APPENDIX C

CONVERSION TECHNOLOGIES EVALUATED
FOR THE CITY OF SAN DIEGO
LONG TERM RESOURCE MANAGEMENT OPTIONS STRATEGIC PLAN

(PREPARED BY: ARI and CLEMENTS ENVIRONMENTAL)

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C1.0 INTRODUCTION

Conversion technologies include a wide array of thermal, biological, chemical, and mechanical technologies capable of converting municipal solid waste (MSW) into energy such as steam and electricity, fuels such as hydrogen, natural gas, ethanol and biodiesel, and other useful products and chemicals. Conversion technologies are successfully used to manage solid waste in Europe, Israel, Japan and other countries in Asia, but are not yet in commercial operation in the United States. There have been pilot demonstrations of conversion technologies in the U.S., but the absence of larger-scale demonstration facilities and commercial facilities in this country has been an obstacle to demonstrating the capabilities and benefits of these technologies for processing MSW.

The City is considering conversion technologies as part of its LRMO Strategic Plan. Conversion technologies offer the City many potential benefits, including: enhanced recycling and beneficial use of waste; diversion of significant amounts of waste from landfill disposal; environmental benefits, including reduction in greenhouse gases and other emissions; and, production of needed renewable products with strong, year-round markets (electricity, gas, fuels).

This paper presents an overview of solid waste management conversion technologies for purpose of initial consideration of these technologies under Phase 1 of the City's LRMO strategic planning process. The information presented herein is based on available, published information from other recent studies including those for New York City, Los Angeles County, and the City of Los Angeles.

C1.1 STATUS OF CONVERSION TECHNOLOGIES IN THE UNITED STATES AND CALIFORNIA

Public sector interest in conversion technologies has increased in the U.S. in recent years, based on the desire to enhance recycling and beneficial use of waste, reduce dependence on landfilling and imported fossil fuels, and reduce greenhouse gas emissions. Investigations and initiatives have been conducted or are underway in such locations as New York City; Los Angeles, CA (City and County); Santa Barbara, CA (City and County); Sacramento, CA; Salinas, CA; St. Lucie County, Florida, and Taunton, Massachusetts. Many of the earlier investigations have focused on identifying new and emerging technologies and compiling available technical, environmental and financial information for such technologies. Some of these public-sector initiatives include consideration of demonstration facilities, while others intend to proceed directly to procurement for a larger commercial facility.

Other initiatives are in a more advanced stage. Taunton, Massachusetts, issued a request for proposals in June 2008 for a facility as large as 1,800 tons per day (tpd). St. Lucie County, Florida, has selected the Westinghouse plasma gasification technology and is proceeding with permitting for a commercial facility to be located at the existing landfill site. Westinghouse reports that the first phase of the facility will be designed to process 1,500 tpd of MSW, with ramp-up to 3,000 tpd.

There are numerous initiatives taking place in California regarding conversion technologies. The City of Los Angeles has issued an RFP for both a demonstration facility (200 tpd) and a larger commercial facility (800 tpd) and is currently evaluating proposals. The County of Los Angeles Department of Public Works and the Los Angeles County Solid Waste Management Committee/Integrated Waste Management Task Force's Alternative Technology Advisory Subcommittee (hereinafter referred to as "Los Angeles County") are also pursuing a project. Los Angeles County has short-listed technologies and sites and issued a Request for Offers (RFO) for a demonstration facility as large as 1,000 tpd. Responses are due on August 15, 2008. The County has purposefully pursued the integration of a conversion technology facility at a material recovery facility (MRF) and/or transfer station (TS), in order to further divert post-recycled municipal waste and MRF residuals from landfilling and to take advantage of a number of beneficial synergies from co-location. The technologies and sites currently under consideration by Los Angeles County are as follows:

Technologies

- Arrow Ecology and Engineering (anaerobic digestion)
- Entech Solutions (low temperature gasification)
- International Environmental Solutions (pyrolysis)
- Interstate Waste Technologies (pyrolysis/high temperature gasification)

Sites

- Perris MRF/Transfer Station (Riverside County - Perris)
- Rainbow Disposal Company, Inc. MRF (Orange County - Huntington Beach)
- Robert A. Nelson Transfer Station and MRF (Riverside County - Unincorporated)

As stated earlier, other procurement initiatives for conversion technology in California are underway in Sacramento, Salinas and the City and County of Santa Barbara.

On a national level, there are various initiatives underway that may facilitate the development of conversion technologies in this Country. In February 2007, the U.S. Department of Energy announced several grant awards under its latest (2006) solicitation. The awards were for cellulosic ethanol projects covering primarily agricultural feedstocks, but also including solid waste (including Blue Fire Ethanol's Southern California acid hydrolysis process and BRI's waste gasification/fermentation process). Google, under its initiative "Develop Renewable Energy Cheaper than Coal", has made investments in renewable energy projects. Initially the focus of Google's initiative is on solar thermal, wind and geothermal; there is not yet a reference to MSW or biomass. To date, Google has made two, $10 million investments - a solar project and a wind project. Initiatives such as these, which directly or indirectly relate to conversion technologies, may be beneficial to developing such technologies in this Country.

