Alternative Waste Processing Technologies Assessment

(A White Paper)

Prepared by:

Gershman, Brickner & Bratton, Inc.
8550 Arlington Blvd, Suite 203
Fairfax, VA 22031
1-800-573-5801

August 15, 2008

Table of Contents

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION AND BACKGROUND 1

2.0 FUTURE ORANGE COUNTY WASTE DISPOSAL NEEDS 3

3.0 WORLDWIDE EXPERIENCE OF WASTE PROCESSING TECHNOLOGIES AND VENDORS 5

3.1 Mass-Burn/Waterwall Combustion 5

3.2 Mass-Burn/Modular Combustion 5

3.3 Refuse-derived Fuel/Dedicated Boiler 6

3.4 RDF/Fluidized Bed 6

3.5 Gasification 6

3.6 Pyrolysis 6

3.7 Plasma Arc 7

3.8 Biological Fuel Production 7

3.8.1 Cellulosic Ethanol 7

3.8.2 Biogas - Anaerobic Digestion 8

4.0 RECENT RESEARCH/PROCUREMENTS FOR WASTE PROCESSING TECHNOLOGIES BY OTHERS 12

4.1 Recent Research 13

4.1.1 New York City, NY 13

4.1.2 City of Los Angeles, CA 14

4.1.3 Los Angeles County, CA 15

4.1.4 King County, WA 17

4.2 Procurements 17

4.2.1 Frederick and Carroll Counties, MD 17

4.2.2 Harford County, MD 18

4.2.3 City of Sacramento, CA 19

4.2.4 Broward County, FL 19

4.2.5 St. Lucie County, FL 20

4.2.6 Hawaii County, HI 20

4.2.7 Pinellas County, FL 20

4.2.8 Hillsborough and Lee Counties, FL 20

4.2.9 Fairbanks North Star Borough, AK 21

4.2.10 City of Tallahassee, FL 21

4.3 Comparison of Technologies Chosen in Recent Research/Procurements 22

5.0 OPINION ON ECONOMIC FEASIBILITY, EFFECTIVENESS, AND ENVIRONMENTAL ISSUES OF WASTE PROCESSING TECHNOLOGIES 23

5.1 Economic Feasibility of Waste Processing Technologies 23

5.1.1 Typical Waste Processing Technologies Project Economic Estimates 23

5.1.2 Assumptions 24

5.1.3 Pro Forma Operating Statement 25

5.2 Effectiveness of Waste Processing Technologies ... 25
5.3 Environmental Issues of Waste Processing Technologies ... 26
5.3.1 Air Quality ... 26
5.3.2 Water ... 29

6.0 OPINION ON WHICH WASTE PROCESSING TECHNOLOGIES SHOULD BE CONSIDERED FOR ORANGE COUNTY ... 30

List of Tables

Table 3-1. U.S. Mass-Burn/Waterwall Facilities ... 5
Table 3-2. Commercial Cellulosic Ethanol Plants in the U.S. ... 8
Table 3-3. Biogas Production in Europe ... 10
Table 3-4. Biogas Firms in Europe ... 10
Table 4-1. Technologies/Vendors Mentioned in Recent Procurements ... 22
Table 5-1. Pro Forma Annual Operating Statement ... 25
Table B-1. WTE Facilities Worldwide ... B-2

List of Figures

Figure 1-1 – Solid Waste Management Hierarchy ... 1
Figure 5-1. Dioxin Emissions from WTE Facilities, 1990 – 2005 ... 28
Figure 5-2. Mercury Emission from WTE Facilities, 1990 - 2005 ... 28
Figure B-1. Waterwall Furnace Section ... B-4
Figure B-2. Typical Mass-Burn Waterwall System ... B-5
Figure B-3. Typical Modular Combustion System ... B-6
Figure B-4. Typical RDF Combustion Facility ... B-7
Figure B-5. Typical RDF Processing Schematic ... B-8
Figure B-6. Typical RDF Fluid Bed System ... B-9
Figure B-7. Typical Gasification System ... B-10
Figure B-8. RDF Fluidized Bed Gasification System ... B-11
Figure B-9. EnTech Process Schematic ... B-12
Figure B-10. Process Diagram of a Pyrolysis System ... B-13
Figure B-11. Cross-Section of a Plasma Arc Furnace ... B-14
Figure B-12. Process Flow of the BCyL Biomass Ethanol Plant ... B-16
Figure B-13. Process Flow for Anaerobic Digestion System[17] ... B-20
Figure B-14. ArrowBio Facility in Haifa ... B-21

Appendices

A-1 Firms Evaluated by Recent Waste Processing Studies or Procurements ... A-1
A-2 Summary of Municipal Waste Processing Technologies ... A-2

B Overview of Waste Processing Technologies ... B-1

Executive Summary

This examination of alternative waste processing technologies (WPT) was undertaken at the behest of the Orange County Board of Commissioners to explore and evaluate alternatives to landfill disposal of the County's municipal solid waste. The purpose of this white paper is to initiate that evaluation and brief the County's solid waste staff, elected officials, Solid Waste Advisory Board, and citizens on state-of-the-art solid waste processing technologies, emerging technologies and their applicability to the County's needs, and the potential of these technologies to contribute to the County's overall solid waste management system.

Orange County generated approximately 116,000 tons of waste in FY2006-07, or about 318 tons per day (TPD). Of that material, 62,900 tons or 172 TPD were disposed of in landfills, and 29,700 tons or 24 percent was recycled. The County is examining ways to achieve its goal of 61 percent waste reduction, up from their current rate of 48 percent. The County's landfill is projected to close in 2011. The County has decided to manage its future waste using a transfer station and contracting for disposal in an out-of-County landfill as well as examining the feasibility of alternatives.

Traditional waste processing technologies now in operation have the potential of managing most of the County's non-recycled waste. Generally, WTE plants reduce the processed waste tonnage by 75 percent and the volume by 90 percent. This leaves a residue, ash, which needs to be landfilled in a permitted Subtitle D landfill. In some states, ash may be used beneficially as alternative daily cover at landfills. Even at 75 percent reduction by weight, a WTE facility has a dramatic effect on the amount of residual waste.

This report examines both proven and unproven waste processing technologies. Table A-2 in the Appendices provides a comparison of these various technologies. Waste-to-energy (WTE) technologies profiled include: mass-burn/waterwall combustion, mass-burn/modular combustion, refuse-derived fuel (RDF)/dedicated boiler, and RDF/fluid bed. Although WTE plants range in size from 10 to 3,000 TPD in the U.S., 71 percent are 500 TPD or larger. Mass-burn/waterwall combustion is the most prevalent WPT in the U.S., employed at 65 of the 89 facilities. However, no new mass-burn WTE facilities have been built in the U.S. for over ten years. Ten WTE facilities currently operate in the Mid-Atlantic States region, processing almost 12,000 TPD. In North Carolina, New Hanover County owns a 500 TPD plant that produces electricity. In contrast to its smaller presence in the U.S., WTE is an accepted and commonly used waste processing technology worldwide, with 400 facilities in Europe, 100 in Japan, and 70 in other nations such as Taiwan, Singapore, and China.

In addition to proven technologies, this report examines the emerging technologies of high-temperature gasification, fluidized-bed combustion, plasma-arc processing, non-thermal anaerobic digestion, and biological fuel production. Although technically not an emerging technology, biological fuel production has not been commercially proven using MSW as a feedstock.

The historical and current context for development and use of WTE in the U.S. is explored, with waste processing technologies currently receiving renewed interest due to: the proven WTE track record, increasing fossil fuel costs, growing interest in renewable energy, a higher ranking in the EPA's waste management hierarchy, concern about greenhouse gases, a change in flow control legislation, and the increasing cost of long distance transfer and disposal.

Recent activity in the evaluation and procurement of WPT by other U.S. cities and counties is detailed. Like Orange County, these localities are exploring alternatives for service to their citizens. Information on the investigations of New York City, the City of Los Angeles, Los Angeles County, and King County, WA into the applicability of WPT is highlighted. Current WPT procurements are outlined, including: a resource recovery facility for Frederick and Carroll Counties, MD; expansion of the Harford, MD WTE facility; negotiations by the City of Sacramento, CA for a plasma gasification project; Broward County, FL's Request for Expressions of Interest to evaluate potential waste disposal options; a plasma arc gasification project proposed in St. Lucie County, FL; and WTE plant expansions in Hillsborough and Lee Counties, FL, that are currently being constructed. A total of 80 technology vendors offering 14 different technologies are represented, evaluated, screened, or selected during these research and procurement projects.

The economic characteristics of the various waste processing technologies, including capital and operating costs and risk, are summarized in the report. Generally, capital cost for the proven technologies are in the range of $150,000 to $250,000 per ton of installed capacity, depending on size and plant configuration. Operating costs are in the range of $35 to $60 per ton processed, not including residue disposal, again dependent on size, equipment and operating profile, and assuming a private operator. These figures are based on industry rules-of-thumb, recent operating results from selected facilities, surveys of industry professionals and related references.

Of the waste processing technologies examined, only WTE is a proven technology which could be recommended for implementation consideration by Orange County at this point in time. As mentioned earlier, there are 89 WTE plants generating power in the U.S. and hundreds worldwide. The other technologies discussed are in various stages of development and are not mature enough to mitigate the risks potentially inherent with their implementation.

In evaluating waste processing technologies for Orange County to consider, it is apparent that there is not enough waste generated by the County to gain the economies of scale necessary to make a waste processing technology a cost-effective investment. The estimated cost to process waste at a 300 TPD WTE facility in Orange County is estimated at $102 per ton. To improve the economics of utilizing waste processing technology, Orange County would need to partner with an adjacent community. The $102 per ton is not competitive with the County's current landfill disposal fee of $49 or with Waste Industries' cost of $42 per ton to transfer and dispose of waste.

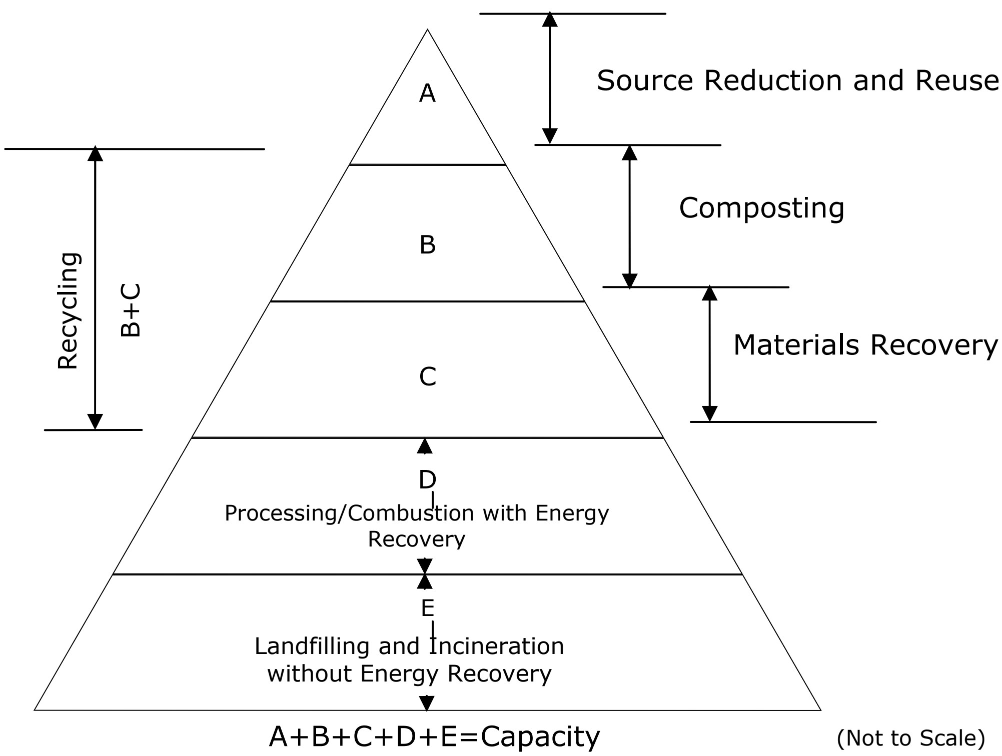
Although currently unknown, the cost of the County's new transfer station and landfilling at a remote site is unlikely to reach $102 per ton. As the County investigates the cost of transfer and disposal in preparation of its landfill closing, WPT could be more economically attractive once the cost of transfer and disposal is known. If $102 per ton were to look competitive, it is recommended that Orange County conduct a WTE plant feasibility study which considers mass-burn modular technologies, and/or fuel production approaches.

1.0 Introduction and Background

The federal government regulates solid waste in the United States under Title 40 of the Code of Federal Regulations Subchapter 1 (40 CFR 239 to 2999). These regulations are in 40 CFR 258 (also known as Resource Conservation Recovery Act [RCRA] Subtitle D), Criteria for Municipal Solid Waste Landfills. Under authority of RCRA, the United States Environmental Protection Agency (U.S. EPA) administers Title 40 regulations and enforces solid waste regulations and policies through its Office of Solid Waste (OSW).

Figure 1-1 shows U.S. EPA's hierarchy of integrated solid waste management which is illustrated in the form of a pyramid of ranked approaches. Source Reduction is at the highest level (A) of the pyramid with landfilling at the bottom. Recycling comprises the middle blocks (B & C) followed by combustion with energy recovery (D) above combustion without energy recovery and landfilling (E).

Figure 1-1 – Solid Waste Management Hierarchy[1]



As Orange County updates its Solid Waste Management Plan en route to achieving their goal of 61 percent waste reduction, the County should consider pursuing the first two approaches: source reduction/reuse and recycling. Such activities include the County's support of local recycling and the encouragement of yard waste composting. As of 2006-07, a reported 47.7 percent waste reduction rate was achieved by the County, eliminating the need to landfill that portion of the waste stream. The portion of waste generated that is not recycled or composted is hauled

[1] U.S. EPA.

to the Orange County Landfill or out-of-county facilities. The County owns the local municipal solid waste (MSW) landfill which is expected to reach capacity in the next few years. A new County construction and demolition waste landfill area was recently developed and is expected to last approximately 15-20 years depending on rate of use.

Another solid waste management strategy the County may want to consider is third in the hierarchy: waste processing to reduce the volume for land disposal. While waste processing technologies (WPT) can include methods of volume reduction (shredding, compaction, baling, etc.), most such technologies involve some form of controlled thermal treatment – incineration – with fuel production or energy recovery. The County may want to consider the need to address such waste processing technologies as possible alternatives to landfill disposal. The capital intensive approaches such as WTE require a sufficient quantity of waste to be cost effective: the more waste, the lower the per ton price.

The purpose of this white paper is to initiate that evaluation and brief the County's solid waste staff, elected officials, Solid Waste Advisory Board, and citizens on state-of-the-art solid waste processing technologies, emerging technologies and their applicability to the County's needs, and the potential of these technologies to contribute to the County's overall solid waste management system. Section 2.0 summarizes the future waste disposal needs identified in the Plan and how waste processing could affect the amount of landfill disposal required.

Section 3.0 discusses the worldwide experience of WPT and respective vendors in the United States and other countries, as some of these technologies have operating demonstrations or facilities outside of the U.S. Section 4.0 reviews most of the recent activity in the evaluation and procurement of waste processing technologies by other U.S. cities and counties. These localities are exploring alternatives for increasing their diversion rates, recovering more resources from their solid waste, and delivering better service to their citizens. Section 5.0 explores the economic feasibility, effectiveness, and environmental issues surrounding the use of the waste processing technologies discussed. Section 6.0 presents opinions as to the most applicable technologies for further consideration by the County.

Appendix B reviews the available "proven" waste processing technologies, all of which are incineration-based, their track record and operating characteristics, and a listing of facilities operating in the region. In addition, Appendix B details "emerging" waste processing technologies including high-temperature gasification, fluidized-bed combustion, plasma-arc processing, and some non-thermal anaerobic digestion.

2.0 Future Orange County Waste Disposal Needs

Based on current data, the County (excluding recycled material from the University of North Carolina (UNC)) generated approximately 116,000 tons of waste in FY 2006-07 or about 318 tons per day (TPD). Of that material, approximately 15,600 tons or 42 TPD were captured recyclables. Approximately 16,500 tons of material were buried in a construction and demolition waste (C&D) landfill located in Orange County and 8,700 tons of C&D were shipped for disposal out of the County. Tires, clean wood, brush, appliances and scrap metal totaling 12,300 were also recycled in 2006-2007. That leaves approximately 62,900 tons of waste or 172 TPD from Orange County disposed in landfills both inside and outside the County. This tonnage could be further reduced with additional diversion programs.

The County is examining ways to achieve its goal of 61 percent waste reduction. As part of this solid waste planning process update, the County has developed a series of reports evaluating current collection programs, looking at ways to increase diversion and deliver services more efficiently and effectively. These reports will be followed by technical reports on integrating the desired actions into the County's system and financing, which will result in a draft plan for the next three year planning cycle.

The County's MSW landfill is now projected to close in early 2011. The County has decided to manage its future MSW using a transfer station and contracting for disposal in an out-of-County landfill. A County-wide search is underway for a suitable site to situate the transfer station with site selection expected by the end of 2008. Following site selection, the County will design, permit, finance, and construct the transfer station, ideally before landfill closure. If the transfer station is not completed by the time the landfill is closed, managing MSW during that time period will be expensive and operationally challenging.

The projected landfill closure date may be impacted by new rules governing what was formerly considered C&D. This material must now be disposed of in lined landfill space. As of April 2008, stricter enforcement of the rules governing C&D landfills require the County to deposit furniture and other bulky items in the lined MSW landfill. This may result in a shift of as much as 8,000 tons of waste a year from C&D landfills to MSW landfills, shortening the life expectancy of the County's MSW landfill by as much as five months.

As it is, the County-generated 172 TPD is probably too small to make an alternative waste processing technology economically viable. However, the Durham Metropolitan Statistical Area, which includes Chatham, Durham, Orange, and Person Counties, had a population of 465,745 people who generated 476,710 tons of municipal solid waste from July 2006 – June 2007, according to the FY 2006-2007 North Carolina Department of Environment and Natural Resources Solid Waste Annual Report. Of that 476,710 tons of waste, an estimated 90,575 tons or 19 percent[2] constitutes recyclables. The resulting 386,135 of MSW could translate into

---

[2] Simmons, Phil; Goldstein, Nora; Kaufman, Scott M.; Themelis, Nickolas J.; and Thompson, Jr., James. "The State of Garbage in America." Biocycle, April 2006: 26. <http://www.jgpress.com/archives/_free/000848.html>.

approximately 1,000 TPD available regionally to make an alternative technology more economically viable.

