116,798,708
Residuals/Ash Disposal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Operating Costs ($)																				
Total Operating Costs	66,608,671	68,606,931	70,665,139	72,785,093	74,968,646	77,217,705	79,534,237	81,920,264	84,377,872	86,909,208	89,516,484	92,201,979	94,968,038	97,817,079	100,751,591	103,774,139	106,887,363	110,093,984	113,396,804	116,798,708
O&M Cost/Ton - - All Tonnage	69.87	71.96	74.12	76.34	78.63	80.99	83.42	85.93	88.50	91.16	93.89	96.71	99.61	102.60	105.68	108.85	112.11	115.48	118.94	122.51
NPV of Total Annual Costs	*1,099,194,417*																			
Debt Service ($)																				
Total Annual Debt Service	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361
Debt Service Cost/Ton - - All Tonnage	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52	55.52
NPV Total Annual Debt Service	*679,652,268*																			
Total Project Costs	119,539,032	121,537,292	123,595,500	125,715,454	127,899,007	130,148,066	132,464,597	134,850,624	137,308,232	139,839,568	142,446,845	145,132,339	147,898,398	150,747,440	153,681,952	156,704,500	159,817,724	163,024,345	166,327,164	169,729,068
Total Cost/Ton - - All Tonnage	125.38	127.48	129.64	131.86	134.15	136.51	138.94	141.44	144.02	146.68	149.41	152.23	155.13	158.12	161.20	164.37	167.63	171.00	174.46	178.03
NPV All Project Costs	*1,778,846,685*																			
Revenues ($)																				
Power Revenue	42,955,369	44,244,030	45,571,351	46,938,491	48,346,646	49,797,045	51,290,957	52,829,685	54,414,576	56,047,013	57,728,424	59,460,276	61,244,085	63,081,407	64,973,849	66,923,065	68,930,757	70,998,679	73,128,640	75,322,499
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminum Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911	3,407,911
Glass Revenue	85,198	87,754	90,386	93,098	95,891	98,768	101,731	104,783	107,926	111,164	114,499	117,934	121,472	125,116	128,869	132,735	136,717	140,819	145,043	149,395
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	99,889	102,885	105,972	109,151	112,426	115,798	119,272	122,851	126,536	130,332	134,242	138,269	142,417	146,690	151,091	155,623	160,292	165,101	170,054	175,156
Other Materials Revenue	19,194	19,770	20,363	20,974	21,603	22,251	22,919	23,606	24,314	25,044	25,795	26,569	27,366	28,187	29,033	29,904	30,801	31,725	32,677	33,657
Other Materials Revenue	124,394	128,126	131,970	135,929	140,007	144,207	148,533	152,990	157,579	162,307	167,176	172,191	177,357	182,677	188,158	193,803	199,617	205,605	211,773	218,126
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																				
Total Annual Revenues ($)	46,691,955	47,990,476	49,327,953	50,705,554	52,124,483	53,585,981	55,091,323	56,641,825	58,238,842	59,883,770	61,578,046	63,323,150	65,120,607	66,971,988	68,878,911	70,843,041	72,866,094	74,949,840	77,096,098	79,306,743
Total Revenues/Ton - - All Tonnage	48.98	50.34	51.74	53.19	54.67	56.21	57.79	59.41	61.09	62.81	64.59	66.42	68.30	70.25	72.25	74.31	76.43	78.61	80.87	83.18
NPV Total Annual Revenues	*758,044,346*																			
Net Annual Cost	(72,847,077)	(73,546,816)	(74,267,547)	(75,009,900)	(75,774,523)	(76,562,085)	(77,373,275)	(78,208,799)	(79,069,390)	(79,955,798)	(80,868,798)	(81,809,189)	(82,777,791)	(83,775,451)	(84,803,041)	(85,861,459)	(86,951,629)	(88,074,505)	(89,231,066)	(90,422,325)
NPV Net Annual Cost	*(1,020,802,339)*																			