C1.2 CHALLENGES TO DEVELOPMENT OF CONVERSION TECHNOLOGIES

There are several challenges to development of conversion technologies in the U.S.:

- **Lack of commercial demonstration in the U.S.** As noted above, conversion technologies are successfully used to manage MSW in other countries, but are not yet in commercial operation in the U.S.

- **Lack of development/acceptance for certain product markets in the U.S., or regulatory hurdles for product use.** Conversion technologies generate readily-marketable electricity or fuel as a primary product, but also generate secondary products that may not have a strongly developed market. Examples include the digestate (compost) from anaerobic digestion and aggregate from thermal conversion technologies.

- **Renewable Energy Credits.** Qualification for renewable energy credits for power sale is not consistent. In California, the California Energy Commission (CEC) is required to certify renewable energy resources under California's Renewable Portfolio Standards. CEC defines eligible renewable energy resources by renewable resource, or fuel, rather than by technology. Digester gas and MSW are included on CEC's list of renewable resources. However, facilities using MSW are subject to additional requirements that must be met for RPS eligibility (see Public Resources Code 40177). One of these requirements is that the technology does not use air or oxygen in the conversion process, except ambient air to maintain temperature control. Some individual conversion technologies may use air or oxygen in the process, in which case those technologies would not currently be eligible for renewable energy credits.

- **Permitting Pathways.** Applicability of regulations for environmental permitting is unclear, non-existent, or inadvertently problematic. In California, certain permitting pathways (i.e., Solid Waste Facility Permit requirements and Siting requirements) depend on whether a particular conversion technology facility falls under the definition of disposal or is considered to be "non-disposal." For example, under current regulations (Public Resources Code 40201 and 40192) pyrolysis is specifically defined to be transformation, which is considered disposal. For conversion technology facilities that are defined as disposal facilities, an amendment to the Countywide Siting Element would be required, which can be an arduous process, particularly in the more populous counties. Otherwise, a much simpler amendment to the Non-disposal Facility Element would likely be required.

- **Diversion Credits.** In California, AB 939 (The Integrated Waste Management Act) mandates 50% diversion from landfill disposal. However, as noted above under "Permitting Pathways", under current regulations certain conversion technologies may be considered "disposal" (e.g., pyrolysis) and would not be eligible for diversion credits.

- **Public Education.** Because conversion technologies are not currently in commercial use in the U.S., there is a need to educate the public about the characteristics and benefits of conversion technologies.

The Conversion Technology projects described in Section C1.1 above are addressing these hurdles, working towards development of the first projects in the U.S.

C2.0 IDENTIFICATION AND DESCRIPTION OF CONVERSION TECHNOLOGIES

The development of new and emerging conversion technologies, and particularly the presence of corporate sponsors and teaming partners for such technologies, is growing. Factors such as success of bench-scale or pilot testing, availability of grant funding, trends and changes in market conditions and the law, and growing or waning interest by the public and private sectors, can impact the technologies that are actively being marketed or otherwise under development. In consideration of the dynamics of emerging conversion technologies, many of the investigations and initiatives that are underway have included a detailed search process to identify current emerging technologies and the sponsors of such technologies. One of the most recent, comprehensive searches was conducted by New York City (*Evaluation of New and Emerging Solid Waste Management Technologies*, Alternatives Resources, Inc., September 2004). A similar search was conducted by the County of Los Angeles (*Conversion Technology Evaluation Report*, URS Corporation, August 2005), and was recently updated by Alternative Resources, Inc. as part of the next phase of the County's project (*Los Angeles County Conversion Technology Evaluation Report - Phase II*, Alternative Resources, Inc., October 2007).

Table C2-1 lists conversion technologies that have been identified in the most recent search efforts, including those conducted by New York City and the County of Los Angeles, California. Although the list provided in Table C2-1 may not capture all possible technologies and corporate sponsors, it represents a broad spectrum of conversion technologies, including the companies that are more established in the industry and that have achieved the greatest level of development (including, in several cases, commercial operation overseas and in Canada).