Traditional waste processing technologies now in operation have the potential of managing most of the residual waste. Generally, WTE plants reduce the incoming waste stream tonnage by 75 percent and the volume by 90 percent. This leaves a residue, ash, that needs to be landfilled in a permitted Subtitle D landfill and in some states ash is used as alternative daily cover. Some emerging technologies could reduce the residual tonnage of the waste stream even further, but those haven't yet been proven in the U.S on a large scale. Even at 75 percent reduction by weight, a WTE facility has a dramatic effect on the amount of residual waste.

3.0 Worldwide Experience of Waste Processing Technologies and Vendors

A variety of WPT are discussed in Appendix B and a summary matrix is in Appendix A, Table A-2. This section discusses the past and current experience of WPT in the U.S. and elsewhere.

3.1 Mass-Burn / Waterwall Combustion

No new mass-burn WTE facilities have been built in the United States for the past ten years, although there have been acquisitions and ownership and operator changes at certain existing facilities, as well as some plant expansions. As a result, the firms associated with mass-burn WTE are operators, owners, or owner/operators of existing facilities. As shown in the Table 3-1, Covanta and Wheelabrator own and operate the majority of privately-owned WTE facilities. Most of the WTE plants, both public and private, are operated by Covanta, Montenay/Veolia or Wheelabrator. Table 3-1 also shows the range in tons processed per day between facility owners and operators, with publicly operated facilities processing smaller amounts of waste than those operated privately.

Table 3-1. U.S. Mass-Burn / Waterwall Facilities[3]

Entity	Owned	Tons processed per day	Operated	Tons processed per day
Public	39	200 – 3,000	12	200 - 500
Covanta	11	400 – 3,000	27	400 – 3,000
Montenay/Veolia	2	500 – 1,200	9	500 – 3,000
Wheelabrator	10	200 – 2,250	16	200 – 2,250
Other	3	550 – 2,250	1	200 – 1,380
Total	65		65	

Some of the mass-burn technology had been purchased from American firms such as Detroit Stoker, Combustion Engineering and Babcock & Wilcox, but the majority of these existing systems are of European design. The two leading suppliers of WTE grate systems in the United States and overseas are The Martin Company of Germany and Von Roll of Switzerland.

While new WTE facility procurements have declined in the United States, the market for this equipment has increased in Europe and in Eastern Asia, with European and Japanese systems suppliers actively marketing their systems, and consistently improving their performance. This technology is well tested and is used more than any other for large WTE facilities in the United States and overseas.

3.2 Mass-Burn / Modular Combustion

Modular systems are used for smaller WTE facilities (between 80 – 360 TPD) and for industrial applications. Unlike mass burn/waterwall systems, there are a number of American firms supplying such systems in the United States, and they are very competitive in overseas markets as well. The more active of these suppliers are Consutech Systems of Richmond, Virginia, Enercon Systems, Inc. of Elyria, Ohio, and

[3] Integrated Waste Management Services Association, 2004 Directory of WTE Plants.

Basic Environmental Engineering of Chicago. They have each been supplying incineration systems for MSW and other wastes for over 25 years.

Other U.S. firms, such as Energy Answers of Albany, NY, and Covanta Energy of Fairfield, NJ, are marketing project development and management services for WTE modular facilities.

3.3 Refuse-derived Fuel / Dedicated Boiler

As with mass-burn systems, there have not been any new Refuse-derived Fuel (RDF) systems constructed in the United States in the past decade. For most of the 12 RDF WTE facilities currently in operation, Excel, Veolia and Covanta Energy are the operating contractors. The front-end processing utilizes a variety of unit processes depending upon the boiler requirements and the design philosophy. The unit process equipment, shredders, magnetic separators, screens, conveyors, etc., are all standard items available from a variety of manufacturers.

Equipment used in this technology is adapted from equipment provided in coal-fired electricity generation plants, and there are many established system and equipment suppliers marketing in the U.S., such as Foster Wheeler, Riley, Babcock and Wilcox, Detroit Stoker, ABB and Wärtsilä.

3.4 RDF / Fluidized Bed

While there are several RDF/fluid bed systems operating in Europe (particularly in Scandinavia, where a number of fluid bed incinerator manufacturers are located), there is only one such facility in operation in the United States, located in French Island, WI. It is owned and operated by Excel Energy of Minneapolis. The equipment was supplied by Energy Products of Idaho in Coeur d'Alene, the only U.S. firm currently manufacturing these furnaces for RDF firing.

3.5 Gasification

Japan currently has seven plants operating with gasification technology. At least two of these facilities fire MSW, with the largest firing up to 700 TPD of MSW. In Europe and Asia, approximately 20 syngas gasification facilities are operating on MSW. Most of these facilities are relatively small, processing less than 10 TPD with none designed to process more than 70 TPD.

3.6 Pyrolysis

With pyrolysis, MSW is heated in an oxygen-starved environment to produce a fuel gas that is then incinerated to generate steam and/or electricity. In the 1970s, a number of pyrolysis facilities were constructed using MSW as a feedstock. Several were built with partial funding provided by U.S. EPA. The largest of these was the Monsanto facility in Baltimore, MD, which had a capacity of 1,000 TPD. This facility did not meet its environmental requirements due to operational scale-up problems and was torn down. Other smaller, 100 to 200 TPD, MSW pyrolysis facilities were built at that time by Union Carbide, Anco Torrax, and Occidental Petroleum. These facilities were recipients of U.S. EPA grant funds and were closed for operational and financial reasons. Currently, there are no full-scale pyrolysis systems in commercial operation on MSW in the United States. A pilot demonstration system has been operating in southern California for two years. It was built and is operated by International Environmental Solutions, of Romoland, CA.

3.7 Plasma Arc

The plasma arc furnace is a commercial unit process made and marketed by Westinghouse. It has been successfully applied to a variety of industrial applications; however, there are no commercial-scale plasma arc systems firing MSW in the United States at the time of this report. There are pilot plants used for ash vitrification in Japan and a smaller Japanese facility firing MSW, but attempts to apply this process in the United States have not yet been successful. However, several vendors are advancing projects as described earlier. The electric power requirements for the torch are significant, and maintenance of torches and reactor refractory materials is also a significant expense item.

Few, if any of the plasma arc pilot facilities have been able to generate a fuel gas (syngas), and air emissions have been found to be no better than conventional incineration systems. The Atlanta firm Geoplasma has a development contract and is negotiating a contract for implementation of a large plasma arc facility for MSW in St. Lucie County, Florida, which will also to be used for processing mined landfill waste. The City of Tallahassee, Florida approved the contract for Green Power Systems to begin development of a 1,000 TPD plasma gasification plant, which is scheduled to begin operations in 2010.

3.8 Biological Fuel Production

3.8.1 Cellulosic Ethanol

There are a number of commercial facilities in the U.S. (See Table 3-2) and worldwide producing cellulosic ethanol, a biofuel produced from lignocellulose, a structural material that comprises much of the mass of plants. These facilities utilize a variety of biomass feedstocks. Biomass is any living or recently dead biological material that can be used as fuel or for industrial production. Biomass feedstocks include crops grown specifically for use as a feedstock, such as corn or hemp, agricultural residues, and other organic residues and wastes, including the organic portion of MSW. At the time of this report, no U.S. facilities are feeding MSW but a number of vendors are planning to use MSW as a feedstock.

Abengoa Bioenergy owns and operates five cellulosic ethanol facilities throughout the United States and Europe with a total production capacity of over 200 million gallons annually. It is currently the fifth largest producer of cellulosic ethanol in the United States with a total of four plants located in Kansas, New Mexico, and Nebraska. The most recent began operations in mid 2007, bringing Abengoa Bioenergy's nameplate capacity to more than 200 million gallons per year in the U.S. In addition, Abengoa Bioenergy operates four plants in Europe.

The world’s first commercial scale demonstration biomass plant is being constructed by Abengoa Bioenergy to exhibit its biomass-to-ethanol process technology. Located in Babilafuente (Salamanca), Spain, the biomass plant will process 77 tons of agricultural residues, such as wheat straw, each day and produce over 1.3 million gallons of fuel grade ethanol per year. Bioethanol is most currently used in Brazil, where longstanding policies promote and encourage the use of bioethanol as fuel for transportation.

CleanTech Biofuels has a cellulosic ethanol pilot plant operating on MSW in Golden, Colorado.

Table 3-2. Commercial Cellulosic Ethanol Plants in the U.S. (Operational or Under Construction)[4]

Company	Location	Feedstock	Capacity (million gallons per year)
Abengoa Bioenergy	Hugoton, KS	Wheat straw	12
Alico	La Belle, FL	Multiple sources	N/A
BlueFire Ethanol	Irvine, CA	Multiple sources	17
Gulf Coast Energy	Mossy Head, FL	Wood waste	70
Mascoma	Lansing, MI	Wood	40
POET Biorefinery	Emmetsburg, IA	Corn cobs	25
Range Fuels	Treutlen County, GA	Wood waste	20
SunOpta	Little Falls, MN	Wood chips	10
Xethanol	Auburndale, FL	Citrus peels	8

None of these plants uses MSW as feedstock. As of January 2008, U.S. DOE had made seven grants to help develop small-scale cellulosic plants. These plants will produce between 1.3 and 5.5 million gallons of ethanol per year. The feedstocks projected for these plants include wood chips, switch grass, corn cobs, and agricultural and forest residues. None of the plants are projected to use MSW. The total projected capital cost of these plants is $634 million, with DOE contributing $199 million in the form of the grants.

3.8.2 Biogas - Anaerobic Digestion

Biogas or synthesis gas, a mixture of carbon monoxide and hydrogen, can be converted into liquid hydrocarbons of various forms. A number of these technologies produce gas, primarily methane, which can be converted to liquid fuels utilizing Fischer-Tropsch Synthesis, a process developed in Germany in the early 20th Century. This process is a catalyzed chemical reaction which takes place at low temperatures (300 to 600 degrees F) and at high pressure. The most common catalysts are based on iron and cobalt, although nickel and ruthenium have also been used. The process produces a synthetic petroleum substitute for use as synthetic fuel, biodiesel. The Fischer-Tropsch process has been used to convert gases from a variety of feedstocks to liquid fuel, including coal and biomass.

When biomass is used, the cellulosic materials must first be converted to biogas and then to liquid fuel using the Fischer-Tropsch process.

Currently, a number of companies have commercial versions of the Fischer-Tropsch technology, including:

1. Conoco-Phillips– natural gas as feedstock
2. BP– natural gas as feedstock
3. Shell Oil – natural gas as feedstock
4. Sasol (South Africa) – coal and natural gas as feedstocks

[4] Source: Grainnet.com *Building Cellulose*

5. Rentech (U.S.) – coal or coke as feedstock
6. Choren Industries (Germany) –
7. Syntroleum (U.S.) – used natural gas as feedstock in a demonstration for the U.S. Air Force.

In addition, there are a number of research projects funded by the U.S. Department of Energy to use organic materials as feedstocks. These include the Renewable Energy Laboratory and Louisiana State University.

The Fischer-Tropsch process is an established technology that has been applied on a large scale in some industrial sectors. Large-scale commercialization is impeded by high capital costs, high operation and maintenance costs, the uncertain and volatile price of crude oil, and environmental concerns.

As mentioned in Appendix B, Section 1.3.2, biogas production from wastes is a mature technology with both large- and small-scale units in production worldwide. In India alone, there are over 2 million farm units that produce biogas from animal manures and other wastes. As of 2006, there were thousands of plants in Europe; Germany alone had 3,500 that produced a total of 1,100 MW. The newest of these plants range between 400 and 800 KW, using crops and manure for feedstock. In southern Europe, the production of biogas is primarily from landfills. In 2007, a report on the potential of biogas in Europe by the Öko-Instituts and the Institut für Energetik in Leipzig concluded that Germany alone can produce more biogas by 2020 than all of the European Union's (EU) current natural gas imports from Russia.

Table 3-3 shows the production of biogas in Europe by country with the production broken into three categories of feedstock: landfill gas, sewage sludge and other. Summarized by feedstock, this results in 64 percent landfill gas, 18.8 from sewage sludge and 17.2 other. The largest producer of biogas is the United Kingdom, closely followed by Germany. The biogas is approximately 50 percent methane, mixed with carbon dioxide and other gases.

Table 3-3. Biogas Production in Europe

(KTOE = thousand tonnes of oil equivalent)

	2004				2005*			
Countries	Landfill Gas	Sewage Sludge Gas	Other Biogas	Total	Landfill Gas	Sewage Sludge Gas	Other Biogas	Total
UK	1326.7	165.0	-	1491.1	1617.6	165.0	-	1782.6
Germany	573.2	369.8	351.7	1294.7	573.2	369.8	651.4	1594.4
Italy	297.7	0.3	37.5	335.5	334.1	0.4	42.0	376.5
Spain	219.1	52.4	23.6	295.1	236.5	56.8	23.6	316.9
France	127.0	77.0	3.0	207.0	129.0	77.0	3.0	209.0
Netherlands	48.7	48.6	28.9	126.2	48.7	48.6	28.9	126.2
Sweden	35.8	69.3	-	105.1	35.8	69.3	-	105.1
Denmark	13.8	19.8	55.6	89.3	14.3	20.5	57.5	92.3
Belgium	56.3	9.7	7.8	73.8	56.3	9.7	7.8	73.8
Czech Rep.	18.6	28.7	2.9	50.2	21.5	31.4	2.8	55.8
Poland	21.5	23.9	-	45.4	25.1	25.3	0.3	50.7
Austria	11.8	19.1	14.5	45.4	11.8	19.1	14.5	45.4
Greece	20.5	15.5	-	36.0	20.5	15.5	-	36.0
Ireland	19.9	4.8	5.1	29.9	24.9	4.8	5.1	34.8
Finland	16.6	9.9	-	26.5	16.6	9.9	-	26.5
Portugal	-	-	4.5	4.5	-	-	10.0	10.0
Slovenia	5.8	0.9	-	6.6	6.0	0.7	-	6.8
Luxemburg	-	-	5.0	5.0	-	-	6.7	6.7
Slovakia	-	5.7	0.2	5.9	-	5.7	0.2	5.9
Hungary	0.7	2.6	0.2	3.5	0.8	2.9	0.2	3.8
EU	2813.8	922.9	540.5	4277.2	3172.7	932.4	854.0	4959.1

*Estimation   Source: EurObser/ER 2006   Note: 1 KTOE is equal to $11.63 MWh.

The biogas sector is booming in Germany and has become the continent's fastest renewable energy sector. The growing interest is due to three factors: it can be produced in a decentralized manner, it is highly efficient - yielding more than twice as much energy per acre of energy crops than ethanol from similar crops, and it can be obtained using known processes from a large variety of biomass resources (organic waste, manure, dedicated energy crops). The biogas can be used as produced as a medium Btu fuel, or it can be processed to produce a pipeline quality gas which is almost pure methane. Also, the biogas has two highly efficient uses: as a gas for compressed clean natural gas (CNG)-capable vehicles and as a fuel that can be used for the cogeneration of power and heat. Meanwhile, advances in biogas technology, microbiology and crop engineering have made production even more efficient.

A number of established firms compete for the biogas plant construction and operation in Europe. Each has developed its own proprietary process, and some are 50 years old or older. There are over 200 operating plants, as shown in Table 3-4.

Table 3-4. Biogas Firms in Europe

Firms	Countries	System	Waste Types	Number of Plants	Total Capacity (Tons/Year)
Linde AG Wies-baden	Germany	Linde BRV/KCA	Wet and dry	24	1,000,000
Kompogas AG	Switzerland	Kompogas	Dry	24	4416,000
Organic Waste Systems	Belgium	Dranco	Dry	14	750,000
Schmack Biogas AG	Germany	Euco/Coccus	Wet	Approx. 100	Unknown
Valorga International SAS	France	Valorga	Dry	12	1,047,000
Biotechnische Abfallverwertung GmbH & Co KG	Germany	BTA	Wet	27	624,500

Source: EurObser/ER 2006

Now, producers in Germany want to feed their upgraded biogas, also known as biomethane, into the main natural gas grid across the EU. However, they face the significant barrier of their purified biogas not meeting the industry standard for pipeline gas. At 1,100 btu per cubic foot, biomethane's heating value is too high compared to the industry standard of 900 btu per cubic foot. Germany is the only country in Europe to impose an upper quality limit on gas. The German Greens and the country's environmentalists and farmers are therefore asking for a new law that allows producers to feed their superior, renewable and green gas into the national pipelines.

4.0 Recent Research/Procurements for Waste Processing Technologies by Others

The most recently constructed MSW-processing WTE facility in the U.S. commenced operations in 1996.[5] Since that time, no commercial plant has been implemented. Several reasons account for this lull of activity in the WTE field:

1. Loss of Tax Credits – The 1986 Tax Reform Act eliminated the significant tax benefits for project owners/developers, contributing to the pipeline of projects.
2. Environmental Activism – Misinformation about air pollution and ash impacts, and preferences for recycling, created public resistance.
3. U.S. Supreme Court's Carbone Decision[6] (1994) – Effectively ended legislated flow control, creating uncertainty in the revenue stream for projects.
4. Megafills – Large landfills with low tipping fees and no put-or-pay waste supply requirement out-competed WTE for the market.
5. Amendment to the Clean Air Act (1998) – New regulations required retrofit on existing plants and drove up WTE costs, effective as of December 2000.
6. Lack of Federal Leadership (1990 – 2005) – Visible opposition by U.S. EPA to combustion and preference for waste reduction/recycling sent negative message about WTE.
7. Moderate Fossil Fuel Costs – The rapidly increasing fossil fuel costs of the 1970s and '80s stabilized, reducing the value of the energy products from WTE facilities, which were key drivers in facilities developed earlier, and making overall project economics less attractive.

In the past few years, however, interest in WTE and waste conversion has begun to grow again. This renewed interest in waste processing technologies is due to several factors:

1. Proven WTE Track Record – superior environmental performance, reliability, advancements in technology and successful ash handling strategies have made WTE an acceptable option to consider as part of waste management planning.
2. Increasing Fossil Fuel Costs – With the price of oil now over $120 per barrel, the cost of transportation fuels is making MSW hauling and landfilling more expensive. In addition, the cost of electricity from fossil fuels is increasing, making electricity from waste more valuable and making WTE more competitive.
3. Growing Interest in Renewable Energy – Many States are requiring utilities to generate a portion of their electricity from renewable sources, which sometimes includes WTE; the Federal government has included WTE in its definition of renewable energy.
4. Change in Approach by U.S. EPA – In 2006, the U.S. EPA revised its waste management hierarchy to include WTE explicitly as the third priority after waste reduction and recycling/composting.