Required Tipping Fee	**$76.41**	**$77.14**	**$77.90**	**$78.68**	**$79.48**	**$80.31**	**$81.16**	**$82.03**	**$82.94**	**$83.87**	**$84.82**	**$85.81**	**$86.83**	**$87.87**	**$88.95**	**$90.06**	**$91.20**	**$92.38**	**$93.59**	**$94.84**
Average Tipping Fee Required	**$84.81**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	679,652,268	679,652,268	679,652,268	679,652,268	658,325,738	636,007,525	612,651,514	588,209,449	562,630,828	535,862,801	507,850,061	478,534,728	447,856,232	415,751,187	382,153,256	346,993,022	310,197,837	271,691,676	231,394,978	189,224,484	145,093,062	98,909,529	50,578,462
Interest	31,603,830	31,603,830	31,603,830	31,603,830	30,612,147	29,574,350	28,488,295	27,351,739	26,162,333	24,917,620	23,615,028	22,251,865	20,825,315	19,332,430	17,770,126	16,135,176	14,424,199	12,633,663	10,759,866	8,798,939	6,746,827	4,599,293	2,351,898
Principal	0	0	0	21,326,530	22,318,214	23,356,011	24,442,065	25,578,621	26,768,027	28,012,740	29,315,333	30,678,496	32,105,046	33,597,930	35,160,234	36,795,185	38,506,161	40,296,698	42,170,494	44,131,422	46,183,533	48,331,067	50,578,462
Annual Debt Service	31,603,830	31,603,830	31,603,830	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361	52,930,361
Ending Balance	31,603,830	63,207,661	94,811,491	658,325,738	636,007,525	612,651,514	588,209,449	562,630,828	535,862,801	507,850,061	478,534,728	447,856,232	415,751,187	382,153,256	346,993,022	310,197,837	271,691,676	231,394,978	189,224,484	145,093,062	98,909,529	50,578,462	0

Rigel Resource Recovery

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000	996,000
Residuals/Ash for Disposal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Costs ($/year)																				
Facility O&M ($/year)	217,636,167	224,165,252	230,890,210	237,816,916	244,951,423	252,299,966	259,868,965	267,665,034	275,694,985	283,965,835	292,484,810	301,259,354	310,297,135	319,606,049	329,194,230	339,070,057	349,242,159	359,719,423	370,511,006	381,626,336
Residuals/Ash Disposal (if separately calculated)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Operating Costs ($)																				
Total Operating Costs	217,636,167	224,165,252	230,890,210	237,816,916	244,951,423	252,299,966	259,868,965	267,665,034	275,694,985	283,965,835	292,484,810	301,259,354	310,297,135	319,606,049	329,194,230	339,070,057	349,242,159	359,719,423	370,511,006	381,626,336
O&M Cost/Ton - - All Tonnage	218.51	225.07	231.82	238.77	245.94	253.31	260.91	268.74	276.80	285.11	293.66	302.47	311.54	320.89	330.52	340.43	350.64	361.16	372.00	383.16
NPV of Total Annual Costs	*3,591,491,258*																			
Debt Service ($)																				
Total Annual Debt Service	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129
Debt Service Cost/Ton - - All Tonnage	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69	114.69
NPV Total Annual Debt Service	*1,466,797,596*																			
Total Project Costs	331,868,296	338,397,381	345,122,339	352,049,045	359,183,552	366,532,095	374,101,094	381,897,163	389,927,114	398,197,964	406,716,939	415,491,483	424,529,263	433,838,177	443,426,359	453,302,186	463,474,288	473,951,552	484,743,135	495,858,465
Total Cost/Ton - - All Tonnage	333.20	339.76	346.51	353.46	360.63	368.00	375.60	383.43	391.49	399.80	408.35	417.16	426.23	435.58	445.21	455.12	465.34	475.85	486.69	497.85
NPV All Project Costs	*5,058,288,854*																			
Revenues ($)																				