In addition to the conversion technologies that have been identified through other public initiatives, the City of San Diego has identified six technology suppliers or proposed facilities (in the City or close proximity) for consideration under the long-term strategic planning process. These companies are described later in this appendix section, and include:

- AdaptiveARC (formerly AdaptiveNRG)
- Balboa-Pacific Corporation
- Envirepel Energy
- Max Products
- Reg Renaud (STI Engineering)
- World Waste International

TABLE C2-1
CONVERSION TECHNOLOGY SUPPLIERS BY TECHNOLOGY CATEGORY

Thermal Processing	Biological Processing (Anaerobic Digestion)
Gasification	**Anaerobic Digestion**
Bioengineering Resources, Inc.	Arrow Ecology and Engineering
Dynecology	Canada Composting
Ebara Corporation	Ecocorp
Ecosystems Projects	KAME/DePlano
Entech Solutions	New Bio
Global Alternative Green Energy	Orgaworld
Global Energy Solutions	Organic Waste Systems
Global Recycling Group	Vagron
Green Energy Corporation	Waste Recovery Systems, Inc. (Valorga)
ILS Partners/Pyromex	
Interstate Waste Technologies (Thermoselect)	**Composting**
KAME/DePlano	Bedminster
Primenergy	Conporec
Taylor Recycling Facility	Herhof
Thermogenics	Engineered Compost Systems
Waste Gasification Systems/Allan Environmenta	
World Waste Internationall	**Chemical Processing**

Zeros Technology Holding Zero Waste Energy Systems **Plasma Gasification** AdaptiveARC Alter NRG/Westinghouse (1) EnviroArc Technologies/Nordic American Group Global Environmental Technologies GSB Technologies Integrated Environmental Technologies Peat International/Menlo Int. Plasco Energy Group Solena Group Startech Environmental **Pyrolysis** Balboa-Pacific Bioconversion Technology LLC (Emerald Power) Eco Waste Solutions Entropic Technologies Corporation GEM America International Environmental Solutions Pan-American Resources	**Hydrolysis** Arkenol Fuels/Blue Fire Ethanol Biofine/BioMetics Genahol Masada OxyNol **Other** Changing World Technologies **Mechanical Processing** CES Autoclaves Cleansave Waste Corporation Comprehensive Resources EnerTech Environmental Herhof Gmbh Recycled Refuse International Tempico WET Systems

(1) Several project developers have proposed or are engaged in projects with the Westinghouse plasma gasification technology, including Geoplasma and Rigel Resource Recovery.

As shown in Table C2-1, conversion technologies can be grouped into several broad categories:

- **Thermal Processing.** Thermal processing includes technologies such as gasification, plasma gasification, and pyrolysis, which use or produce heat, under controlled conditions, to convert MSW into a synthesis gas (that can be used to produce a fuel, or cleaned and combusted to generate electricity) and other usable products (e.g., vitrified aggregate, carbon-based char, metal).

- **Biological Processing (Anaerobic Digestion and Composting).** Anaerobic digestion is a biological process that reduces the biodegradable, organic fraction of MSW through controlled decomposition by microbes. Anaerobic digestion, which occurs in the absence of oxygen, produces a biogas that can be combusted to generate electricity as well as compost. Biological technologies such as anaerobic digestion are often combined with mechanical pre-processing systems, which allow for the recovery of traditional recyclables.

MSW can also be aerobically ("with oxygen") digested through various types of vessels and systems to produce either a soil amendment (compost) or a solid fuel. These systems are enclosed (at least for the active portion of the composting term) and include controlled air, moisture and oxygen as well as the ability to capture and treat air emissions.

- **Hydrolysis.** Hydrolysis is a chemical reaction in which water, typically with an acid, reacts with the cellulose fraction of MSW (e.g., paper, food waste, yard waste) to produce sugars, with additional processing to convert the sugars to ethanol or other products.

- **Mechanical Processing**. Mechanical processing technologies employ physical processing, such as steam classification (autoclaving), primarily to recover recyclables and separate the organic and inorganic fractions of MSW. Mechanical processing technologies are typically followed by other conversion processes.

- **Chemical Processing**. Chemical processing technologies use one or a combination of various chemical means to convert MSW into usable products, often uniquely encompassing other conversion processes (e.g., biological, thermal). Hydrolysis, separately identified above, is a subset of chemical processing technologies.

The different categories of conversion technologies are at various stages of development, as summarized in Table C2-2.

TABLE C2-2
DEVELOPMENT STATUS OF CONVERSION TECHNOLOGIES FOR MSW

Technology Category	Commercial Use Outside U.S. for MSW	Pilot Testing with MSW	Additional Research and Testing Required for MSW	Desirable for Monitoring
Anaerobic Digestion	✓	✓		
Thermal Processing	✓	✓		
Hydrolysis		✓		
Aerobic Digestion/composting		✓		
Chemical Processing			✓	✓
Mechanical Processing		✓		

Summary descriptions of these technology categories follow, including a general description of the technology category followed by more specific descriptions of individual companies that are prominent in the industry and for which information has been published in recent studies.