---

[5] Covanta's 2,250 TPD plant in Niagara Falls, NY.
[6] C & A Carbone, Inc. v. Town of Clarkstown, 511 U.S. 383 (1994).

5. Concern About Greenhouse Gases – WTE has a smaller carbon footprint than landfilling or fossil-fuel generated electricity[7].
6. Reversal of Carbone – The 2007 Supreme Court decision in the Oneida-Herkimer case[8] effectively restored to city and local governments the ability to implement flow control, increasing the security of the waste stream to support the financing of WTE projects.
7. Long distance transfer and disposal getting more expensive.

These and other local considerations have led a growing number of communities to re-investigate waste processing technologies as a component of their solid waste management systems. The following sections describe several of the recent initiatives to evaluate and choose waste processing technologies – WTE and others – to handle significant waste streams in the future. At the end of Section 4.0 is a summary of the technologies and vendors selected through these evaluation processes that represent the most promising alternatives for adopting WTE as a waste disposal option.

4.1 Recent Research

4.1.1 New York City, NY[9]

In 2004, the City of New York commissioned a report to evaluate new and emerging waste management and recycling technologies and approaches. The objective of the evaluation was to provide information to assist the City in its ongoing planning efforts for its waste management system. The report identified which innovative technologies were available at present, i.e., commercially operational processing of MSW, and which were promising but in an earlier stage of development. It also compared the newer technologies to conventional WTE technology to identify the potential advantages and disadvantages that may exist in the pursuit of innovative technologies. Conventional WTE was chosen as a point of comparison since such technology was the most widely used technology available at the time for reducing the quantity of landfilled post-recycled waste.

The report was released in September 2004. 44 companies responded to the initial request for information. The City has commenced a siting Task Force to look at the five boroughs to identify a site on which to build a pilot facility. Once the site has been identified, an RFP will be issued based on the specifications and condition of the site and will be made available to all proven and unproven technology vendors.

As part of the process, the City collected information on capital cost from the suppliers. Based on six responses, the capital cost per installed ton for anaerobic digestion ranged from $74,000 (586 TPD) to $82,000 (500 TPD); for gasification, the range was $155,000 (2,612 TPD) to $258,000 (2,959 TPD); one plasma arc gasification response gave a capital cost of $321,000 (2,729 TPD). These figures were for plants of widely varying sizes and were not standardized.

---

[7] Thorneloe, Susan A., Weitz, Keith A., Nishtala, Subba R., Yarkosky, Sherry, and Zanes, Maria. "The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States." Journal of the Air & Waste Management Association 52 (September 2002): 1000-1011.

[8] United Haulers Assn., Inc. v. Oneida-Herkimer Solid Waste Management Authority, No. 05-1345, 2007 WL 1237912 (U.S. April 30, 2007).

[9] Evaluation of New and Emerging Solid Waste Management Technologies, September 16, 2004.

4.1.2 City of Los Angeles, CA

Phase I[10]

In 2004, the City of Los Angeles, Bureau of Sanitation (Bureau) began a study to evaluate MSW alternative treatment technologies capable of processing Black Bin material (curbside-collected residential MSW) to significantly reduce the amount of such material going to landfills. The Bureau's overall objective was to select one or more suppliers to develop a facility using proven and commercialized technology to process the Black Bin material and produce usable by-products such as electricity, green fuel, and/or chemicals.

The first step of this project was to develop a comprehensive list of potential technologies and suppliers. About 225 suppliers were screened, and 26 suppliers were selected to submit their detailed qualifications to the City. In order to screen the technology suppliers, they were sent a brief survey based upon the technology screening criteria. The criteria applied were as follows:

- Waste Treatability: The supplier was screened on whether they have MSW or similar feedstock processing experience.

- Conversion Performance: The supplier was asked if their facility would produce marketable byproducts.

- Throughput Requirement: This criterion was already met because the technology passed the technology screen.

- Commercial Status: This criterion was already met because the technology passed the technology screen.

- Technology Capability: The supplier was asked if their technology had processed at least 25 tons per day of feedstock.

Of the 26 suppliers requested to submit qualifications, seventeen provided responses. These suppliers and their technologies were thoroughly evaluated, and an Evaluation Report was published in September 2005 with the findings and ranking of the 26 suppliers' technologies that had met the criteria.

A Request for Qualifications (RFQ) was prepared and provided to the suppliers that met the screening criteria. A detailed technical and economic evaluation of the suppliers that responded to the RFQ was completed. This resulted in the development of a short list of alternative treatment technology suppliers. In 2006, several suppliers were added to the short list, based on additional screening and a supplemental RFQ process.

As part of the process, the City collected information on capital cost from the suppliers. Based on 18 responses, the capital cost per installed ton for anaerobic digestion ranged from $99,000 to $201,000; for gasification, the range was $50,000 to $266,000; for pyrolysis, the range was $60,000 to $221,000; one mixed waste

---

[10] Request for Proposals for a Development Partner(s) for Processing Municipal Solid Waste Utilizing Alternative Technologies premised on Resource Recovery for the City of Los Angeles, February 5, 2007.

composting proposer gave a capital cost of $114,000. These figures were for plants of widely varying sizes and were not standardized.

Phase II[11]

On February 7, 2007, the City of Los Angeles released a Request for Proposals (RFP) soliciting competitive proposals for a development partner(s) for processing MSW utilizing alternative technologies premised on resource recovery. The responsibilities of the development partners were to finance, design, build, own, and operate (with the option to transfer to the City after 20 years) the resource recovery facility, at a throughput rate of 200-1,000 TPD. The facility was expected to provide diversion from landfill of no less than 80 percent of the City's Black Bin (waste) material delivered to the facility. In addition, the City considered proposals from emerging/experimental technologies that could process less than 200 tons per day as a potential second facility for testing emerging technologies. The emerging/experimental technology suppliers were to meet requirements outlined by the City in the RFP in order to be considered for the potential testing facility. Proposers of emerging/experimental technologies that did not meet those requirements were not evaluated further. A total of 12 technology suppliers submitted applications in August 2007. The City of Los Angeles' Bureau of Sanitation has reviewed the proposals and received presentations by the proposers. The Bureau has conducted site analyses and visits to all facilities and is putting together a recommendation by December 2008 of the finalists to be further evaluated.

Phase III

Phase III will start before the end of the year. It will include developing contracts for selection and increasing the focus on public outreach.

4.1.3 Los Angeles County, CA

Phase I – Initial Technology Evaluation[12]

Beginning in 2004, Los Angeles County conducted a preliminary evaluation of a range of conversion technologies and technology suppliers, and initiated efforts to identify material recovery facilities (MRFs) and transfer stations (TSs) in Southern California that could potentially host a conversion technology facility. A scope of investigation beyond Los Angeles County itself was considered important, as stakeholders in the evaluation extended beyond the County and the implications of this effort would be regional.

In August 2005, the evaluation report was adopted. Phase I resulted in identification of a preliminary short list of technology suppliers and MRF/TS sites, along with development of a long-term strategy for implementation of a conversion technology demonstration facility at one of these sites. The County intentionally pursued integrating a conversion technology facility at a MRF/TS site in order to further divert post-recycling residual waste from landfilling and take advantage of a number of beneficial synergies from co-locating a conversion facility at a MRF.

---

[11] ibid.

[12] Los Angeles County Conversion Technology Evaluation Report ~ Phase II – Assessment, October 2007.

Phase II – Facilitation Efforts for Demonstration Facility[13]

In July 2006, the County further advanced its efforts to facilitate development of a conversion technology demonstration facility. The approach was multi-disciplined, including environmental analysis and constructability. Key Phase II study areas included:

- An independent evaluation and verification of the qualifications of selected technology suppliers and the capabilities of their conversion technologies;
- An independent evaluation of candidate MRF/TS sites, to determine suitability for installation, integration and operation of one of the technologies;
- A review of the required permits to facilitate the project;
- Identification of funding opportunities and financing means;
- Identification of potential county incentives (i.e., supporting benefits) to encourage facility development amongst potential project sponsors; and
- Negotiation activities to assist parties in developing project teams and a Demonstration project.

The report described progress to date on Phase II, and represented a culmination of approximately one year of work conducted by the County. Five companies were issued Request for Offers (RFO) early in 2008 for a demonstration to be constructed at any one of four sites by the selected vendor. The five conversion technology suppliers considered and their corresponding technologies offered were: Arrow Ecology utilizing anaerobic digestion; Changing World Technologies utilizing thermal depolymerization; International Environmental Solutions utilizing pyrolysis; Interstate Waste Technologies utilizing pyrolysis/gasification; and Ntech Environmental utilizing gasification. Five materials recovery facilities (MRF) were considered for partnering with the technology supplier. Only one MRF, Community Recycling/Resource Recovery, Inc. MRF, is located in L.A. County. The Perris MRF/Transfer Station and the Robert A. Nelson Transfer Station and MRF (RANT) are located in Riverside County. Del Norte Regional Recycling and Transfer Station is situated in Ventura County and the Rainbow Disposal Co. Inc MRF is in Orange County.

Phase III – Evaluation and Presentation of Request for Offers

Phase III of the project is expected to be finalized by the end of 2008. At the time of this report, the County had received several offers, with a deadline of August 15, 2008 for receipt. It appears that Changing World Technologies is no longer participating and that the County is mostly working to locate these projects in privately owned MRFs in Riverside and Orange counties. Phase III will include the evaluation of these offers and the presentation of the results to the Board. Phase IV of the project will begin in 2009.

[13] ibid.

4.1.4 King County, WA

A proviso to the 2007 King County Solid Waste Division budget required that the Division prepare a comparative evaluation of waste conversion technologies (i.e. WTE incineration) and waste export. After review and comment on the draft report by the Metropolitan Solid Waste Management Advisory Committee (MSWMAC) and others, the final report was submitted to the King County Council on August 6, 2007. Based on the report, MSWMAC made the following recommendations to the Council:

1. That the King County Council continue its current policy course toward waste export by implementing the recommendations in the Solid Waste Transfer and Waste Export System Plan.

2. That every avenue to extend the life of the Cedar Hills Landfill be explored, including increased recycling and partial early waste export, to keep solid waste rates as low as possible for as long as possible and to provide maximum flexibility for long-term planning.

3. That no further resources be expended on the study of incineration technologies at this time. They believed that there was sufficient information in the report to analyze waste export and incineration technologies at a programmatic level in the Comprehensive Solid Waste Management Plan update and its EIS.

There were concerns about the practicality of waste conversion technologies in the King County region, and there was a need recognized to continue planning for the existing transfer system and the potential of extending the life of the Cedar Hills Landfill.

4.2 Procurements

4.2.1 Frederick and Carroll Counties, MD

In May 2006, the Northeast Maryland Waste Disposal Authority (Authority) began a search for firms with Qualified Technologies to provide WTE facilities for Frederick and Carroll Counties. The Authority was seeking technologies that demonstrated success in the efficient and feasible conversion of MSW into marketable steam, thermal energy, fuel and electricity. Technologies that produced a fuel were to be considered if the fuel had been demonstrated to reliably and efficiently produce energy (Qualified Technologies). The Authority conducted a two-step procurement. The first step was the Request for Qualifications (RFQ) to identify firms with Qualified Technologies. Qualified Technologies were to be eligible for consideration in the second step, the Basis of Negotiation (BON). In order to be deemed a Qualified Technology, operating statistics from a reference facility had to be provided, with a minimum of three consecutive years of operating data, including waste processed, energy produced, air emissions and residue generation.

The size of each unit could be as small as 100 TPD and as large as 750 TPD. The selection of unit size for each project was to be determined during the BON phase.

The Authority understood that there were many new and emerging technologies which convert MSW into various fuels or energy. However, the Authority is dependent on bond financing for its projects, and the lending community insisted on proven technology as a minimum requirement for making capital available to the Authority.

In October 2006, the Authority solicited Proposals from qualified, experienced firms in the refuse management and power facility construction and operation fields to provide for the construction, testing, operation and maintenance of a new refuse power plant (RPP) capacity for the counties. The Authority had pre-qualified eight technologies for this solicitation.

The facilities were to be owned by the Authority and leased to the successful Proposer (Company) on a long-term basis (at least 20 years from the commercial operations date). The site was to be provided by the Authority. The Authority would provide most of the refuse (fuel) under a put-or-pay contract and would apply residues for beneficial use as daily cover at the counties' landfills.

The Company would have the rights to all or a portion of the energy revenues (as specified by it in its proposal) and all of the excess waste disposal capacity that could be used to dispose of non-residential waste from any other Authority jurisdiction.

In response to the directives, proposals were requested for the following three facility options:

- A 900 TPD resource recovery facility to be located in Frederick County to process residential and commercial waste generated in Frederick County; and

- A 600 TPD resource recovery facility to be located in Carroll County to process residential and commercial waste generated in Carroll County; or

- A 1,500 TPD resource recovery facility to be located in Carroll County to process residential and commercial waste generated in both Frederick and Carroll Counties.

After receipt of proposals from three vendors, the Authority, in conjunction with the participating jurisdictions, completed an initial review of the proposals and short-listed Covanta Energy and Wheelabrator Technologies. As part of the initial review, the Authority met with Covanta and Wheelabrator to clarify their proposals and to ensure that the initial financial modeling results correctly represented their proposals and met the needs of the local jurisdictions. As of the time of this report, the Authority is currently seeking approvals from the jurisdictions to begin formal negotiations with the vendors to arrive at a final contract to be voted on by the jurisdictions' Commissioners. If approved by the jurisdictions, the permitting and construction of the facilities could take up to five years.

4.2.2 Harford County, MD

In May 2006, the Northeast Maryland Waste Disposal Authority (Authority) began a search for firms with Qualified Technologies to provide an expansion of the WTE facility for Harford County, similar to the process conducted for Frederick and Carroll counties (see 5.2.1 above).

In December 2006, The Authority issued a Request for Proposals (RFP) for a Resource Recovery Facility (RRF) located in Harford County, Maryland. This was the second step in the two-step competitive procurement being conducted by the

Authority. While the RFP was open to all interested and qualified vendors, only those technologies deemed qualified by the Authority were eligible for consideration.

The Authority was directed to obtain proposals for expanding the current WTE capacity in two ways: (1) additional capacity at the current facility to meet Harford County's needs, but not provide significant additional energy to the Aberdeen Proving Ground (APG), and (2) build a new RRF to accommodate the waste disposal needs of Harford County, including capacity for some of the waste disposal needs of adjacent "Base Realignment and Closure Act" (BRAC) affected counties (Baltimore and Cecil Counties), and provide a greater amount of the energy needs of APG. APG had agreed to lease an additional 20 acres of land next to the existing RRF for the larger regional facility.

The Authority has short-listed both Covanta Energy and Wheelabrator Technologies proposals as responsive and will continue the procurement process with those firms. The Authority is currently seeking approval from Harford County to begin formal negotiations with the vendors to arrive at a final contract to be voted on by the Harford County Council. Best and final offers have been requested from both companies and should be received by the end of September 2008, followed by final selection and negotiations.

4.2.3 City of Sacramento, CA

In August 2007, the City of Sacramento, CA issued an RFQ soliciting an experienced and qualified firm to partner with it to process MSW utilizing alternative technologies premised on resource recovery and/or energy creation. To qualify, firms must have had demonstrated experience and capacity to finance, design, build, own and operate a facility that processed MSW in excess of what the City currently disposes of, approximately 2,300 TPD after diversion. Sacramento was interested in a facility that used treatment technologies including, but not limited to, pyrolysis, gasification, advanced thermal recycling (a second generation advancement of mass-burn technologies), biological, chemical, physical and/or a combination thereof. They wanted technologies that were well proven at commercial scale, had high landfill diversion rates, and could generate a wide range of useful by-products that could be marketed for revenue sharing by the City and its development partner.

In October 2007, the City received 11 responses to the RFQ, not all of them waste processing technologies. The City performed a technical evaluation of the responses and went to the Council to request an Exclusive Negotiating Rights Agreement (ENRA) with a single company, U.S. Science and Technology. A plasma arc gasification project is being evaluated with due diligence expected to be completed in early September. City officials traveled to Japan to visit a plant that employs a similar technology at a commercial level (Westinghouse Plasma Corporation). A decision on the implementation of the project is expected in the near term.

4.2.4 Broward County, FL

The Broward County Solid Waste Disposal District (District) in July 2007 was considering changes to its solid waste management infrastructure in the near term. Because its disposal contracts with two privately-owned WTE facilities will reach the end of their initial service agreement terms in the near future, the District recognized that many options to be considered would require significant development time, and thus began the process to proactively evaluate such options. The District sought, through a Request for Expressions of Interest (RFEI), to identify firms that could meet all or a portion of the District's future solid waste processing and disposal requirements, and that were consistent with its long-term objectives. While this was not a procurement, it was understood that information obtained during the process would be used to support future procurement(s).

The expressions of interest were due by October 2007, and 25 vendors responded to the REFI. To date The Broward County Solid Waste Disposal District, Resource Recovery Board has received all the expressions of interests from the 25 respondents as well as 11 presentations made to the Board by some of the respondents and no further decisions have been made. Not all of the submittals were for WTE solutions. Negotiations for a contract extension are taking place with Wheelabrator, and a decision to move to forward is expected in 2008.

4.2.5 St. Lucie County, FL

On April 30, 2006, the Board of County Commissioners, St. Lucie County, Florida, solicited offers for the purpose of obtaining services to permit, finance, construct, operate, and own a Plasma Arc Gasification Facility to process MSW for St. Lucie County. The due date for the qualifications was May 2006.

There was only one respondent to the RFQ issued by the County: Jacoby/Geoplasma. As of November 2007, the development contract has been signed, and the County is moving forward with the project. The developer plans to process 3,000 TPD, generating 120 megawatts of electricity, one-third of which will be consumed internally. According to the developers, the plant will cost over $425 million and take two years to construct. Construction is slated to begin in 6 – 8 months pending permits.