Power Revenue	201,177,745	207,213,077	213,429,470	219,832,354	226,427,324	233,220,144	240,216,748	247,423,251	254,845,948	262,491,327	270,366,067	278,477,049	286,831,360	295,436,301	304,299,390	313,428,372	322,831,223	332,516,160	342,491,644	352,766,394
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminum Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906	1,380,906
Glass Revenue	172,191	177,357	182,677	188,158	193,802	199,616	205,605	211,773	218,126	224,670	231,410	238,352	245,503	252,868	260,454	268,268	276,316	284,605	293,144	301,938
Other Materials Revenue	1,060,111	1,091,915	1,124,672	1,158,412	1,193,165	1,228,959	1,265,828	1,303,803	1,342,917	1,383,205	1,424,701	1,467,442	1,511,465	1,556,809	1,603,513	1,651,619	1,701,167	1,752,202	1,804,768	1,858,911
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	21,534	22,180	22,845	23,530	24,236	24,963	25,712	26,484	27,278	28,096	28,939	29,808	30,702	31,623	32,572	33,549	34,555	35,592	36,660	37,759
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487	203,812,487
Total Revenues/Ton - - All Tonnage	204.63	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
NPV Total Annual Revenues	*2,617,054,141*																			
Net Annual Cost	(128,055,809)	(134,584,894)	(141,309,852)	(148,236,558)	(155,371,065)	(162,719,608)	(170,288,607)	(178,084,676)	(186,114,627)	(194,385,476)	(202,904,452)	(211,678,996)	(220,716,776)	(230,025,690)	(239,613,872)	(249,489,699)	(259,661,801)	(270,139,065)	(280,930,648)	(292,045,978)
NPV Net Annual Cost	*(2,441,234,713)*																			
Required Tipping Fee	**$128.57**	**$135.13**	**$141.88**	**$148.83**	**$156.00**	**$163.37**	**$170.97**	**$178.80**	**$186.86**	**$195.17**	**$203.72**	**$212.53**	**$221.60**	**$230.95**	**$240.58**	**$250.49**	**$260.70**	**$271.22**	**$282.06**	**$293.22**
Average Tipping Fee Required	**$203.63**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	1,466,797,596	1,466,797,596	1,466,797,596	1,466,797,596	1,420,771,555	1,372,605,303	1,322,199,321	1,269,449,461	1,214,246,732	1,156,477,076	1,096,021,131	1,032,753,985	966,544,916	897,257,126	824,747,453	748,866,081	669,456,225	586,353,810	499,387,133	408,376,506	313,133,885	213,462,482	109,156,358
Interest	68,206,088	68,206,088	68,206,088	68,206,088	66,065,877	63,826,147	61,482,268	59,029,400	56,462,473	53,776,184	50,964,983	48,023,060	44,944,339	41,722,456	38,350,757	34,822,273	31,129,714	27,265,452	23,221,502	18,989,508	14,560,726	9,926,005	5,075,771
Principal	0	0	0	46,026,041	48,166,252	50,405,982	52,749,860	55,202,729	57,769,656	60,455,945	63,267,146	66,209,069	69,287,790	72,509,673	75,881,372	79,409,856	83,102,414	86,966,677	91,010,627	95,242,621	99,671,403	104,306,123	109,156,358
Annual Debt Service	68,206,088	68,206,088	68,206,088	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129	114,232,129
Ending Balance	68,206,088	136,412,176	204,618,265	1,420,771,555	1,372,605,303	1,322,199,321	1,269,449,461	1,214,246,732	1,156,477,076	1,096,021,131	1,032,753,985	966,544,916	897,257,126	824,747,453	748,866,081	669,456,225	586,353,810	499,387,133	408,376,506	313,133,885	213,462,482	109,156,358	0

GEM America

Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740	1,006,740
Residuals/Ash for Disposal	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914	285,914
Operating Costs ($/year)																				