C3.0 THERMAL PROCESSING

Thermal technologies encompass a variety of processes that use or produce heat, under controlled conditions, to convert MSW to usable products. The organic fraction of MSW is converted to energy, and the inorganic fraction is recovered as products (e.g., aggregate, metal). Thermal technologies can potentially convert all organic components of MSW into energy (i.e., all carbon and hydrogen-based materials, including plastic, rubber, textiles, and other organic materials that are not converted in biological processes). Thermal processing includes such technologies described as gasification, plasma gasification, and pyrolysis. Distinctions between the different thermal technologies center around the processing temperature, the means of maintaining the elevated temperatures, and the degree of decomposition of the organic fraction of the MSW. Some of these distinctions are noted below. The distinction between the different types of thermal technologies is not always clearly defined, and therefore, the sub-classification of many thermal technologies is based largely on the representations made by the technology suppliers.

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

With some thermal technologies, such as gasification, the inorganic fraction of MSW is commonly recovered in the form of a vitrified material (i.e., a solid, glassy substance often called "aggregate" or "slag"), mixed metals, industrial salts, chemicals, and other byproducts. Some thermal technologies, such as pyrolysis, generate a char (i.e., a carbon-based solid) rather than a vitrified product. Depending upon market conditions, these byproducts of thermal processes may have beneficial uses or may require landfill disposal.

The syngas produced by thermal conversion technologies can be combusted to generate electricity. Thermal conversion technologies can also convert the syngas to fuels, rather than electricity. However, for MSW processing, the production of fuels is more complex, technically, than is the production of electricity, and has not been proven on a commercial scale. Although some MSW technology suppliers are conducting research and development efforts on fuel production (either to augment or substitute for electricity generation), the prevailing practice in the MSW market continues to be electricity generation, with the newest focus being on the use of combined cycle power generation systems for greater efficiency.

In an overview fashion, thermal processing of MSW can be described in two primary steps: (1) pre-processing, if required, and (2) thermal conversion, including combustion of the syngas to generate electricity.

- **Pre-processing.** Pre-processing requirements are often very minimal for thermal technologies. Except for the common requirement to remove or size-reduce very large, over-sized materials such as furniture and large appliances, many thermal processing technologies do not require size reduction or separation of MSW by component. This is not always the case, though, as some thermal technologies (e.g., many pyrolysis technologies) shred and/or dry the waste prior to processing. While recyclables such as metals can be recovered in a pre-processing step, many of the thermal technologies recover the metal after the thermal conversion process (i.e., as a "product" rather than as a front-end "recyclable".)

- **Thermal Conversion and Use of Gas.** The thermal conversion process results in a syngas and other products, as described above. The gas may be processed into fuels such as hydrogen or chemicals such as methanol, but currently, most technology suppliers have been or are focusing on converting the syngas to energy by using it as a fuel in traditional boilers, reciprocating engines and combustion turbines. Some of the thermal technologies pre-clean the syngas prior to combustion using standard, commercially-available technology to remove sulfur compounds, chlorides, heavy metals and other impurities. Pre-cleaning the syngas prior to combustion can be more cost-effective than post-combustion controls. Even with pre-cleaning, most technologies apply some post-combustion air pollution control technology. The extent of syngas cleaning and the type of post-combustion air pollution control varies by technology.

Some of the more advanced thermal conversion technologies, i.e., those with commercial facilities or pilot facilities processing MSW, include technologies provided by Ebara, Interstate Waste Technologies, Entech Solutions, Westinghouse plasma gasification, Plasco Energy Systems, AdaptiveARC, GEM America, and International Environmental Solutions. These technology suppliers were reviewed and evaluated as part of comprehensive studies conducted by New York City and/or Los Angeles County, and/or through the more recent

Request for Information issued by the City and County of Santa Barbara, California. A summary is presented below.

C3.1 EBARA

Ebara Corporation (Ebara), headquartered in Tokyo, Japan, is the project sponsor for the Twin-Rec fluidized bed gasification technology (also called TIFG - twin internally revolving fluidized-bed gasifier). The technology consists of a fluidized bed gasifier coupled with a high-temperature, ash-melting furnace. The system requires shredding of MSW prior to processing. Recyclable metals (ferrous and aluminum) are recovered from the gasifier reactor. Synthesis gas created in the reactor is combusted at a very high temperature in the ash melting furnace. Steam generated from the combustion of the gas is used to generate electricity. The synthesis gas enters the ash melting furnace in a "raw" state, containing tar, fine char, and ash residue. These materials are melted in the furnace and extracted as a vitrified, glassy slag, which is marketed to the construction industry as an aggregate.

Ebara's Twin-Rec technology has been in commercial operation in Japan since 2000, with 25 units currently in operation in Japan. Six plants (with 16 Twin-Rec units in aggregate) are in operation processing MSW. The first Twin-Rec plant fed with MSW began commercial operation in March 2002 (Sakata Area), with two additional plants later in 2002 (Kawaguchi City, Ube City), two plants in 2003 (Chuno Union, Minami-Shinshu Wide Area Union), and one plant in 2004 (Nagareyama City). Ebara's largest MSW facility is the 420-tpd Kawaguchi City Asahi Clean Center (see photo), which began commercial operations in November 2002.