4.2.6 Hawaii County, HI

In 1995, the County started searching for a landfill replacement. After searching for more than a decade and spending about $1 million, it selected Wheelabrator Technologies Inc., a wholly-owned subsidiary of Houston-based Waste Management Inc. Wheelabrator emerged from a field of three finalists, including Covanta, which runs HPower on Oahu, and L-Con Contractors, a partnership with Barlow Projects, Inc. In January 2008, the County received a best-and-final offer from Wheelabrator. In May, the County Council voted against the 650 TPD project because of the estimated $12.5 million cost, leaving the County with no plan for dealing with Hilo-area trash after 2012.

4.2.7 Pinellas County, FL

Pinellas County had three companies bid on the contract to operate the existing WTE plant. The process began with an RFQ to pre-qualify firms. The three firms that were pre-qualified all submitted bids. Those respondents were Wheelabrator, Covanta and Veolia. The bid went out in September 2006 for an operator replacement for an existing 2,000 ton per day plant and was awarded to Veolia in January 2007. Veolia actually began operating the facility effective May 7, 2007.

4.2.8 Hillsborough and Lee Counties, FL

Two operating mass-burn waterwall facilities in Florida began expansions in 2007. In Lee County, the 1200 TPD plant will add a third line with a 636 TPD capacity, using the same Covanta technology as the two operating lines, at a cost of $123.2 million or $194,000 per ton of installed capacity. Hillsborough County sole-sourced to Covanta a new 600 TPD line to add to the two operating 600 TPD lines already in place. The cost to Hillsborough County for the new line will be $123 million or $205,000 per installed ton of capacity. The project is expected to be completed, tested and accepted by the County in July 2009.

4.2.9 Fairbanks North Star Borough, AK

The Fairbanks North Star Borough (FNSB) is soliciting proposals for optimizing the management of the MSW stream. The FNSB is seeking a long-term partnership to implement a method for economical disposal of the community's MSW while returning energy savings to the Borough - with an emphasis on waste reduction, recycling and WTE options. Proposals were due May 29, 2008.

The following dates represented the FNSB's best estimate of the schedule being followed to select the successful proposer for this project.

Proposal Evaluations	June 1 – July 31, 2008
Notice of Intent to Award (NOIA) Issued	August 2008
Contract Negotiations	August/September 2008
Assembly Approval of Contract Award	September/October 2008
Contract Execution	November 2008

After the Notice of Intent to Award has been issued, the Borough and the successful offeror shall conduct good faith negotiations to address all aspects of a resulting contract. Should the Borough be unable to negotiate a contract with the successful offeror, negotiations will be formally terminated. The Borough may then initiate negotiations with the second highest ranked offeror. This process may continue until an agreement is reached.

4.2.10 City of Tallahassee, FL

The City of Tallahassee, FL, a Public Power Community, in November 2006 issued a letter of interest to seven project developers requesting a two-page summary for consideration of their technology for development of a renewable energy facility serving the City of Tallahassee's service territory within Leon County, FL. The City received three written responses, all from developers using biomass as fuel for conventional steam generation. Two additional companies made formal presentations to City representatives for advanced gasification projects, one project utilizing MSW and the other utilizing woody biomass as fuel sources. In January 2007, the City began direct negotiations with one of the companies that made the formal presentations, Green Power Systems based in Jacksonville, Florida. In June of 2007, the City approved the contract for Green Power Systems to begin development of a 1,000 TPD plasma gasification plant generating 35 MW net. The purchase power agreement for the sale of electricity to the City of Tallahassee was signed in June 2007. To date, Green Power Systems is conducting geo-technical work on site suitability as well as design and engineering work based on site suitability. Financing has been secured for the development of the plant, and it is scheduled to begin operation in October 2010.

4.3 Comparison of Technologies Chosen in Recent Research/Procurements

In the foregoing studies, reports and procurements, a total of 78 technology vendors were represented, evaluated, screened or selected in some way for consideration as waste processing solutions for the local entities. These 78 vendors offered 14 different technologies. The listing of the 78 vendors is presented in Table A-1 in Appendix A of this paper. Several of those technologies/vendors were mentioned more than once. Table 4-1 lists the 14 that were cited three or more times in the various documents.

The most often cited technology was mass burn, represented by Covanta and Wheelabrator, who have the most commercial experience of any of the vendors listed. Second on the list is gasification firm IWT, which employs the Thermoselect technology in use in Europe and Japan. Other gasification technology providers are also mentioned, along with four anaerobic digestion vendors, one plasma arc firm two pyrolysis providers and a thermal depolymerization firm. While this review is not systematic, it does provide a good summary of the firms and technologies that are most active in the field, and those that localities across the U.S have been most interested in using as they contemplate alternatives to landfilling MSW.

Table 4-1. Technologies/Vendors Mentioned in Recent Procurements

Vendor-designated Technology	Vendor	Total Times Cited
Mass Burn	Covanta Energy Corporation	7
Gasification	InterCity Waste Technologies/Thermoselect (IWT)	6
Mass Burn	Wheelabrator Technologies Inc.	5
Anaerobic Digestion	Valorga S.A.S. (Valorga)/Waste Recovery Systems	4
Anaerobic Digestion	Waste Recovery Seattle, Inc. (WRSI)	4
Anaerobic Digestion	Arrow Ecology and Engineering	3
Anaerobic Digestion	Urbaser	3
Gasification	Ebara	3
Gasification	Taylor Recycling Facility	3
Gasification	Whitten Group /Entech Renewable Energy System	3
Plasma Gasification	Global Energy Solutions	3
Pyrolysis	Pan American Resources	3
Pyrolysis	International Environmental Solutions	3
Thermal Depolymerization	Changing World Technologies	3

5.0 Opinion on Economic Feasibility, Effectiveness, and Environmental Issues of Waste Processing Technologies

5.1 Economic Feasibility of Waste Processing Technologies

The economic characteristics of the waste processing technologies, including capital and operating costs and risk, are summarized in Table A-2 in Appendix A. Generally, capital cost for the proven technologies are in the range of $150,000 to $250,000 per ton of installed capacity, depending on size and plant configuration. Operating costs are in the range of $35 to $60 per ton processed, not including residue disposal, again dependent on size, equipment and operating profile, and assuming a private operator. These figures are based on industry rules-of-thumb, recent operating results from selected facilities, surveys of industry professionals and related references.

A significant factor in the net operating costs for these facilities is revenue from the sale of recovered energy and recyclables. The energy revenue is a function of negotiations between the facility operator and the energy markets, typically a utility, and may include, besides a power rate, revenue for capacity and a requirement for standby power. Capital equipment necessary for utility connections can also be part of the negotiations, and the actual figures have to be developed and refined for specific sites and requirements during a procurement/development and negotiation process.

5.1.1 Typical Waste Processing Technologies Project Economic Estimates

To provide the County with an idea of the project economics that it could expect from adopting a WTE strategy for the future management of its MSW that is not reduced/reused/recycled, a representative preliminary project pro forma Operating Statement was prepared. By deriving an order-of-magnitude cost per ton for the processing and disposal of MSW using a waste processing technology, the County can compare the cost of developing new landfill capacity or other means of disposal after the existing landfill is filled to capacity.

The technology chosen for modeling was mass burn/waterwall incineration, the technology with the most extensive track record at the size and scale needed to serve the County. The nominal size of the facility selected is 300 TPD, making it one of the smallest WTE plants in the United States. (There are two mass-burn facilities in that size range – Commerce, CA and Wallingford, CT.) This assumes that Orange County would be able to partner with an adjacent community.

The procurement method assumed for the analysis was a design-build-operate public-private partnership, with public ownership and financing through 100 percent tax-exempt revenue bonds. This structure is the one recommended by numerous solid waste financing professionals and experienced facility owners throughout the U.S. This method gives the County the benefit of single-source private involvement in the construction and long-term operation of the facility, while retaining the advantages of public ownership. Such advantages include:

1. Lower overall financing costs. Tax-exempt debt is generally less costly than private debt-equity structures, even if the private debt portion of the financing is through tax-exempt private activity bonds.
2. More waste flow control. Public owners have a greater ability to control waste flow to their facilities based on the recent Oneida-Herkimer Supreme Court decision (See reference in Section 4.0).
3. Post-financing control. After the expiration of the initial financing, usually 20-30 years, the County would still be the owner of the plant, reaping the benefit of lower disposal costs without debt service payments, and not subject to market pricing by a private owner-operator. Several existing plants, especially in New England, are now reaching the end of their initial service agreements and financings, and the communities they are serving that still need disposal services are facing higher tipping fees or loss of guaranteed available capacity.

Of course, the actual procurement method should be the result of an open procurement process with several alternatives open to proposers to suggest as they deem them advantageous to the County.

5.1.2 Assumptions

The following are the assumptions used for the pro forma Operating Statement:

1. Size/Throughput. As stated above, the representative plant is 300 TPD processing a total of 87,600 tons per year, which equals an availability of about 80 percent. The remainder of the annual waste generated would need to be transferred and landfilled; a cost of $50.00 per ton has been assumed for bypass.
2. Ash Generation/Disposal. Using a rule of thumb, 25 percent of the annually processed waste (21,900 tons) would remain as ash after the thermal recovery process. The ash can be disposed at a landfill at $50.00 per ton but may have to be disposed separately from the bypassed waste in an ash monofill. If found to be hazardous, ash would need to be separately disposed of as a hazardous waste. The cost of such ash management would be in the range of $150 to $250 per ton, including transportation and disposal at a specially designed and operated landfill. If a beneficial use, such as alternative daily landfill cover, was found, the cost could be reduced.
3. Capital Cost/Financing. The capital cost per ton is set at $150,000 per ton of installed capacity or a total of $45 million. The effective net amount to be financed was estimated at 125 percent of the cost of the installed capacity, taking into account development and permitting costs, financing costs, etc. That brings the total financed to $56.25 million. The all-in cost of financing using revenue bonds was estimated at 5 percent for 25 years, an annual financing factor of 0.0651, bringing net annual debt service to $3.99 million.
4. Electricity Revenues. The net amount of electricity generated from the system, excluding in-plant use was set at 350 kilowatt-hours per ton processed. The assumed price of the electricity sold was $0.06 per kilowatt-hour, which is typical of what many plants receive for their electrical sales. Any electrical agreement and its associated price would have to be negotiated with the utility. It was also assumed that the plant operator would receive 10 percent of the electricity sales as an incentive payment, with 90 percent going to the County.

5. Materials Revenues. Ferrous metals can be recovered from the bottom ash and sold as scrap on the open market. It was assumed that 2 percent of the incoming waste or 1,752 tons per year would be recovered and sold at a current price of $80.00 per ton. It was assumed that the plant operator would receive 50 percent of the sales as an incentive payment, a standard industry practice.
6. Operating Costs. A cost of $57.00 per ton processed was assumed for the analysis.

5.1.3 Pro Forma Operating Statement

Based on the assumptions above, the annual Operating Statement of the system would be as presented in Table 5-1.

Table 5-1. Pro Forma Annual Operating Statement

Revenues		
	Electricity	$1,839,600
	Ferrous Recovery	$140,160
	Total Revenues	$1,979,760
Costs		
	Operating & Maintenance	$4,993,200
	Ash Disposal	$1,095,000
	ByPass Disposal	$660,000
	Annual Debt Service	$3,991,076
	Operator Revenue Sharing	$183,960
	Total Costs	$10,923,236
	Net Cost	$8,943,476
	Net Cost / Ton	**$102.09**

The ash produced by the facility would need to be transferred and landfilled. The estimated cost for this is projected at $50 per ton in Table 5-1.

The cost per ton is quite sensitive to the price of electricity. For example, if it could be assumed that electricity could be sold for $0.09 per kilowatt-hour instead of $0.06 per kilowatt-hour, the net disposal cost of approximately $102 per ton would be reduced to $89 per ton, an approximate 13 percent reduction in cost.

5.2 Effectiveness of Waste Processing Technologies

Since any WPT will have some residual in need of disposal, when discussing effectiveness of a WPT, emphasis is placed on obtaining the least amount of residual material for final disposal. While combustion technologies significantly reduce the volume of material destined for landfills, the resulting ash must be managed. Typical management methods include disposal in a Subtitle D landfill or beneficial use in construction projects and alternative daily cover for landfill wastes. In Europe, where land for landfilling is scarce and several countries have banned landfills, the ash is processed to recycle the ferrous and nonferrous metals and the remainder is graded and used in road and other construction.

The biological processes produce residues as well. These are of two types: (1) inert residues that are landfilled and (2) organic residues that can be cured to be a soil amendment or compost. Biological WPT are mass reduction technologies so that contaminants such as heavy metals are concentrated in the residue. Tests for these contaminants need to be conducted during operations and appropriate measures taken.

For all but the high-temperature thermal options and the anaerobic digestion system, an ash will be generated. Bottom ash will be discharged from the bottom of the furnace chamber, and fly ash will be collected by the air pollution control system. In accordance with applicable law, WTE ash must be tested to ensure it is non-hazardous. The test is called the Toxicity Characteristic Leaching Procedure (TCLP).

Generally, the bottom ash has not been classified as a hazardous material, subject to ash testing and analysis. Fly ash, however, will have a higher concentration of heavy metals and may also contain residual organics. As such, it would likely be classified as a hazardous material if it fails toxicity testing, unless it is combined with bottom ash, as is the current U.S. practice.

It should be noted that communities with aggressive, comprehensive recycling programs and programs focused on removing toxics from the MSW stream, such as those to divert used electronics (e-waste), household hazardous waste (HHW), mercury thermometers, fluorescent light fixtures, batteries, various metals and white goods, and the like, could be expected to have a post-diversion MSW stream for combustion containing less toxic materials and thus the ash from combustion to have a lower potential to exhibit hazardous characteristics upon TCLP testing.

The solids residual from high temperature systems, such as plasma-arc or pyrolysis, may have a better opportunity for end-use applications and marketing. These glassy-type granules may be classified as non-hazardous and used in construction materials or as a fill.

Vendors claim the substrate after digestion is beneficially processed and recovered, with the residue from anaerobic digestion is nothing more than stones, glass or similar items, which is normally directed to a solid waste landfill. However, digestion, like combustion, is a concentrating process. This is the result of the organic matter being converted to gas and utilized or released into the atmosphere. As a result toxic materials in the waste will be part of the residue but in a higher concentration than in the original feedstock. These claims are unproven in plants operating using MSW as feedstock.

5.3 Environmental Issues of Waste Processing Technologies

5.3.1 Air Quality

5.3.1.1 Applicable Regulations

Solid waste incinerators, which the U.S. EPA refers to as Municipal Waste Combustors, are regulated under the federal Clean Air Act, originally passed by Congress in 1963 and updated in 1967, 1970, 1977,1990 and 1995 and 1998. Numerous city and local governments have enacted similar legislation, either implementing federal programs or filling in locally important gaps in federal programs.

Section 111 of the federal Clean Air Act directs the U.S. EPA to establish pollution control requirements for certain industrial activities which emit significant "criteria air pollutants." These requirements are known as new source performance standards (NSPS) and regulate pollutants. For thermal destruction of solid waste, the NSPS control particulate matter (PM), sulfur dioxide(SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), hydrogen chloride (HCl), dioxins/furans, cadmium, lead, mercury, fugitive ash and opacity. NSPS are detailed in Chapter 40 of the Code of Federal Regulations, Part 60 (40 CFR Part 60), and are intended primarily to establish minimum nationwide requirements for new facilities.

Section 112 of the pre-1990 federal Clean Air Act directed the U.S. EPA to establish standards to reduce emissions of hazardous air pollutants (HAPs). These pollutants include asbestos, benzene, beryllium, inorganic arsenic, mercury, radionuclides, and vinyl chloride. National emission standards for hazardous air pollutants (NESHAPs) are detailed in 40 CFR Part 61 and establish minimum nationwide requirements for existing and new facilities.

The post-1990 NESHAPs require the maximum achievable control technology (MACT) for a particular industrial source category, and are often referred to as "MACT standards." The pre-1990 Clean Air Act prescribed a risk-based chemical-by-chemical approach. The 1990 Clean Air Act Amendments outlined a new approach with two main components. The first component involves establishing technology-based source category standards, and the second component involves addressing any significant remaining risk after the national standards are in place. The NESHAPs promulgated under the 1990 Clean Air Act Amendments can be found in 40 CFR Part 63 and establish nationwide requirements for existing and new facilities.

The U.S. EPA may implement and enforce the requirements, or the U.S. EPA may delegate such authority to state or local regulatory agencies. Clean Air Act Section 111 and 112 emissions limits applicable to new Municipal Waste Combustors are:

Dioxin/furan (CDD/CDF)	13 nanograms per dry standard cubic meter
Cadmium (Cd)	10 micrograms per dry standard cubic meter
Lead (Pb)	140 micrograms per dry standard cubic meter
Mercury (Hg)	50 micrograms per dry standard cubic meter
Particulate Matter (PM)	20 milligrams per dry standard cubic meter
Hydrogen chloride (HCl)	25 PPM or 95 percent reduction
Sulfur dioxide (SO_2)	30 ppm or 80 percent reduction
Nitrogen Oxides (NO_x)	180 ppm dry volume, and 150 ppm dry volume after first year of operation

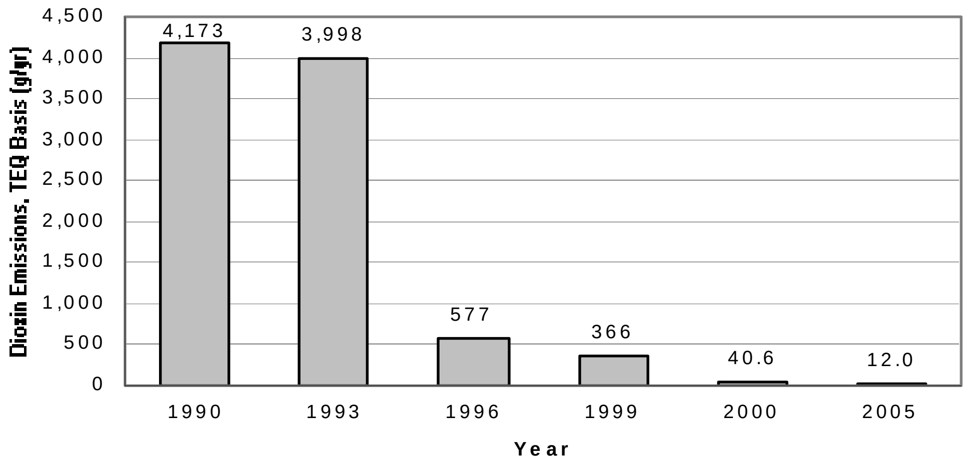
A new source review (NSR) permit is required for a new municipal waste combustor and, in addition, depending on its size and emission quantities, it must meet the prevention of significant deterioration (PSD) permit requirements.