Facility O&M ($/year)	68,109,160	70,152,435	72,257,008	74,424,718	76,657,460	78,957,184	81,325,899	83,765,676	86,278,646	88,867,006	91,533,016	94,279,006	97,107,377	100,020,598	103,021,216	106,111,852	109,295,208	112,574,064	115,951,286	119,429,825
Residuals/Ash for Disposal	29,844,263	30,739,591	31,661,779	32,611,633	33,589,981	34,597,681	35,635,611	36,704,680	37,805,820	38,939,995	40,108,195	41,311,440	42,550,784	43,827,307	45,142,126	46,496,390	47,891,282	49,328,020	50,807,861	52,332,097
Total Annual Operating Costs ($)																				
Total Operating Costs	97,953,424	100,892,026	103,918,787	107,036,351	110,247,441	113,554,865	116,961,511	120,470,356	124,084,467	127,807,001	131,641,211	135,590,447	139,658,160	143,847,905	148,163,342	152,608,242	157,186,490	161,902,084	166,759,147	171,761,921
O&M Cost/Ton - - All Tonnage	97.30	100.22	103.22	106.32	109.51	112.79	116.18	119.66	123.25	126.95	130.76	134.68	138.72	142.88	147.17	151.59	156.13	160.82	165.64	170.61
NPV of Total Annual Costs	*1,616,454,056*																			
Debt Service ($)																				
Total Annual Debt Service	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714
Debt Service Cost/Ton - - All Tonnage	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49	60.49
NPV Total Annual Debt Service	*781,944,229*																			
Total Project Costs	158,850,138	161,788,741	164,815,501	167,933,065	171,144,156	174,451,579	177,858,225	181,367,070	184,981,181	188,703,715	192,537,925	196,487,161	200,554,874	204,744,619	209,060,056	213,504,957	218,083,204	222,798,799	227,655,861	232,658,636
Total Cost/Ton - - All Tonnage	157.79	160.71	163.71	166.81	170.00	173.28	176.67	180.15	183.74	187.44	191.25	195.17	199.21	203.37	207.66	212.08	216.62	221.31	226.13	231.10
NPV All Project Costs	*2,398,398,285*																			
Revenues ($)																				
Power Revenue	49,009,220	50,479,496	51,993,881	53,553,698	55,160,309	56,815,118	58,519,571	60,275,158	62,083,413	63,945,916	65,864,293	67,840,222	69,875,429	71,971,691	74,130,842	76,354,767	78,645,410	81,004,773	83,434,916	85,937,963
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032	1,797,032
Aluminum Revenue	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906	3,271,906
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																				
Total Annual Revenues ($)	54,078,158	55,548,434	57,062,819	58,622,636	60,229,247	61,884,056	63,588,509	65,344,097	67,152,351	69,014,854	70,933,231	72,909,160	74,944,367	77,040,630	79,199,780	81,423,706	83,714,349	86,073,711	88,503,854	91,006,902
Total Revenues/Ton - - All Tonnage	53.72	55.18	56.68	58.23	59.83	61.47	63.16	64.91	66.70	68.55	70.46	72.42	74.44	76.52	78.67	80.88	83.15	85.50	87.91	90.40
NPV Total Annual Revenues	*873,851,179*																			
Net Annual Cost	(104,771,980)	(106,240,306)	(107,752,682)	(109,310,429)	(110,914,909)	(112,567,523)	(114,269,715)	(116,022,973)	(117,828,829)	(119,688,861)	(121,604,694)	(123,578,001)	(125,610,508)	(127,703,990)	(129,860,276)	(132,081,251)	(134,368,855)	(136,725,088)	(139,152,007)	(141,651,734)
NPV Net Annual Cost	*(1,524,547,106)*																			
Required Tipping Fee	**$104.07**	**$105.53**	**$107.03**	**$108.58**	**$110.17**	**$111.81**	**$113.50**	**$115.25**	**$117.04**	**$118.89**	**$120.79**	**$122.75**	**$124.77**	**$126.85**	**$128.99**	**$131.20**	**$133.47**	**$135.81**	**$138.22**	**$140.70**