Asahi Clean Center
Kawaguchi City, Japan

Ebara is continuing development efforts for its Twin-Rec technology, with its "second generation" unit being designed to de-couple the gasification process from the ash-melting furnace (i.e., the vitrification process). This de-coupling is intended to allow for the collection and cleaning of the synthesis gas prior to its combustion, and to enable other uses for the gas. The first commercial plant to use the "second generation" of the Twin-Rec technology is planned to be a 200-tpd facility in Chiba, Japan.

The Ebara gasification technology recovers recyclables (metals), and generates energy and other products as described below:

- **Recyclables.** Ferrous metal and aluminum drop by gravity to the bottom of the gasifier reactor (along with other dense inorganic materials), where they are removed intact (i.e., unmelted and unoxidized) and recovered using magnets and eddy current separators. Ebara represents that it can recover approximately 80% of the ferrous metal and aluminum present in the waste feedstock.

- **Energy.** The technology generates energy, in the form of steam and electricity, associated with the combustion of the synthesis gas. The electricity is used to meet internal needs, with the balance (net electricity) sold as a product. Energy output will depend on the characteristics of the waste. Net electricity output is estimated to be on the order of 400 kilowatt hours per ton of MSW processed (kWh/ton). The energy conversion efficiency of the technology is estimated to be approximately 15%.

- **Other Products.** Fly ash entrained in the synthesis gas is turned into a glassy slag in the ash melting furnace. The slag is continuously discharged at the bottom of the furnace and quenched, resulting in a glassy, granulate material that is marketed as a product for civil construction uses. Approximately 7% by weight of the incoming MSW is expected to be turned into a glassy slag. If a stable market is not established for the slag, this material would require disposal as a residue.

- **Residue Requiring Disposal.** Residue requiring landfill disposal is generated in Ebara's process from the solid output of the gasifier and as a result of the air pollution control system. An estimated 6% by weight of the MSW received for processing will be residue requiring landfill disposal. If the glassy slag product identified above requires disposal due to lack of a market, the quantity of residue requiring landfill disposal would increase to approximately 13%.

C3.2 INTERSTATE WASTE TECHNOLOGIES

Interstate Waste Technologies (IWT), represented in the United States out of Middleburg, Virginia, and Malvern, Pennsylvania, offers the Thermoselect high-temperature gasification technology. IWT is the sole North American licensee of the Thermoselect technology. The technology is a closed-loop process based on high-temperature gasification with an extended residence time for process gases. The technology simultaneously gasifies organic materials and melts down inert materials. There is no size reduction or separation of the MSW prior to gasification (i.e., no pre-processing), and no front-end recovery of recyclables. Rather, all MSW is input to the process and is either converted to energy or extracted as a product. Assuming all products can be marketed, which has reportedly been demonstrated at operating facilities in Japan, the technology generates no residue requiring disposal.

Thermoselect Facility
Chiba, Japan

The Thermoselect technology is currently in commercial operation at seven locations in Japan (Chiba, Mutsu, Kurashiki, Nagasaki, Yorii, Tokushima, and Izumi). The Chiba facility, which began commercial operations in September 1999, is the longest-operating Thermoselect facility in Japan (see photo). Chiba was initially operated with MSW, but currently processes industrial waste (primarily plastic and paper, along with sludge, wood chips, oil, and miscellaneous organic waste). The Kurashiki facility is one of the newest facilities, but has the largest capacity of all the Thermoselect facilities currently in operation. Kurashiki began operations in March 2005, and has a design capacity of 612 tpd. It processes MSW from the City of Kurashiki along with industrial waste (including auto shredder residue) from area industries.

The Thermoselect gasification technology recovers metals, and generates energy and other products as described below:

- **Recyclables.** The Thermoselect technology processes MSW as received, with no pre-processing. Therefore, no recyclables are recovered at the front-end of the process. All materials input to the process are either converted to energy or extracted as a product. As described below, metals are recovered, but classified as a product rather than a recyclable.

- **Energy.** The technology generates energy in the form of electricity, associated with the combustion of the synthesis gas. The electricity is used to meet internal needs, with the balance (net electricity) sold as a product. Energy output will depend on the characteristics of the waste and the method used to generate electricity. Net electricity output is estimated to range from approximately 500 kWh/ton to as high as 850 kWh/ton, under the wide range of MSW characteristics and equipment options available for generating electricity. The energy conversion efficiency of an IWT Thermoselect facility is estimated to range from approximately 15% to as high as 21%.

- **Other Products.** Materials in the waste that are not converted to energy are recovered as products. Quantities are directly related to the characteristics of the waste. Aggregate and mixed metals are generated from the melting of inorganic material in the high-temperature gasification reactor. Both would be generated and recovered at a rate of approximately 7.5% by weight of the incoming MSW. The aggregate is silica-based, and includes encapsulated impurities that are rendered inert. The mixed metals include iron, aluminum and copper. Other products include industrial salts (sodium chloride, sodium fluoride and other minor salts), sulfur, and zinc hydroxide, which are generated during the cleaning of the synthesis gas. These other products are expected to be generated and recovered at a rate of approximately 2% or more (combined total) by weight of the incoming MSW.