5.3.1.2 Air Quality Impacts

In the early 1980s, dioxins were discovered in the exhaust of a WTE facility on Long Island, NY. This chemical, toxic to animals in even very small quantities, was considered a major pollutant. Other WTE plants were tested, as well as other industries, and were found to be a major dioxin source. In 1995, amendments to the Clean Air Act (CAA) were enacted to control the emissions of dioxins, as well as other toxins, such as mercury, hydrogen chloride and particulate matter.

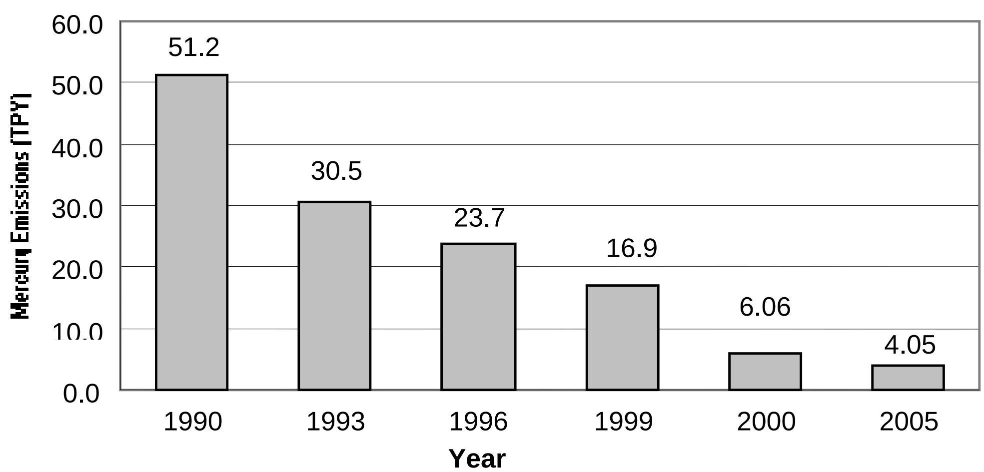
With the implementation of the CAA requirements in the following years, dioxin emissions from WTE decreased significantly, as shown in Figure 5-1.[14] The U.S. EPA has stated that "Waste-to-Energy is no longer a major contributor of dioxin emissions."

Figure 5-1. Dioxin Emissions from WTE Facilities, 1990 – 2005



Mercury is another toxin that was found in WTE exhaust and that was addressed in the CAA amendments. By modifications in the burning process and the use of activated carbon injection in the air pollution control system, dioxins and mercury, as well as hydrocarbons and other constituents, have effectively been removed from the gas stream. Mercury emissions from WTE have been reduced from 1990 levels, as shown in Figure 5-2.[15]

Figure 5-2. Mercury Emission from WTE Facilities, 1990 - 2005



[14] Emissions from Large MWC Units at MACT Compliance, Docket A-90-45 (Large MWCs), U.S. EPA, Research Triangle Park, NC.
[15] Ibid.

5.3.2 Water

Mass-burn and RDF incineration technologies and any WTE that produces steam will require a water supply, and all types of projects have a wastewater discharge. Water is required for the boilers, and domestic water for workers is also needed.

Non-potable water may be used as cooling water for the steam condensers, but the large cooling water supplies necessary for condenser cooling are normally not available, and cooling towers or cooling water ponds are provided as part of the facility. Air-cooled condensers are an option, but they increase capital costs and reduce net power production.

If the energy is going to a steam customer, the water requirement may be increased significantly from that needed for electricity generation, assuming that the customer generally does not return condensate. Some projects may cogenerate steam and electricity for sale, such as district heating/cooling projects or those with a significant steam user in proximity of the WTE facility site.

Technologies such as gasification and anaerobic digestion will not necessarily use a boiler. They may generate a gas stream for use off-site and not require a condenser cooling water system. They may utilize the gas to power a turbine or piston engine. These approaches are not inherent water users; however, gasification systems may require water in the gas cleanup and processing. Each system would need individual evaluation.

Biologic systems, including ethanol production and anaerobic digestion, are wet processes. The question to be examined is how much water is required and how much is recycled. The answers to these questions will be system-specific. For example, Arrow-Bio, which uses a water-based system, claims that no water is required for the process other than that in the waste, which is recycled.

6.0 Opinion on Which Waste Processing Technologies Should Be Considered for Orange County

Of the waste processing technologies examined, only WTE is a proven technology which could be recommended for implementation consideration by Orange County at this point in time. As mentioned earlier, there are 89 WTE plants generating power in the U.S. and hundreds worldwide. The other technologies discussed are in various stages of development.

The alternative technologies are not mature enough to mitigate the risks potentially inherent with their implementation:

- Risk of technical failure - The technology is unproven.
- Risk of pricing uncertainty – Should the County enter into a purchasing agreement with a vendor for a WPT, the ultimate price paid may be much higher than that indicated in the proposal.
- Risk of environmental non-compliance – The technology's environmental performance may be insufficient to meet regulations.

In evaluating waste processing technologies for Orange County to consider, it is apparent that there is not enough waste generated by the County to gain the economies of scale necessary to make a waste processing technology a cost-effective investment. The estimated cost to process a ton of waste at a WTE facility in Orange County is $102. To improve the economics of utilizing waste processing technology, Orange County would need to partner with an adjacent community. The $102 per ton is not competitive with the County's current landfill disposal fee of $49, nor with Waste Industries' cost of $42 per ton to transfer and dispose of waste. Although currently unknown, the cost of the County's new transfer station and landfilling at a remote site is unlikely to reach $100 per ton. As the County investigates the cost of transfer and disposal in preparation of its landfill closing, WPT may be more economically attractive once the cost of transfer and disposal is known.

If $102 per ton were to look competitive, it is recommended that Orange County conduct a WTE plant feasibility study which considers both mass-burn and modular technologies, and/or fuel production approaches.

Appendix A

Table A-1. Firms Evaluated by Recent Waste Processing Studies or Procurements
Table A-2. Summary of Municipal Waste Processing Technologies

Table A-1. Firms Evaluated by Recent Waste Processing Studies or Procurements

Technology	Jurisdiction Vendors	New York City	City of Los Angeles - Phase I	City of Los Angeles - Phase II	Los Angeles County - Phase I	Los Angeles County - Phase II	Frederick/Carroll County, MD	Harford County, MD	City of Sacramento, CA	Broward County, FL	St. Lucie County, FL	Pinellas County, FL	Total Times Evaluated/Proposed
Advanced Thermal Recycling	Global Environmental Technologies	X											1
Advanced Thermal Recycling	Consutech Systems LLC		X										1
Advanced Thermal Recycling	Basic Envirotech Inc.		X										1
Aerobic composting	Wright Environmental Management Inc. (Wright)		X		X								2
Aerobic composting	American Bio-Tech		X										1
Aerobic composting	Horstmann Recyclingtechnik GmbH		X										1
Aerobic Digestion	Mining Organics	X											1
Aerobic Digestion	Real Earth Technologies	X											1
Aerobic Digestion	American Bio-Tech				X								1
Aerobic Digestion	HotRot Exports Ltd, or Outspoken Industries				X								1
Aerobic Digestion	International Bio Recovery Corporation (IBR)				X								1
Anaerobic Digestion	Arrow Ecology and Engineering	X			X	X							3
Anaerobic Digestion	Canada Composting	X			X								2
Anaerobic Digestion	Kame/DePlano	X											1
Anaerobic Digestion	New bio	X											1
Anaerobic Digestion	Orgaworld	X											1
Anaerobic Digestion	Organic Waste Systems	X			X								2
Anaerobic Digestion	VAGRON	X											1
Anaerobic Digestion	Valorga S.A.S. (Valorga)/Waste Recovery Systems	X	X		X					X[1]			4
Anaerobic digestion	Canada Composting, Inc. (CCI)		X										1
Anaerobic digestion	Organic Waste Systems N.V. (OWS)		X										1
Anaerobic digestion	ISKA GmbH		X										1
Anaerobic digestion	Arrow Ecology Ltd. (Arrow)		X										1
Anaerobic digestion	Citec		X										1
Anaerobic digestion	Global Renewables/ISKA		X		X								2
Anaerobic Digestion	Waste Recovery Seattle, Inc. (WRSI)		X	X					X	X			4
Anaerobic Digestion	Urbaser			X[1]					X	X[1]			3
Composting	Zanker								X				1
Composting	RRI - Switzerland								X				1
Gasification	BRI Energy	X			X								2
Gasification	Dynecology	X											1
Gasification	Ebara	X	X		X								3
Gasification	Ecosystem Projects	X											1
Gasification	Emerald Power/Isabella City	X											1
Gasification	GEM America	X											1
Gasification	ILS Partners/Pyromex	X											1
Gasification	Interstate Waste Technologies/Thermoselect (IWT)	X	X	X	X	X				X			6
Gasification	Jov Theodore Somesfalean	X											1
Gasification	Kame/DePlano	X											1
Gasification	Taylor Recycling Facility	X	X		X								3
Gasification	Thermogenics	X											1
Gasification	Primenergy (RRA)		X		X								2
Gasification	Omnifuel /Downstream Systems (Omni)		X										1
Gasification	Whitten Group /Entech Renewable Energy System		X		X	X							3
Gasification	Energy Products of Idaho (EPI)		X										1
Gasification	Brightstar Environmental		X										1
Gasification	Omnifuel Technologies, Inc.				X								1
Gasification	Green Energy Corp				X								1
Gasification	Envirepel								X				1
Gasification	Zia Metallurgical Processes, Inc.			X									1
Hydrolysis	Arkenal Fuels	X											1
Hydrolysis	Biofine	X											1
Hydrolysis	Masada Oxynol	X											1
Mass Burn	Covanta Energy Corporation		X	X			X	X	X	X		X	7
Mass Burn	Wheelabrator Technologies Inc.			X			X	X		X		X	5
Mass Burn	Veolia Environmental Services											X	1
Mass Burn	Seghers Keppel Technology, Inc. (Seghers)		X	X[1]									2
Other Thermal (Microwave)	Molecular Waste Technologies, Inc.				X								1
Plasma Gasification	Global Energy Solutions	X			X					X			3
Plasma Gasification	GSB Technologies	X											1
Plasma Gasification	Peat International/Menlo Int.	X											1
Plasma Gasification	Rigel Resource Recovery and Conversion Company	X			X								2
Plasma Gasification	Solena Group	X											1
Plasma Gasification	Startech Environmental	X											1
Plasma Gasification	Geoplasma LLC				X						X		2
Plasma Gasification	Plasma Environmental Technologies, Inc.				X								1
Plasma Gasification	Plasco Energy Group			X									1
Plasma Gasification	USST								X				1
Pyrolysis	Entropic Technologies Corporation	X											1
Pyrolysis	Pan American Resources	X	X		X								3
Pyrolysis	WasteGen Ltd. /TechTrade (WasteGen)		X		X								2
Pyrolysis	Conrad Industries				X								1
Pyrolysis	Graveson Energy Management				X								1
Pyrolysis	International Environmental Solution				X	X			X				3
Steam Classification	BLT/World Waste Technologies								X				1
Thermal Depolymerization	Changing World Technologies	X			X	X							3
Thermal Oxidation	Zeros Technology Holding	X											1

Footnote:
[1] Companies submitted a combined proposal to local government

Table A-2. Summary of Municipal Waste Processing Technologies

Alternative	Technology: Description	Technology: Experience Record	Technology: Size Applicability	Technology: Reliability	Environmental Issues	Economic Issues: Capital	Economic Issues: Operations/ Maintenance	Applicability to RI (Risks/Liability)*	RI Risk Summary
Mass-Burn/Waterwall	Unprocessed MSW fired in a chamber built of water tubes. Heat recovered for steam and/or electricity production	The predominant method of WTE in the US and overseas for decades. Over 60 plants currently in commercial operation	Modules up to 750 TPD, with total facility size over 3,000 TPD	High proven reliability, over 90%	Air emissions (controlled by statute). Requires residual disposal.	$200k to $262k per installed ton (high)	$35 to $50/ton (moderate) O&M costs. Minimal materials recovery.	Proven commercial technology at appropriate scale. Requires new legislation.	Very Low
Mass-Burn/Modular	Unprocessed MSW fired in a series of refractory chambers followed by a heat recovery boiler for steam and/or electricity production	Substantial experience with facilities firing MSW in Europe and to a lesser extent in the U.S.	Modules up to 150 TPD, with total facility size up to 450 TPD	High proven reliability, over 90%	Air emissions (controlled by statute). Requires residual disposal.	$146k to $183k per installed ton (moderate)	$50 to $60/ton (high) O&M costs. Minimal materials recovery.	Proven commercial technology; limitations in scaling up to size needed. Requires new legislation.	Low
RDF/ Dedicated Boiler	Shredded MSW, with ferrous metals removed, and fired in a chamber built of water tubes. Preprocessing can increase materials recovery.	Dozens of facilities in operation since the 1970's	Modules up to 750 TPD, with total facility size over 3,000 TPD	Good proven reliability, over 80%	Air emissions (controlled by statute). Requires residual disposal.	$158k to $198k per installed ton (moderate)	$50 to $55/ton (high) O&M costs. Good materials recovery revenue potential.	Proven commercial technology at appropriate scale. Requires new legislation.	Low
RDF/Fluid Bed	Shredded MSW fired in a sand bed. Preprocessing can increase materials recovery.	One facility firing MSW in the US, other units in Europe and Japan	Facility size up to 460 TPD	Good proven reliability, over 80%	Air emissions (controlled by statute). Requires residual disposal.	High capital cost	High O&M costs. Good materials recovery revenue potential.	Proven technology; limited U.S commercial experience; scalability an issue. Requires new legislation.	Moderate
Pyrolysis	Heated MSW in oxygen-starved environment produces a fuel gas that is incinerated to generate usable energy - steam and/or electricity	One pilot plant in California operating for 2 years	Pilot plant sized for 50 TPD MSW	Insufficient experience to establish reliability estimate	Air emissions (controlled by statute), Odors from MSW transport. Residue may have beneficial use.	High capital cost	High O&M costs	High risk, uncertain commercial potential. No operating experience with large scale operations. May require new legislation.	High
Gasification	Heated MSW in oxygen-starved environment generates a fuel gas that can be exported for heat or power generation	Two facilities firing MSW in Japan since 1998, 10 small units firing MSW in Europe and Asia	Multiple modules of 300 TPD MSW each	Insufficient experience to establish reliability estimate	Limited air emissions (controlled by statute), potential air emissions when gas is fired. Residue may have beneficial use.	High capital cost (one vendor estimates $235k-$250k/installed ton)	High O&M costs	Limited operating experience at only small scale. Subject to scale-up issues.	High
Anaerobic Digestion	Extensively preprocessed/Shredded MSW directed to a series of digesters for gas generation that can be exported for heat or power generation	One facility in operation in Israel for less than two years; other limited facilities in Europe	Operating facilities up to 300 TPD	Insufficient experience to establish reliability estimate	Odor, potential air emissions when gas is fired. Residue may have beneficial use.	Low capital cost	High O&M costs. Several materials revenue streams may be available,	Limited operating experience at small scale. Subject to scale-up issues.	High
Plasma Arc	MSW heated by a plasma-arc in oxygen-starved environment produces a fuel gas that is incinerated to generate usable energy for steam and/or electricity. Similar to gasification.	Two pilot plants in operation since 1999 in Japan	Less than 200 TPD MSW	Insufficient experience to establish reliability estimate	Air emissions (controlled by statute). Residue may have beneficial use.	Very high capital cost	Very high O&M costs	No commercial experience to date. Subject to scale-up issues. May require new legislation.	High

* Does not include risks related to procurement, such as vendor quality and deep-pockets (ability to provide technical, construction and operating guarantees; underwrite risks, etc.)

Appendix B

Overview of Waste Processing Technologies (WPT)

Appendix B
Overview of Waste Processing Technologies (WPT)

1.1 "Proven" Technologies

Waste has been converted to beneficial use on a large scale for well over 100 years. Incineration with electric power generation was first applied to MSW in 1894 in New York City. Since that time, the burning of MSW with energy recovery (now known as WTE) has matured into a safe, effective and environmentally acceptable technology. The proven large-scale waste processing methods include incineration and starved-air combustion, as defined below:

Mass-burn Incineration: This is the controlled combustion of organic or inorganic waste with more than the ideal air (stoichiometric) requirement – excess air - to assure that complete burning occurs.

Starved Air Combustion: Starved air incineration utilizes less air than conventional incineration, and it produces ash similar in appearance to that from a conventional incineration process. The gases that result are burned in a second chamber. The lower air requirement leads to smaller equipment sizes. This process, however, is an incineration process.

Refuse-derived Fuel (RDF): An RDF system processes waste by shredding it and removing ferrous metals in preparation for combustion. The removal of non-combustibles can increase the specific heat content by over 10 percent and can allow for revenues from the metals removed.

It has been found that recycling, the most preferred waste management option aside from waste reduction, increases when WTE exists in the United States as well as in other countries. As shown in *BioCycle's* "2006 State of Garbage in America," (http://www.jgpress.com/archives/_free/000848.html), most of the states with large energy recovery rates have recycling rates higher than the national recycling average of 28.5 percent.[1] These recycling rates range from 43 percent in Minnesota (where 21 percent of the waste is burned for energy) to 24 percent in Connecticut (where 65 percent of the waste is burned for energy). North Carolina illustrates the inverse with 19 percent recycling and .9 percent combustion for energy. Apparently, where WTE exists, there is greater public awareness of waste disposal and the need to deal with waste reduction overall.

Other methods of MSW disposal, such as mixed-waste composting and landfilling, are being used but they are becoming less and less attractive. Mixed-waste composting requires large land areas, creates significant odor, and produces compost that is limited in its application because of contaminants. Landfilling is not a processing technology, it is storage. It also requires large land areas or a large capital investment, generates methane (a greenhouse gas that is more than 20 times as potent as carbon dioxide, which is generated from WTE), and creates other

---

[1] *BioCycle* includes recycling, composting, yard waste, WTE and landfill collection in its figures. EPA reports MSW from a slightly different source. They include collection receipts for domestic waste and for industrial waste, but their recycling quantities are derived from firms that recycle the waste, such as paper mills or steel plants, rather than from collection data. This difference in methodology from that used by *Biocycle* is reflected in the difference in recycling rates in the United States in 2006, which is reported as 32.5% by EPA and 28.5% by *Biocycle*.

environmental impacts, like uncontrolled discharge of leachate that may pollute groundwater sources.