Average Tipping Fee Required	**$120.77**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	781,944,229	781,944,229	781,944,229	781,944,229	757,407,922	731,730,676	704,859,438	676,738,688	647,310,323	616,513,538	584,284,704	550,557,228	515,261,425	478,324,367	439,669,736	399,217,665	356,884,572	312,582,990	266,221,385	217,703,965	166,930,485	113,796,039	58,190,840
Interest	36,360,407	36,360,407	36,360,407	36,360,407	35,219,468	34,025,476	32,775,964	31,468,349	30,099,930	28,667,880	27,169,239	25,600,911	23,959,656	22,242,083	20,444,643	18,563,621	16,595,133	14,535,109	12,379,294	10,123,234	7,762,268	5,291,516	2,705,874
Principal	0	0	0	24,536,308	25,677,246	26,871,238	28,120,750	29,428,365	30,796,784	32,228,835	33,727,475	35,295,803	36,937,058	38,654,631	40,452,071	42,333,093	44,301,582	46,361,605	48,517,420	50,773,480	53,134,447	55,605,198	58,190,840
Annual Debt Service	36,360,407	36,360,407	36,360,407	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714	60,896,714
Ending Balance	36,360,407	72,720,813	109,081,220	757,407,922	731,730,676	704,859,438	676,738,688	647,310,323	616,513,538	584,284,704	550,557,228	515,261,425	478,324,367	439,669,736	399,217,665	356,884,572	312,582,990	266,221,385	217,703,965	166,930,485	113,796,039	58,190,840	0

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Model Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Waste Quantities																				
Amount of MSW (tons/year)	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108
Pro Forma																				
Throughput (Tons/Year)																				
Tons MSW to Facility (tons/year)	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108	1,080,108
Residuals/Ash for Disposal	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103	66,103
Operating Costs ($/year)																				
Facility O&M ($/year)	41,050,088	42,281,590	43,550,038	44,856,539	46,202,235	47,588,302	49,015,951	50,486,430	52,001,023	53,561,053	55,167,885	56,822,922	58,527,609	60,283,438	62,091,941	63,954,699	65,873,340	67,849,540	69,885,026	71,981,577
Residuals/Ash for Disposal	6,899,913	7,106,910	7,320,118	7,539,721	7,765,913	7,998,890	8,238,857	8,486,023	8,740,603	9,002,821	9,272,906	9,551,093	9,837,626	10,132,755	10,436,737	10,749,840	11,072,335	11,404,505	11,746,640	12,099,039
Total Annual Operating Costs ($)																				
Total Operating Costs	47,950,001	49,388,501	50,870,156	52,396,260	53,968,148	55,587,193	57,254,808	58,972,453	60,741,626	62,563,875	64,440,791	66,374,015	68,365,235	70,416,192	72,528,678	74,704,539	76,945,675	79,254,045	81,631,666	84,080,616
O&M Cost/Ton - - All Tonnage	44.39	45.73	47.10	48.51	49.97	51.46	53.01	54.60	56.24	57.92	59.66	61.45	63.29	65.19	67.15	69.16	71.24	73.38	75.58	77.84
NPV of Total Annual Costs	*791,283,959*																			
Debt Service ($)																				
Total Annual Debt Service	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	-
Debt Service Cost/Ton - - All Tonnage	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	92.10	0.00
NPV Total Annual Debt Service	*1,237,292,717*																			
Total Project Costs	147,430,160	148,868,660	150,350,315	151,876,420	153,448,308	155,067,352	156,734,968	158,452,612	160,221,786	162,044,035	163,920,951	165,854,175	167,845,395	169,896,352	172,008,838	174,184,698	176,425,834	178,734,205	181,111,826	84,080,616
Total Cost/Ton - - All Tonnage	136.50	137.83	139.20	140.61	142.07	143.57	145.11	146.70	148.34	150.03	151.76	153.55	155.40	157.30	159.25	161.27	163.34	165.48	167.68	77.84