- **Residue Requiring Disposal.** Assuming all products can be marketed, the technology would generate no residue requiring landfill disposal. The ability to market all of the products is supported based on performance at existing facilities in Japan. For a project in the U.S., the metals and other minor products are expected to have stable markets. Some uncertainty exists regarding the presence of stable markets for the aggregate, although, IWT has identified concrete companies in the U.S. that would likely use the product. If the aggregate product requires disposal due to lack of a market, the quantity of residue requiring disposal would be approximately 7.5%.

C3.3 ENTECH SOLUTIONS

Entech Solutions, previously represented as Ntech Environmental, Ltd, headquartered in Devon, England, integrates three distinct technologies into a system. The core technology is the Entech gasifier, which consists primarily of a low temperature gasification unit and a syngas-fueled boiler. The Entech gasifier can be used to process a variety of wastes, including MSW and sewage sludge. Prior to gasification, MSW is pre-processed using the Wastec Kinetic Streamer technology, which is a mechanical system for front-end recovery of recyclables. The third component of the system is the Royco plastic-to-oil technology, a pyrolytic cracking process that converts plastics recovered from the MSW during pre-processing into diesel oil and other fuel products. The system recovers traditional recyclables and generates two primary products: electricity from syngas, and oil from plastics.

Entech Gasifier
Genting, Malaysia

The three distinct technologies aggregated by Entech have not yet been demonstrated or developed as an integrated system. However, the individual system components are currently in commercial operation overseas. The Entech gasifier has been in commercial use since 1989. Over 100 units have been installed, and more than 20 of the installations process MSW. The largest facility processing MSW is located in Genting, Malaysia (see photo). The facility in

Malaysia has a single unit with a design capacity of 67 tpd, and has been in commercial operation since 1998.

Wastec Kinetic Streamer
North Yorkshire, England

The Wastec Kinetic Streamer technology was developed in 2001 based on mineral ore sorting equipment. There is one Wastec installation, located at a landfill in the United Kingdom (North Yorkshire, England). The system was initially operated on a demonstration basis from 2001 to 2004, processing source-separated recyclables. Beginning in 2005, the system was operated on a commercial basis processing mixed (unsorted) MSW. It has a design capacity of 220 tpd. Very recently, the Kinetic Streamer was taken out of operation to provide for system optimization; it is expected to resume continuous operations in 2008.

There are two Royco installations in commercial operation, one in North Korea and one in South Korea. These facilities have been in operation for several years, but the dates of commercial operation are not available. A third facility, also in North Korea, is currently in start-up. All three installations are small-scale, commercial units. The newest facility, which has a design capacity of approximately 6 tpd (less than 2,000 tpy), is the largest of all three installations. The photo to the right shows one of the older facilities, which has a capacity of approximately 3 tpd (1,000 tpy). A facility under development in Melbourne, Australia, has a planned capacity of 18 tpd (5,000 tpy).

Royco Plastic-to-Oil
Technology, Korea

The Entech system recovers recyclables, and generates electricity and other products, including diesel oil, as described below:

- **Recyclables.** The Wastec Kinetic Streamer and associated pre-processing equipment, supplemented with some hand picking, recovers traditional recyclables from the incoming MSW. Materials that are recovered in the process and the recovery efficiency estimated by Entech include cardboard (50% recovery), ferrous metal and aluminum (90% recovery), film plastic (95% recovery), rigid plastic (88% recovery), and glass (98% recovery), with an overall average recovery efficiency of approximately 70% of these recyclable materials. With these recovery rates, it is estimated that approximately 30% by weight of the MSW received for processing could be recovered as recyclables.

- **Energy.** The technology generates energy, in the form of electricity, associated with the combustion of the syngas. The electricity is used to meet internal needs, with the balance (net electricity) sold as a product. Net electricity output is estimated to be on the order of 500-600 kWh/ton. The energy conversion efficiency is estimated to be approximately 17%.

- **Other Products.** The integrated Royco system generates an oil product expected to be similar in composition to a diesel product. The oil would be used for parasitic use (gasifier startup) and the excess would be sold as a product. On a mass basis, approximately 65-70% of the plastics fed to the system are converted to oil, generating approximately 200 gallons of oil (or more) for each ton of plastics processed.

- **Residue Requiring Disposal.** Residue requiring landfill disposal includes residue from pre-processing, residue from the Royco plastic-to-oil process, and air pollution control residue. In addition, ash from the gasifier and rubble and dirt from pre-processing, which are intended to be sold as products, may require disposal in a landfill due to lack of markets for these materials. Up to approximately 10% by weight of the MSW received from processing may be residue requiring landfill disposal.