WTE has proven to be a reliable method for waste processing and disposal. Modern plants are compatible with aggressive recycling programs and have an environmentally acceptable track record.

While new WTE procurements have declined in the United States, the market for this equipment has increased in Europe and in Eastern Asia. European and Japanese systems suppliers actively market their systems and are consistently improving their performance. The technology is well tested and is used more than any other for WPT facilities in the United States and overseas. Table B-1 illustrates the use of WTE technology throughout the world.

Table B-1. WTE Facilities Worldwide

Location	Number of Facilities	Amount of MSW Managed by WTE as a % of Total MSW Generated
USA	89	12.5% based on MSW reported by U.S. EPA and *BioCycle's* data
Europe	400	Varies from country to country
Japan	100	70 to 80%
Other nations (Taiwan, Singapore, China, etc.)	70	Varies from country to country

Source: "The 2008 IWSA Directory of Waste-to-Energy Plants," Integrated Waste Management Services Association website

Table B-2 illustrates the size and ownership of WTE facilities in operation in the United States. Fifty-two percent of the facilities are owned by public entities, Wheelabrator Technology (Waste Management Inc.) owns 13 percent, Covanta Energy owns 21 percent, and other private firms own 13 percent. Private companies own more of the larger facilities.

Table B-2. WTE Facilities in the United States

Size (Ton Per Day)	Publicly Owned	Privately Owned	Total
≤100	7	0	7
101-499	14	5	19
500-999	8	17	25
1,000-1,999	11	9	20
≥ 2,000	6	12	18
Total	**46**	**43**	**89**

Table B-3 shows the various technologies used in U.S. plants with the majority of plants utilizing mass burn technology.

Table B-3. U.S. WTE Plants by Technology

Technology	Operating Plants	Daily Design Capacity (TPD)	Annual Capacity [1] (Million Tons)
Mass Burn	65	71,354	22.1
Modular	9	1,342	0.4
RDF-Processing & Combustion	10	15,428	4.8
RDF-Processing Only	5	6,075	1.9
RDF-Combustion Only	5	4,592	1.4
Total U.S. Plants [2]	94	98,791	30.6
WTE Facilities	89	92,716	28.7

[1] Annual Capacity equals daily tons per day (TPD) of design capacity multiplied by 365 (days/year) multiplied by 85 percent. Eighty-five percent of the design capacity is a typical system guarantee of annual facility throughput.

[2] Total Plants includes RDF Processing facilities that do not generate power on site.

Source: J.V.L. Kiser and M. Zannes, Integrated Waste Management Services Association, April 2004.

In the region, 10 WTE facilities currently operate, processing almost 12,000 TPD of MSW. Table B-4 describes those plants.

Table B-4. WTE Plants in Region

Location	Size (TPD)	Start Date	Energy Product	Owner / Operator
North Carolina				
New Hanover County	500	1984	electricity[1]	New Hanover County
South Carolina				
Charleston	600	1989	steam & electricity	AT&T/Montenay Charleston RRI
Virginia				
Alexandria	975	1988	electricity	Covanta Arlington-Alexandria, Inc.
Fairfax County	3000	1990	electricity	Covanta Fairfax, Inc.
Hampton	240	1980	steam	NASA and City of Hampton/City of Hampton
Harrisonburg	200	1982	steam & electricity	City of Harrisonburg
Portsmouth	2000	1988	RDF & electricity	Southeastern Public Service Authority (SPSA)
Maryland				
Baltimore	2250	1985	electricity	John Hancock Life Insurance Company/ Wheelabrator Baltimore, L.P.
Harford County	360	1988	steam & electricity	Northeast Maryland Waste Disposal Authority/Energy Recovery Operations, Inc.
Montgomery County	1800	1995	electricity	Northeast Maryland Waste Disposal Authority/ Covanta Montgomery, Inc.

[1] Originally built as a "steam" plant, the facility now generates and sells electricity.[2]

Source: Integrated Waste Management Services Association

The following sections describe the basic types of MSW combustion technologies, all of which have been in use for decades in the U.S.

[2] New Hanover County Government, Department of Environmental Management website.

1.1.1 Mass-Burn / Waterwall Combustion

In mass-burn waterwall combustion, MSW is placed directly into the system for incineration with no pre-processing except for removal of identifiable white goods (refrigerators, washing machines, microwave ovens, etc.). Waste is placed onto a grate at the bottom of a combustion chamber in a furnace with walls built of water tubes, as shown in Figure B-1. Air for combustion is forced through the grates (under-fire air) and through parts in the sides of the combustion chamber (over-fire air).

Figure B-1. Waterwall Furnace Section[3]

Half the heat generated from the burning waste is absorbed by the waterwalls and the balance heats water in the boiler, as shown Figure B-2.

[3] Source: Babcock and Wilcox.

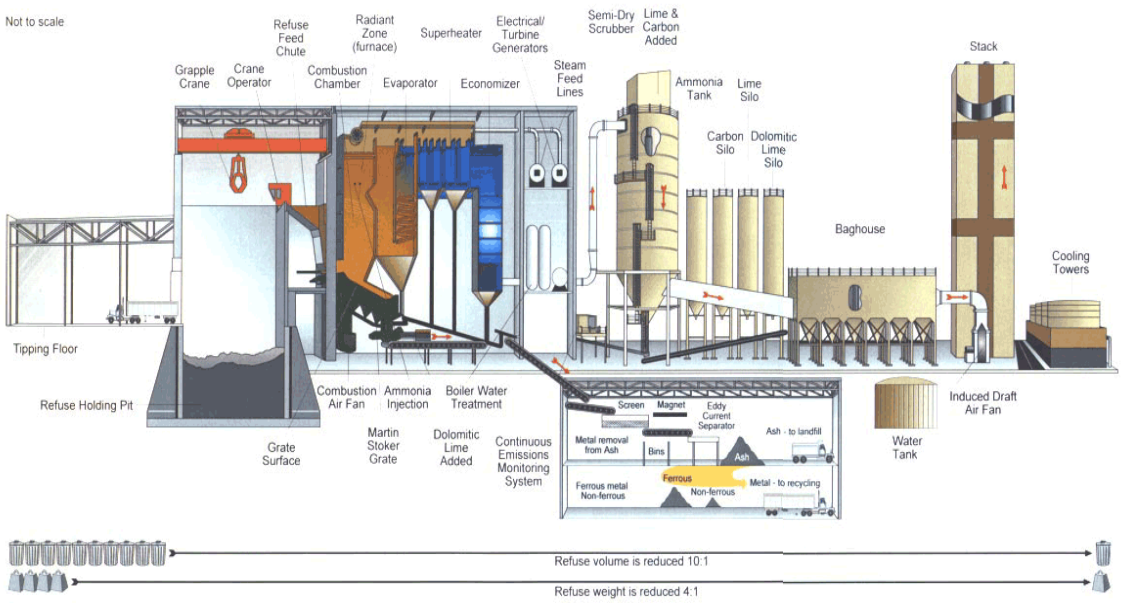


Figure B-2. Typical Mass-Burn Waterwall System[4]

The off-gas exiting the boiler passes through an air pollution control system where the majority of pollutants is removed and is discharged through a stack to the atmosphere. Waste is burned out to an ash in the furnace. Heat extracted from the waterwalls and the boiler section generates steam which, in most facilities, is directed to a turbine generator for electric power production. Waterwall systems are fabricated on-site. They are generally applied to larger systems, 200 TPD up to 750 TPD, with multiple units used when higher capacity is required. They are forgiving in their operation, and are reasonably efficient in the burnout of waste and in the generation of energy.

1.1.2 Mass-Burn / Modular Combustion

Modular combustion is another incineration process. Unprocessed MSW is placed directly into a refractory lined chamber. The primary chamber of the incinerator includes a series of charging rams which push the burning waste from one level to another until it burns out to an ash and is discharged to a wet ash pit, as in Figure B-3. No or limited under-fire air is used to limit the entraining of ash into the flue (exhaust) gas stream.

[4] Source: Fairfax County, VA.

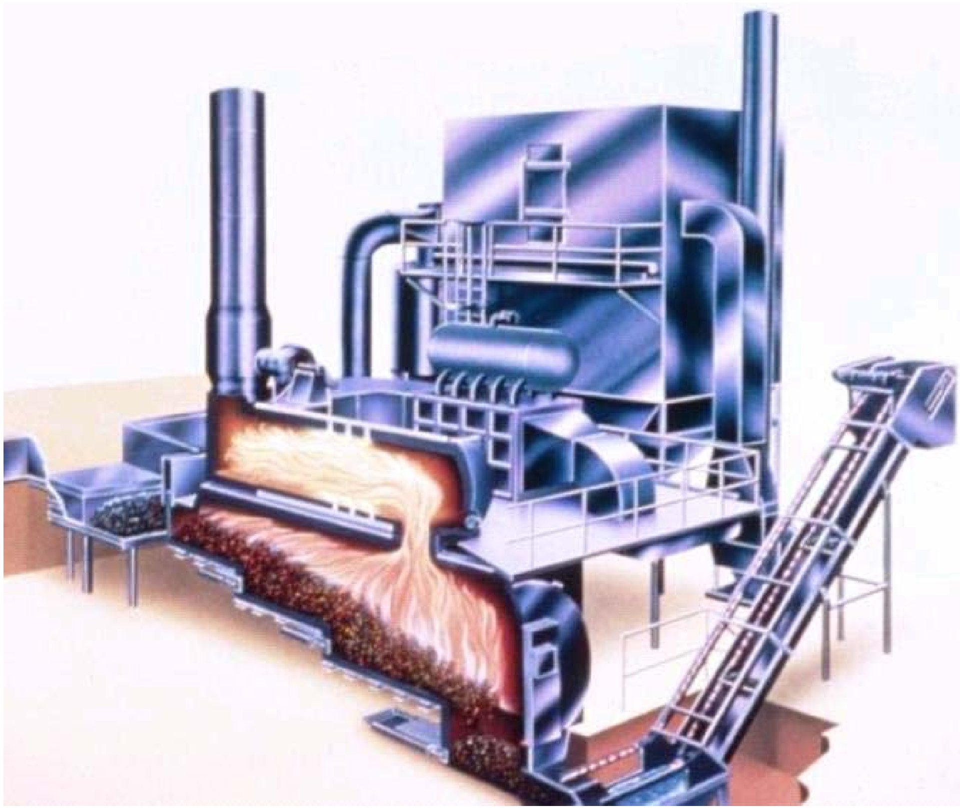


Figure B-3. Typical Modular Combustion System[5]

Less than the ideal (stoichiometric) amount of combustion air is injected into the primary combustion chamber, and a combustible gas is produced from the incomplete waste combustion. The gas from the burning waste is directed to a secondary combustion chamber where additional air is added to complete the burning process. Hot gases pass though a separate waste heat boiler for steam generation and then through an air pollution control system before discharge through the stack to the atmosphere.

A major advantage of this system is injection of less air than ideal in the primary combustion chamber. With less air, the fans can be smaller and the chamber itself can be smaller than with other systems. Also, with less air flow, less particulate matter (soot) enters the gas stream and the air pollution system can be sized for a smaller load.

Modular systems are factory built and can be brought to a site and set up in a relatively short period of time. They are less efficient than waterwall units in waste burn-out and in energy generation. They have been built in unit sizes up to 150 TPD. Multiple units are used to increase plant size to 300 – 400 TPD, such as in Agawam, MA.

1.1.3 Refuse-derived Fuel / Dedicated Boiler

RDF, in its simplest form, is shredded MSW with ferrous metals removed. Additional processing, such as screening, can be applied to the incoming waste stream to remove and recover glass, aluminum, and other non-combustible materials. Additional processing stages may also be placed in the processing line, such as

[5] Source: Consutech Systems, Richmond, VA.

pelletizing. Pelletizing is the compression of "fluff" RDF into dense pellets generally to be fired along with lump coal. The pellet size depends on the size of the coal used in existing power plants.

RDF production is a distinct process; therefore, it is not necessary to be co-located with the combustion plant. In Figure B-4, RDF is blown into the furnace from the left, above the grate. What does not burn in suspension (above the grate) will burn on the grate, and the hot gases generated will pass through a waterwall section and then a boiler section. This system is similar to the mass-burn waterwall facility except in the nature of waste charging and burnout.

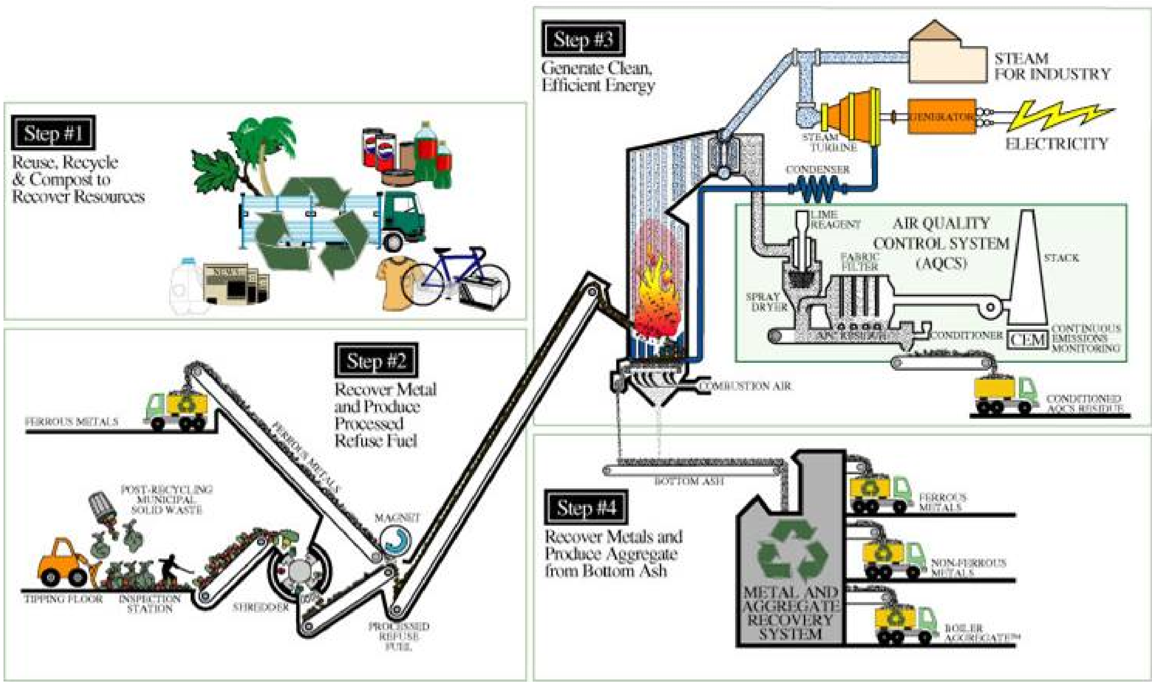


Figure B-4. Typical RDF Combustion Facility[6]

The unique feature of RDF systems is in the pre-processing of waste. As seen in the diagram of a typical RDF processing facility in Figure B-5, MSW enters the facility and then passes through a trommel, where bags of waste are broken open and large material is removed. The small material dropping out of the first trommel passes through a second trammel to remove fine noncombustible material. The majority of waste goes through a shredder for size reduction. A magnetic separator removes ferrous metals and the balance of the material is fired in the furnace.

[6] Source: Energy Answers Corporation.

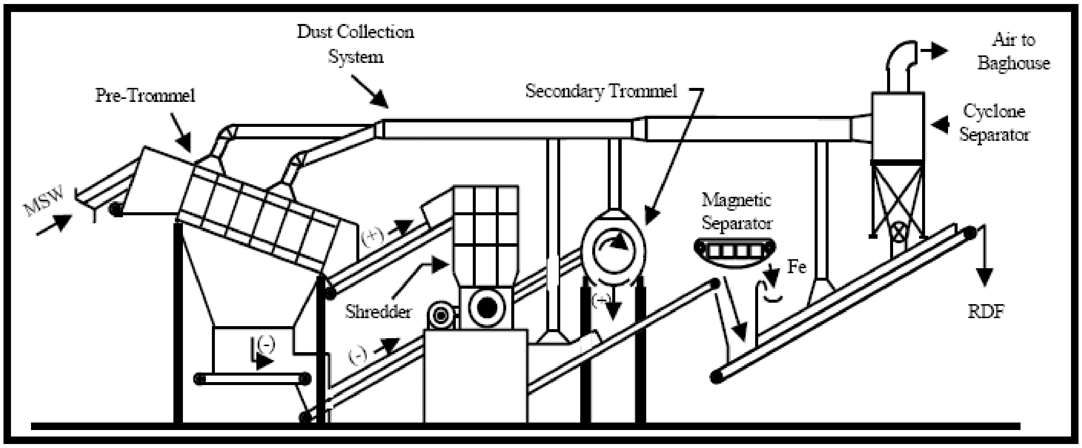


Figure B-5. Typical RDF Processing Schematic[7]

Other configurations may include additional separating equipment or exclude trommels, but the RDF generated is always shredded so that it is capable of being blown into a furnace. Although results vary with the processing configuration, in general, about 80 percent of the incoming waste stream is converted into RDF for the thermal process.

An advantage of this system is in the removal of metals and other materials from the waste stream. While not all these facilities include this step in the processing line, those that do can realize revenue from the sale of recovered metal. For instance, at the North County Resource Recovery Project in West Palm Beach, Florida, the nominal 3,000 TPD facility removed and sold over 30,000 tons of ferrous metals in 2003, which represented over 3 percent of the weight of the incoming waste stream. With the removal of non-combustibles, the specific heat content of the RDF can be increased by 10 percent over the original MSW.

1.1.4 Refuse-derived Fuel/Fluidized Bed

In this incineration process, MSW is shredded to less than four inches mean particle size (the same as with the RDF process described in 1.3.1 above) to produce the fuel (see Figure B-5) before it is blown into a bed of sand in a vertical cylindrical furnace. Hot air is also injected into the bed from below, and the sand has the appearance of a bubbling fluid as the hot air agitates the sand particles. Moisture in the RDF is evaporated almost instantaneously upon entering the bed, and organics burn out both within the bed and in the freeboard, the volume above the bed. Steam tubes are embedded within the bed, and a transverse section of boiler tubes captures heat from the flue gas exiting the furnace, as shown in Figure B-6.