NPV All Project Costs	*2,028,576,676*																			
Revenues ($)																				
Power Revenue	37,772,871	38,906,057	40,073,238	41,275,436	42,513,699	43,789,110	45,102,783	46,455,866	47,849,542	49,285,029	50,763,579	52,286,487	53,855,081	55,470,734	57,134,856	58,848,902	60,614,369	62,432,800	64,305,784	66,234,957
Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrous Revenue	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842	1,414,842
Aluminum Revenue	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716	4,515,716
Plastics Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass Revenue	94,929	97,777	100,710	103,731	106,843	110,048	113,350	116,750	120,253	123,861	127,576	131,404	135,346	139,406	143,588	147,896	152,333	156,903	161,610	166,458
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Materials Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APC Metals Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Revenues ($)																				
Total Annual Revenues ($)	43,798,357	44,934,391	46,104,506	47,309,724	48,551,099	49,829,716	51,146,690	52,503,174	53,900,353	55,339,447	56,821,713	58,348,448	59,920,985	61,540,698	63,209,002	64,927,355	66,697,259	68,520,260	70,397,951	72,331,973
Total Revenues/Ton - - All Tonnage	40.55	41.60	42.69	43.80	44.95	46.13	47.35	48.61	49.90	51.24	52.61	54.02	55.48	56.98	58.52	60.11	61.75	63.44	65.18	66.97
NPV Total Annual Revenues	*701,056,052*																			
Net Annual Cost	(103,631,803)	(103,934,269)	(104,245,809)	(104,566,696)	(104,897,208)	(105,237,637)	(105,588,278)	(105,949,438)	(106,321,433)	(106,704,588)	(107,099,238)	(107,505,727)	(107,924,410)	(108,355,655)	(108,799,836)	(109,257,343)	(109,728,575)	(110,213,945)	(110,713,875)	(11,748,643)
NPV Net Annual Cost	*(1,327,520,624)*																			
Required Tipping Fee	**$95.95**	**$96.23**	**$96.51**	**$96.81**	**$97.12**	**$97.43**	**$97.76**	**$98.09**	**$98.44**	**$98.79**	**$99.16**	**$99.53**	**$99.92**	**$100.32**	**$100.73**	**$101.15**	**$101.59**	**$102.04**	**$102.50**	**$10.88**
Average Tipping Fee Required	**$94.55**																			

Debt Service Calculation

Model Year	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Beginning Balance	1,277,374,942	1,277,374,942	1,277,374,942	1,277,374,942	1,237,292,717	1,195,346,669	1,151,450,129	1,105,512,401	1,057,438,568	1,007,129,301	954,480,654	899,383,845	841,725,034	781,385,088	718,239,335	652,157,305	583,002,460	510,631,914	434,896,139	355,638,650	272,695,687	185,895,877	95,059,875
Interest	59,397,935	59,397,935	59,397,935	59,397,935	57,534,111	55,583,620	53,542,431	51,406,327	49,170,893	46,831,513	44,383,350	41,821,349	39,140,214	36,334,407	33,398,129	30,325,315	27,109,614	23,744,384	20,222,670	16,537,197	12,680,349	8,644,158	4,420,284
Principal	0	0	0	40,082,225	41,946,048	43,896,540	45,937,729	48,073,833	50,309,266	52,648,647	55,096,809	57,658,811	60,339,946	63,145,753	66,082,031	69,154,845	72,370,545	75,735,776	79,257,489	82,942,962	86,799,810	90,836,001	95,059,875
Annual Debt Service	59,397,935	59,397,935	59,397,935	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160	99,480,160
Ending Balance	59,397,935	118,795,870	178,193,804	1,237,292,717	1,195,346,669	1,151,450,129	1,105,512,401	1,057,438,568	1,007,129,301	954,480,654	899,383,845	841,725,034	781,385,088	718,239,335	652,157,305	583,002,460	510,631,914	434,896,139	355,638,650	272,695,687	185,895,877	95,059,875	0