C3.4 WESTINGHOUSE PLASMA GASIFICATION TECHNOLOGY - RIGEL RESOURCE RECOVERY

Rigel Resource Recovery and Conversion Company (Rigel) is a project development team that has previously proposed (for New York City) to engineer and build a conversion facility based on application of the Westinghouse plasma arc gasification system. Rigel team members are located in the United States (including Baltimore, Maryland) and abroad. Rigel's application of the Westinghouse plasma system to the processing of MSW is new, with no existing facilities that combine the system components as planned by Rigel. Rigel's application of the Westinghouse technology, as proposed for New York City, is designed to serve as a power plant as well as a waste management facility. The review provided herein focuses on the Westinghouse plasma arc gasification system, as it was proposed to be configured by Rigel.

The Westinghouse plasma arc gasification system uses high-temperature ionized air, called plasma, to convert carbon-based materials into a synthesis gas. The technology can process various types of waste, including MSW and sewage sludge. Inorganic materials leaving the plasma reactor as molten liquid are separated into metals and a glassy slag. There is no size reduction or separation of the MSW prior to gasification (except for over-sized materials greater than approximately 3 feet, which must first be shredded), and no front-end recovery of recyclables. Rather, all MSW is input to the process and is either converted to energy or extracted as a product. Assuming all products can be marketed, the technology generates no residue requiring disposal.

Westinghouse Plasma Corporation (WPC) is a wholly owned subsidiary of Alter Nrg, a Canadian firm that acquired WPC in April 2007. Therefore, Alter Nrg is now the owner of the Westinghouse plasma gasification technology. In April 2007, Alter Nrg entered into a technology license agreement with NRG Energy, Inc., a Princeton, New Jersey-based corporation that is a distinct and separate corporate entity from Alter Nrg. The License agreement grants NRG Energy a five-year, exclusive license to use the proprietary gasification technology in the United States. Previously, the Westinghouse plasma technology was commercially available to any interested party (such as Rigel). This new ownership and license agreement impacts the ability of such companies to use the Westinghouse technology.

Plasma Gasification Facility
Utashinai, Japan

The Westinghouse plasma gasification system was operated at a pilot scale (5 tpd) in Yoshii, Japan, from 1999-2000. The pilot plant demonstrated the ability to process MSW, and resulted in construction of two commercial facilities in Japan, both constructed by Hitachi Metals. The largest facility, located in Utashinai, Japan, began commercial operations in 2003 (see photo). It was designed to process auto shredder residue (ASR), MSW, or a blend of the two, and generates electricity. The Utashinai facility primarily processes ASR, and has a design capacity for this feedstock of approximately 165 tpd. The facility also processes some MSW, but the quantity typically processed is not available. The design capacity for processing all MSW is approximately 300 tpd. The second and smaller commercial facility, located in Mihama-Mikata, Japan, began commercial operations in 2002. This facility processes approximately 26 tpd of MSW and 4 tpd of sewage sludge, and generates heat for sale to a local industry. In addition to these commercial installations, WPC operates a research and development facility, called the Westinghouse Plasma Center, located near Pittsburgh, Pennsylvania. This facility houses offices and is used for pilot demonstration for customer process development for solid, liquid and gaseous feedstock.

The newest application of the Westinghouse plasma gasification technology is for the planned facility in St. Lucie County, Florida. The planned facility will process MSW, with an initial capacity of 1,000 tpd and an expansion to

3,000 tpd within a five-year period. The project is planned to be operational in 2010. The project developer is Geoplasma, Inc.

Rigel's design utilizing the Westinghouse technology includes the use of fossil fuels (i.e., coke, supplied to the reactor, and natural gas, supplied to the combustion turbine). Primary outputs are energy in the form of steam and electricity, recovered metals, glassy slag, chlorine and sulfur products as summarized below:

- **Recyclables.** Rigel's application of the Westinghouse technology processes MSW as received, with no pre-processing. Therefore, no recyclables are recovered at the front-end of the process. All materials input to the process are either converted to energy or extracted as a product. As described below, metals are recovered, but classified as a product rather than a recyclable.

- **Energy.** The technology generates energy in the form of steam and electricity, associated with the combustion of synthesis gas combined with natural gas. The electricity is used to meet internal needs, with the balance (net electricity) sold as a product. Net electricity output is estimated to be more than 2,200 kWh/ton. This high electric output reflects the large amount of fossil fuel input to the system (approximately 40% of the total energy input), including coke to the reactor and natural gas to the combustion turbine. The energy conversion efficiency of the Rigel facility is estimated to be approximately 37-40%.