[7] Source: generic.

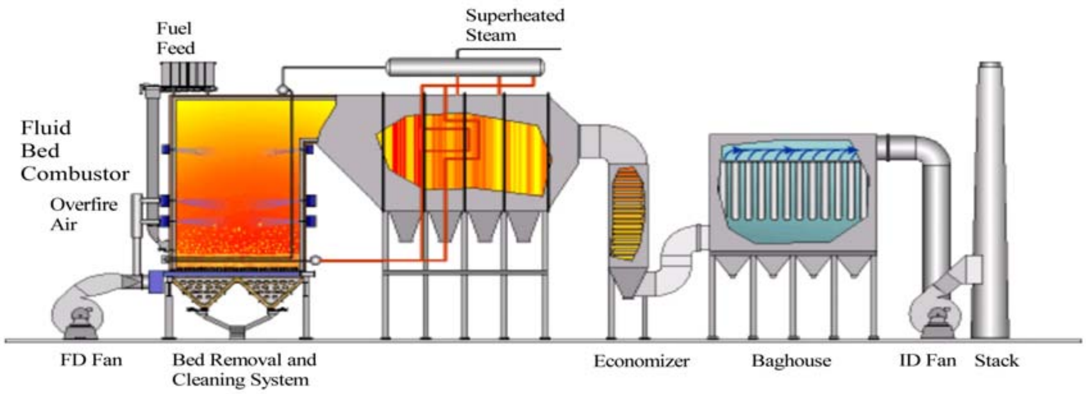


Figure B-6. Typical RDF Fluid Bed System[8]

Fluid bed incineration is more efficient than grate burning-based incineration systems. The bed is very effective in waste destruction and requires less air flow than mass-burn or modular systems. The fluid bed, however, does require relatively uniform-sized material, and RDF preparation is necessary for system operation, not for resource recovery, as discussed above.

1.2 "Emerging" Technologies

There are many technologies currently being proposed for the treatment and disposal of MSW throughout the world. Most of these involve thermal processing, but some others comprise the biological or chemical decomposition of the organic fraction of the waste to produce useful products like compost or energy products, notably synthetic gas (syngas) for downstream combustion.

Thermal processing refers to a number of different types of technologies utilizing heat as the mode of waste treatment. However, most of them, as listed and described below, are variations of conventional incineration.

Gasification: Heating of an organic waste to produce a burnable gas (approximately 85 percent hydrogen and carbon monoxide mix) for use off-site. As long as the off-gas produced from the system is usable and burned off-site, the system is a gasifier, not an incinerator. Typically, the energy in MSW is both used to fire the system and contained in the gas product.

Pyrolysis: A form of gasification where organic waste is heated without air. A gas is generated that is burned in the gaseous phase, requiring much less oxygen than conventional incineration. This process also generates a char, or frit, depending on the process temperature. (Frit is a glassy, granular material that is uniform in appearance.) The presence of a secondary combustion chamber for the burnout of the pyrolysis gas requires that this system be classified as an incinerator.

Plasma arc: Plasma arc refers to the means of introducing heat into the process. Essentially a plasma arc system is a pyrolysis or starved air process generating heat by firing the waste with a plasma arc to produce a syngas, which is then combusted to produce steam and/or electricity, and is classified as an incinerator. If the system

[8] Source: Energy Products of Idaho, Coeur D'Alene, ID.

generates an off-gas that contains burnable gases (e.g., hydrogen and carbon monoxide) that can be used off-site, it can be classified as a gasifier.

1.2.1 Gasification

Gasification is the heating of an organic waste (MSW) to produce a burnable gas (approximately 85 percent hydrogen and carbon monoxide mix) for use off-site. While pyrolysis systems are primarily focused on waste destruction, a gasifier is designed primarily to produce a usable gas. As shown in Figure B-7, Thermoselect, a European firm represented in the U.S. by InterCity Waste Technologies of Malvern, PA, has developed a system composed of 400 TPD modules processing MSW.

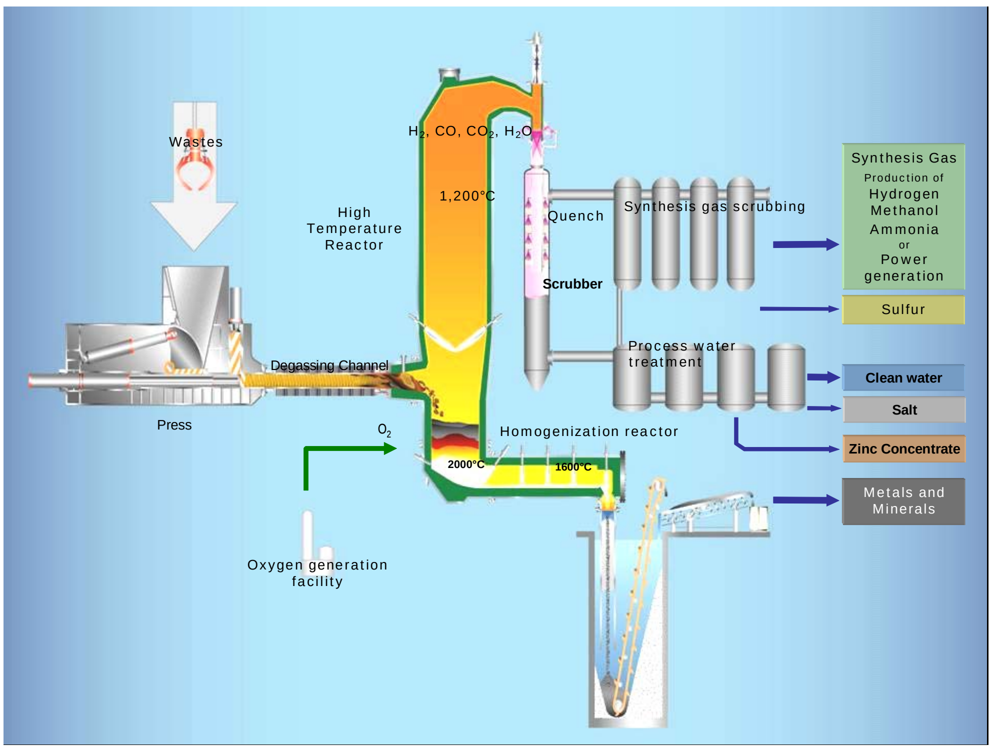


Figure B-7. Typical Gasification System[9]

Waste is fed into a gasification chamber to begin the heating process, after being compressed to remove entrapped air. Some oxygen, sufficient only to maintain the heat necessary for the process to proceed, is injected into the reactor where temperatures in excess of 3,000^{o}F are generated. At this high temperature, organic materials in the MSW will dissociate into hydrogen, methane, carbon dioxide, water vapor, etc., and non-organics will melt and form a glass-like slag. After the gas is cleaned, water is removed, and the gas can be used for power generation, heating, or other purposes. The glass-like slag can be used as fill, or as a building material for roads, etc.

A variation of the fluid bed incineration system described in this section is the fluidized-bed gasifier, shown in Figure B-8.

[9] Source: International Waste Technologies, Malvern, PA.

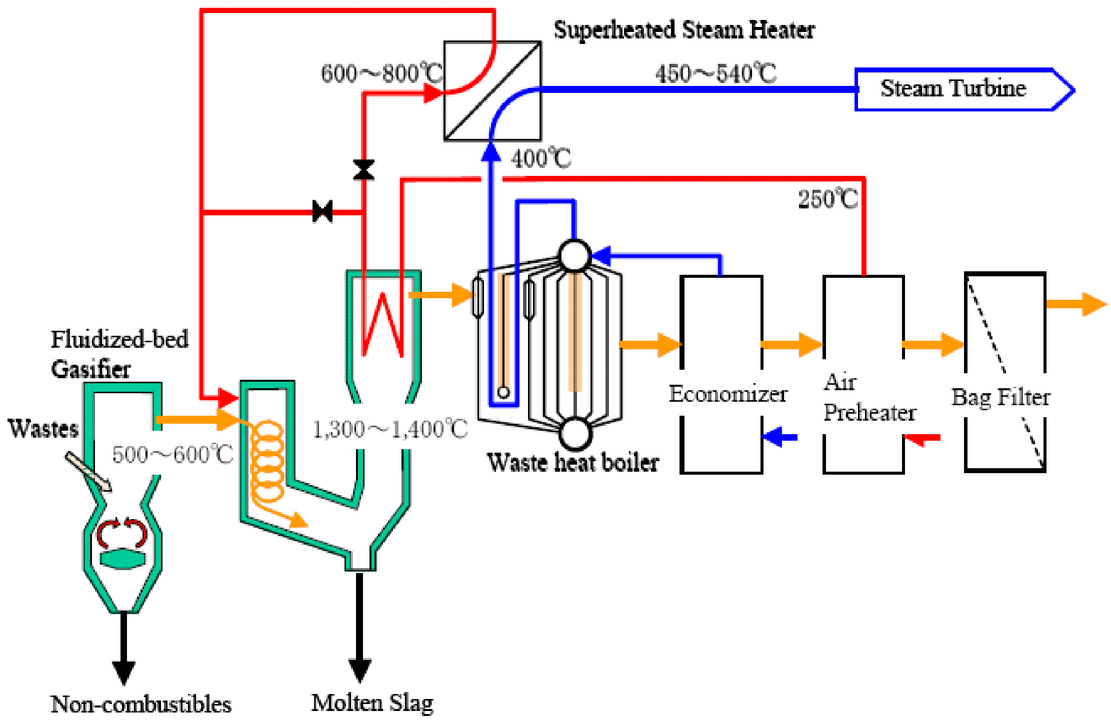


Figure B-8. RDF Fluidized Bed Gasification System[10]

Although this system is described as gasification technology, it does not export a burnable gas. RDF is first prepared using a process similar to the ones illustrated in Figures B-4 and B-5. The RDF (called "wastes" in Figures B-7 and B-8) is then charged to the fluid bed and the gas generated is directed to a secondary combustion chamber, shown above, with molten slag dropping out to a water-cooled sump. The molten slag solidifies into a glass-like material which can be used as a construction material or fill. Heat from the gas fired in the combustion chamber is captured in hot water tubes to generate steam which can be used for electric power generation. Without the generation of a usable gas stream and with the necessity of a combustion chamber for gas burn-out, this system is an incinerator.

A gasifier marketed for MSW is built by EnTech of Devon, England, as shown in the schematic in Figure B-9. This is a complex system which generates recyclable metals, plastics and other potential revenue streams, in addition to a salable gas (syngas). EnTech provides case studies of nine small-scale facilities in operation. A 67 TPD facility operates on a mixture of MSW.

[10] Source: Ebara Corporation, Tokyo.

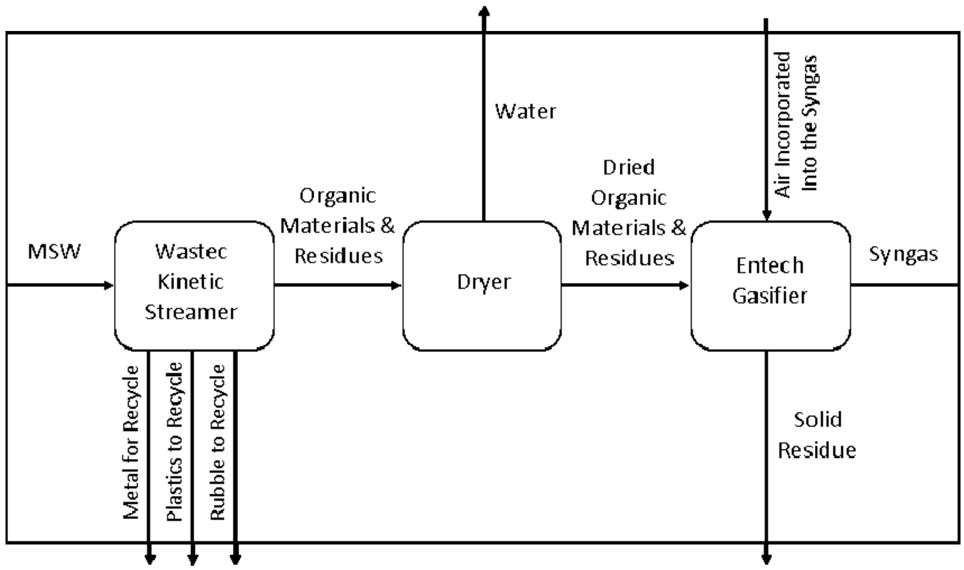


Figure B-9. EnTech Process Schematic[11]

As shown in Figure B-9, MSW is classified by a combination bag breaker and gravity separator process, termed a Kinetic Streamer. Oversize materials, which are basically inorganic, are directed either to a plastics recycler or a non-plastics recycling station, while the majority of waste (presumably organic) is directed to a dryer to remove entrained moisture. The dryer utilizes the latent heat inherent in the organic content of the waste to produce the heat necessary to drive the gasification process. The syngas can be fired in a waste heat boiler for steam and subsequent electric power production.

1.2.2 Pyrolysis

In pyrolysis, an organic waste (MSW) is heated without oxygen (or air), similar to the generation of coke from coal or charcoal from wood. Both a char and a gas are generated. The gas is burned out in a gaseous phase, requiring much less oxygen than incineration. The char will usually melt at the temperatures within the pyrolysis chamber and will be discharged along with a black gravel-like substance, termed frit. Advantages of this process are in the lack of air entering the chamber and the resulting smaller size of system components. Without air, there is little nitrogen oxide generation and low particulate (soot) formation. There have been many attempts to develop this technology outside a laboratory or a pilot plant. In full-scale demonstrations in the 1970s, it was difficult to maintain a sealed chamber to keep air out, and waste variability creates problems in maintaining consistent operation. When the pyrolysis gas is fired in a combustion chamber that is part of the system, the system is classified as an incinerator.

As shown in Figure B-10, MSW is shred into a uniform size capable of feeding into the thermal converter, or pyrolysis chamber. The pyrolysis gas generated is fired in a secondary combustion chamber, or thermal oxidizer, and passes through a waste heat boiler for heat recovery. Char drops out the bottom of the pyrolysis chamber for disposal or further processing for recovery of metals and other constituents. Although this system is marketed as a pyrolysis system, a combustion chamber is necessary for its operation (for destroying organics in the off-gas) and the presence of this chamber classifies the system as an incinerator.

[11] Source: Entech.

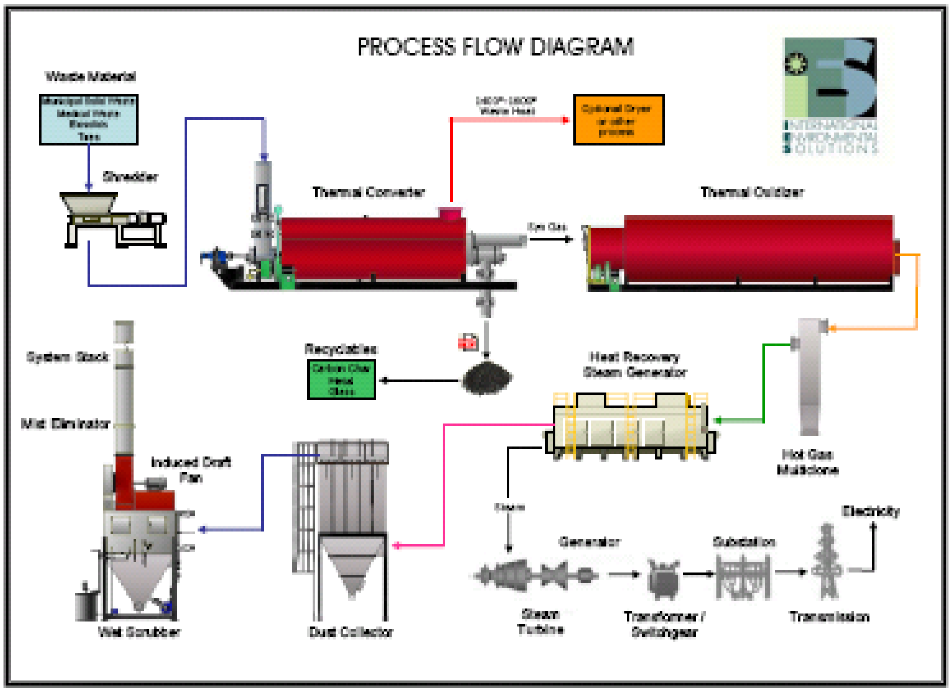


Figure B-10. Process Diagram of a Pyrolysis System[12]

1.2.3 Plasma Arc

Plasma arc technology is a gasification system that uses the intense heat generated by a plasma torch to drive the process. Net energy generation is not established based on Japanese and European experience. It is a pyrolysis-related process where little or no oxygen is injected into a reactor. A typical unit is shown in Figure B-11.

Electric current is passed through a series of torches at the bottom of a reactor, which heat a process gas (not shown) to a temperature in excess of 5,000°F. This hot gas stream heats waste within the reactor to over 3,500°F and, as air is provided to the system at a low controlled rate, some of the waste will burn to help maintain reactor temperature. At this high temperature, organics within the waste will form elemental compounds, such as hydrogen, oxygen and carbon, with some of this carbon converting to carbon monoxide or methane. The gas flow will have a high enough heat content to be able to sustain its own combustion and be used as a fuel gas external to the system.

The inorganic portion of the waste will form a liquid slag which eventually drops from the reactor into a water bath. As soon as it hits the water it will shatter into a glassy-looking residue or frit that may be suitable for fill or use as a construction material.

---

[12] Source: Integrated Energy Systems, Inc., Romoland, CA.

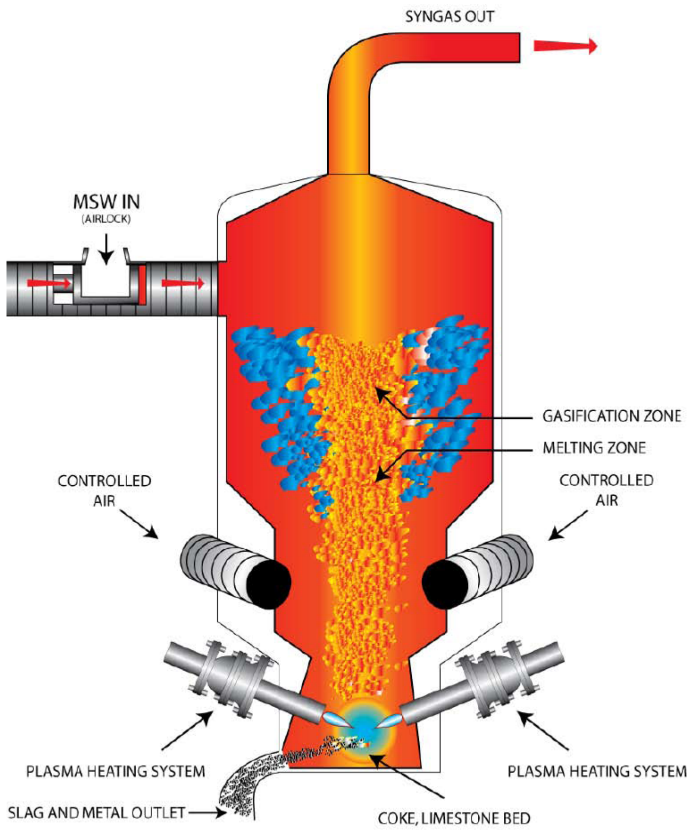


Figure B-11. Cross-Section of a Plasma Arc Furnace[13]

1.3 Biological Fuel Production

Producing a "fuel" product from organic materials in waste by biological processes is termed biological fuel production. Typically, this fuel product takes the shape of combustible gas or liquid formed when organic material in waste breaks down. Decomposition of the organic portion of waste by microorganisms in the absence of oxygen, known as "anaerobic digesting," creates methane (CH_4) and other gases in combination with about half the energy of natural gas. This biogas can be used as a fuel and burned for energy or power production directly. It can also be refined to produce a pipeline-quality gas that is almost pure methane and further processed into a liquid fuel like methanol.

1.3.1 Cellulosic Ethanol

Ethyl alcohol, ethanol, is a biofuel that is usually produced from sugar or starch but can be produced from wood, grasses, or other cellulose containing material, including the organic portion of solid waste. This is referred to as cellulosic ethanol. It is chemically identical to ethanol from other sources, such as corn starch or sugar, but has the advantage that the feedstock is lignocellulose raw material that is highly abundant and diverse. (The word "cellulosic" simply refers to the source material.) However, it differs in that it requires a greater amount of processing to make the sugar monomers available to the microorganisms that are typically used to produce ethanol by fermentation.

[13] Geoplasma, Atlanta, GA.

According to U.S. Department of Energy studies conducted by the Argonne Laboratories of the University of Chicago, one of the benefits of cellulosic ethanol is that it reduces greenhouse gas emissions (GHG) by 85 percent over reformulated gasoline. By contrast, ethanol from corn, which most frequently uses natural gas to provide energy for the process, may not reduce GHG emissions at all depending on how the starch-based feedstock is produced.

There are five steps to produce ethanol using a biological approach:

1. A "pretreatment" phase to make the lignocellulosic material, such as wood, straw or solid waste, amenable to hydrolysis, and to remove as many contaminants as possible;
2. Cellulose hydrolysis (cellulolysis) to break down the molecules into sugars;
3. Separation of the sugar solution from the residual materials, notably lignin;
4. Microbial fermentation of the sugar solution;
5. Distillation to produce 99.5 percent pure alcohol.

The process is shown graphically in Figure B-12; however, steps 2, 3 and 4 are shown in one stage or process. Abengoa accomplishes these steps in a single reactor.

1. Pretreatment

The first stage is physical processing of the feedstock: size reduction and removal of contaminants. This is similar to the production of RDF. This is especially important with solid waste where the fermentable portion may only be 60 to 70 percent of the feed. Once the MSW is physically prepared cellulose, its susceptibility to fermentation is still curtailed by its rigid structure. As the result, an effective additional treatment is needed to liberate the cellulose from the lignin seal and its crystalline structure so as to render it accessible for a subsequent hydrolysis step. A number of pretreatment approaches have been developed to liberate the cellulose and increase its reactability. To date, the available pretreatment techniques include acid hydrolysis, steam explosion, ammonia fiber expansion, alkaline wet oxidation and ozone pretreatment. Besides effective cellulose liberation, an ideal pretreatment has to minimize the formation of degradation products because of their inhibitory effects on subsequent hydrolysis and fermentation processes.

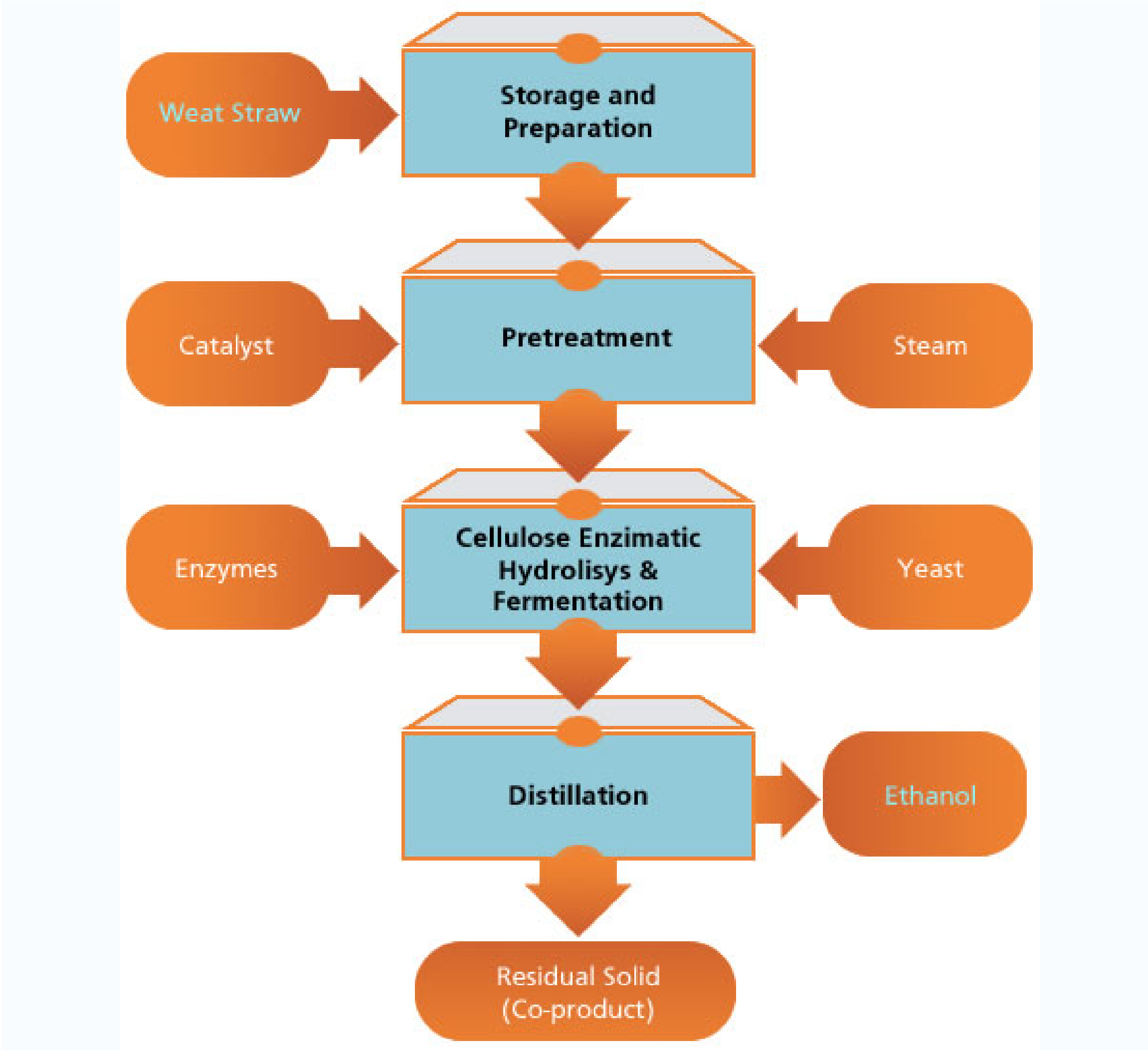


Figure B-12. Process Flow of the BCyL Biomass Ethanol Plant[14]

2. Hydrolysis

The cellulose molecules are composed of long chains of sugar molecules. In order to break the cellulose down into sugars, the hydrolysis process is employed. There are two major cellulose hydrolysis processes:

a) Acid hydrolysis - dilute acid may be used under high heat and high pressure, or more concentrated acid can be used at lower temperatures and pressure. A decrystalized cellulosic mixture of acid and sugars reacts in the presence of water to complete individual sugar molecules (hydrolysis).

b) Enzymatic hydrolysis - uses several enzymes at various stages of this conversion and has the advantage that lignocellulosic materials can be hydrolyzed with relatively mild processing conditions, which avoids the formation of byproducts that would otherwise inhibit enzyme activity.

These have been utilized singly or in combination to break the cellulose chains into free sugar, which is fermented for alcohol production.

[14] Source: Abengoa Bioenergy

3. Sugar Separation

Approximately half of the energy value in the cellulosic feedstock is captured in the sugars produced in hydrolysis. Fermentation will be more efficient if this is separated from other compounds, especially lignin. This can be accomplished with membranes. The lignin also contains about half of the energy and can be used as an energy source for the process.

4. Fermentation

Once the cellulose has been broken into sugars, microorganisms are used to ferment the sugar and produce ethanol. Traditionally, baker's yeast has long been used in the brewing industry to produce ethanol from hexoses (6-carbon sugar). When lignocellulosic biomass is hydrolyzed to produce sugars, several sugars are produced including xylose and arabinose (5-carbon sugars). As a result, specially engineered microorganisms, mainly yeasts, have been developed and utilized in fuel ethanol production from cellulose.

5. Distillation

The liquid resulting from fermentation is separated from any solids and heated to volatize the ethyl alcohol which is then condensed. The process is repeated to increase the ethanol concentration. An adsorption technique may be used to remove the remaining water to produce anhydrous ethanol.

Because of the concern about using food crops to produce fuels and the potential cost savings, a large number of companies have developed cellulosic ethanol technologies, including:

- Abengoa Bioenergy
- Alico
- BlueFire Ethanol
- China Resources Alcohol Corporation (CRAC)
- Dyadic International, Inc.
- GreenField Ethanol
- Gulf Coast Energy
- Iogen Corporation
- Mascoma
- POET Biorefinery
- Range Fuels
- SunOpta Inc.
- Verenium Corporation
- Xethanol

1.3.2 Biogas

Roger Haug defines composting as "the biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land." [15] Composting of MSW or a portion of MSW such as yard waste is usually carried out in the presence of air (aerobically) to produce a soil amendment and to reduce the amount of MSW being deposited in landfills. When composting is done in the absence of air (anaerobically), the biogas produced contains a significant amount

[15] Roger T. Haug, The Practical Handbook of Compost Engineering, Lewis Publishers, 1993.

of methane, about 50 percent. To capture this biogas the process must be in a closed vessel.

When anaerobic digestion is applied to the organic fraction of MSW, the primary purpose of the facility shifts from landfill diversion to biogas production. There are many anaerobic digestion plants both in use today and historically that have been installed to produce and utilize biogas as well as manage a waste. However, most of these facilities utilize sewage sludge, animal manures and other homogenous wastes as feedstock. Very few utilize MSW as a feedstock.

It has long been common practice in Europe to use anaerobic digestion at waste water treatment plants to treat sewage sludge. It has been less common over the same period to use anaerobic digestion to treat industrial effluents and agricultural sludges, although there are a number of examples dating back to the 1950s. In the last ten years or so in Europe, because of the introduction of a requirement that the separated organic fraction of MSW be treated before landfill disposal, anaerobic digestion has been adopted for this purpose. Anaerobic digestion has long been popular in India where a large number of small and simple plants are in use processing farm wastes. Currently, a number of vendors are offering farm-based systems in both Europe and the United States.

The process of producing biogas from MSW by anaerobic digestion has similar steps to the production of liquid biofuel discussed above. The process includes:

1. A "pretreatment" phase to make the organic material more available for digestion by size reduction and to remove recyclable materials and contaminates;
2. Digestion of the organic material in a closed vessel by microorganisms;
3. Treatment of the biogas to remove water, compress the gas, and other processes depending on the end use; and
4. Curing of the solid residue from the digestion to produce a compost product which may be marketable.

The longest established anaerobic treatment processes include:

- Anaerobic suspended growth,
- Upflow and down-flow anaerobic attached growth,
- Fluidized-bed attached growth,
- Upflow anaerobic sludge blanket (uasb),
- Covered anaerobic lagoons,
- Membrane separation anaerobic processes, and
- Dry process anaerobic digestion of MSW.

The above emerge in process designs, when developed and offered by the technology providers, which are either optimized to:

1. Efficiently remove material (mostly organic) from liquid streams to permit discharge of a treated effluent to a specified water quality standard, and biogas production may be just incidental; or
2. To provide treatment of a waste material, including MSW, to make it suitable for diversion away from landfill, with biogas generation optimized for revenue creation, and potential sales of fibrous and liquid fertilizer by-products.

Table B-5 provides a list of vendors that are offering anaerobic digestion systems in Europe and elsewhere. The table categorizes the technologies offered by moisture level, process temperature (mesophilic low temperature and thermophilic high temperature) and number of stages of the process. The U.S. EPA recently published an industry directory for firms offering equipment and services in this technology.[16]

Table B-5. International Anaerobic Digestion and Biogas Vendors

	Anaerobic Digestion					
Technology Provider	**Wet Single-Stage Mesophilic**	**Wet Single-Stage Thermophilic**	**Dry Single-Stage Mesophilic**	**Dry Single-Stage Thermophilic**	**Wet Multi-Stage Mesophilic**	**Wet Multi-Stage Thermophilic**
ArrowBio					√	
Biogen	TBD					
BTA					√	
CAMBI						√
CiTEC	TBD					
Dranco			√	√		
Eco Technology JVV Oy	TBD					
Entec Biogas GMBH	√				√	
GRL					√	
Farmatic AG	TBD					
Grontmij		√				
Haase					√	
Hese						√
HiRAD	TBD					
ISKA					√	
Kompogas	TBD					
Kruger ASBioTherm	TBD					
Linde				√	√	
OWS (Dranco)				√		
Passavant				√	√	
Paques	TBD					
Portagester					√	
RosRoca	√					
SBI		√				
Schmack Biogas AG	TBD					
Schwarting (Uhde)	√					
Valorga			√	√		
Wehrle					√	

Mechanical-Biological-Treatment: A Guide for Decision Makers – Processes, Policies and Markets, Juniper Consultancy Services, 2005

[16] Industry Directory for On-Farm Biogas Recovery Systems, U.S. EPA, March 2008.

1.3.3 Anaerobic Digestion

As applied to the processing of MSW, anaerobic digestion is a wet treatment process where waste is first pre-sorted and then fed into water tanks. Using agitators, pumps, conveyors and other materials handling equipment, MSW is wetted and dissolved. Metals, glass and other constituents of MSW that have no affinity for water are eventually discharged from the system into dedicated containers for recycling, further processing or final disposal. The paper, garbage, soluble components, etc., generate "black water" which has a relatively high organic content. This stream is taken to a series of digesters where the time it sits in the chamber, the residence time, will be sufficient to generate an off-gas. The process is shown in the schematic in Figure B-13.

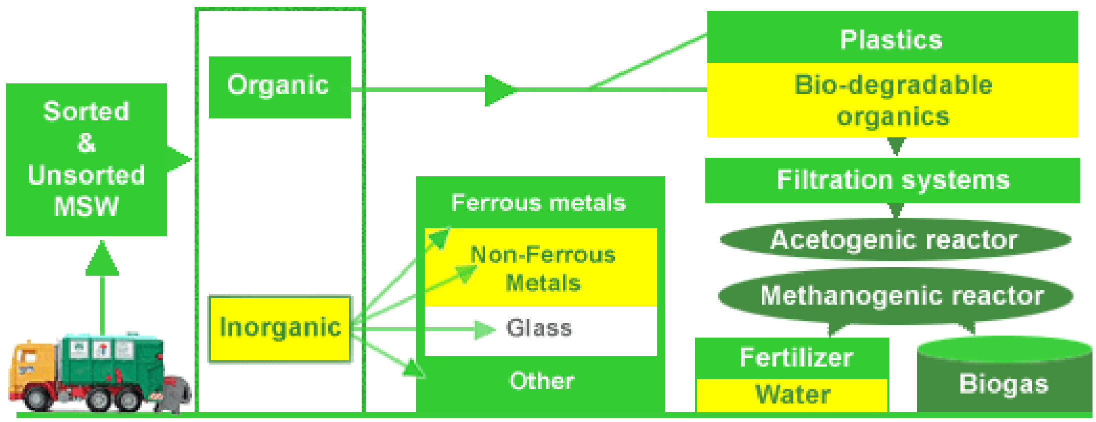


Figure B-13. Process Flow for Anaerobic Digestion System[17]

This gas is rich in methane and other organics and can be burned as a fuel for heating or for electric power generation. The solid residual from the digestion process is similar to compost and can be used as a soil amendment. The process also separates out recyclable materials such as glass and metals. There are many such facilities processing sewage sludge, manure and other homogeneous wastes.

ArrowBio of Haifa, Israel, is an example of a vendor that is offering to construct anaerobic digestion facilities to process MSW in the United States. They have responded to procurements in Los Angeles and New York. They operate a 300 TPD full-scale MSW demonstration process line in Tel Aviv, illustrated in Figure B-14.[17]

The system operates without high temperatures or pressure. In theory, it is extremely simple, relying on non-specialized mechanical equipment (pumps, screens, macerators, tanks, conveyors, etc.) for operation. Digestion occurs through the presence of natural microorganisms in MSW, so charging with specialty or unique bacteria is not necessary. It has a high resistance to upsets because of the scale of its operation, i.e., 300 tons of MSW entering the system per day, and any poisons that might threaten the digestion process (as has been experienced with sewage treatment plant digesters) are likely to be of such small fraction that it will have no significant effect on digester cultures.

The system is equipment and labor intensive. Although redundancy is normally built into the system, with multiple process lines and duplication of critical pumps,

[17] Source: ArrowBio, Haifa, Israel.

conveyors, etc., additional equipment adds to the number of separate process and associated equipment necessary for operation. The Tel Aviv installation of Arrow has thus far experienced many shut-downs due to the presence of troublesome components in the input waste stream. To combat this, a higher level of pre-processing is being implemented so that future applications can operate more reliably.

Figure B-14. ArrowBio Facility in Haifa