- **Other Products.** Materials in the waste that are not converted to energy are recovered as products. Quantities are directly related to the characteristics of the waste, with the majority of materials recovered as glassy slag. Glassy slag consists of inorganic materials that do not volatilize in the gasification process and do not separate out as mixed metals after discharge from the reactor. The slag is primarily silica-based, and includes impurities that are encapsulated in the glassy material and rendered inert. Materials fed to the reactor that contain silica and contribute to the slag product are MSW, coke, and silica flux (a sand-like material used to promote vitrification). In addition, particulate matter captured in the cyclone during the cleaning of the synthesis gas is fed to the reactor, to enable encapsulation of the particulate within the slag. Glassy slag is expected to be recovered at a rate of approximately 16% by weight of the MSW received for processing. Other products and their recovery rates are mixed metals (7%), hydrochloric acid (about 3%), and elemental sulfur (less than 0.5%).

- **Residue Requiring Disposal.** Assuming all products can be marketed, the technology would generate no residue requiring landfill disposal. For a project in the U.S., the metals and other minor products are expected to have stable markets. Some uncertainty exists regarding the presence of stable markets for the slag. If the slag requires disposal due to lack of a market, the quantity of residue requiring disposal would be approximately 16%.

C3.5 PLASCO ENERGY GROUP

Plasco Energy Group, a privately-held Canadian company, is the developer of the Plasco Conversion System, a patented process using plasma arc gasification technology. Plasco has recently demonstrated its technology with MSW at a 110-tpd commercial-scale demonstration facility in Ottawa, Canada. The facility has been operating with MSW since July 2007. The Plasco system is designed to accept mixed MSW or residual wastestreams after recyclables have been removed, including MRF residue.

Plasco's system includes front-end waste preparation, consisting of shredding the waste and recovering recyclable metal. The prepared waste is then fed to the converter chamber where the material is gasified. The gasified product is refined in a secondary chamber with the application of plasma torches. For improved system performance, Plasco has the option to feed a supplemental waste stream along with MSW, which it calls Consistent Carbon Feed (CCF). The CCF is a waste with a known, consistent energy content (such as tires or low-grade, non-recyclable plastic) which can be used to control the quality of the syngas. However, initial operations at the Ottawa facility indicate that the CCF will not be necessary for operations with typical MSW feedstock.

The syngas is cleaned and then combusted in Jenbacher gas engines to generate electricity. Supplemental electricity is generated with the use of heat recovery steam generators/waste heat boilers coupled with a steam turbine.

Plasco is also investigating the direct sale of syngas to local gas suppliers as an alternative to power generation. Under this scenario, the Plasco plant would be a “zero emission” facility.

Primary outputs of the Plasco system are as follows:

- **Recyclables.** During front-end waste preparation, recyclable metals are recovered.

- **Energy.** The technology generates syngas, which is combusted to produce electricity. The company estimates a net electrical output as high as 1,250 kWh/ton, which has not been independently verified. The company's estimate of electricity generation also assumes use of GE Jenbacher gas engine generators, along with heat recovery steam generators that capture the heat from the syngas cooling equipment and the Jenbacher engines and generate steam that is fed to a steam turbine for supplemental electricity generation.

- **Other Products.** In addition to electricity, the technology generates a vitrified slag, used as construction aggregate (approximately 17% by weight of the MSW processed), and smaller quantities of industrial-grade salt and agricultural sulfur.

- **Residue Requiring Disposal.** Assuming all products can be marketed, the only residue generated by the technology would be a very small amount of particulate matter removed from the air pollution control system. The technology provides for greater than 99% diversion, with residue amounting to less than 1% by weight of the MSW processed.

C3.6 ADAPTIVEARC

AdaptiveARC offers a patented plasma-arc gasification technology it calls plasmaFILL™. This technology has not been extensively evaluated in other published studies released to date. Based on information that is available, AdaptiveARC's technology is portable and modular, and is offered in various standard configurations. The technology can accept waste without pre-processing, but the company acknowledges the ability to add front-end recovery of recyclables to its system when beneficial to do so. The technology uses electricity and high pressure air to create plasma, with temperatures reaching 2,300-3,300°F. These high temperatures promote rapid and complete gasification of feed materials resulting in syngas that is used to generate electricity. Other products include construction aggregate, agricultural fertilizer, potable water and commercial salt.

The plasmaFILL™ technology has been demonstrated at a 100-tpd pilot plant in Monterey, Mexico, which has been operated daily since 2005 to process MSW. The demonstration unit is portable and has reportedly been transported for use at several landfills in Mexico. There were two previous installations of the technology (1991, 1994) at Shell Oil Corporation for processing refinery waste. AdaptiveARC is being considered by Santa Cruz County, CA, to develop a 200-tpd turn-key project. The first phase will consist of one reactor, constructed at the landfill, which will operate for 6-12 months for testing purposes. The second phase will add two additional reactors, for full system capacity.

City of Santa Cruz Pilot Facility

The company is currently working with the City of Santa Cruz, building a pilot facility in their Eco-Park, calling it a waste-to-clean energy facility. A pilot project is anticipated to begin this year. Pre-sorting of the white goods and large items is required, the higher the recycling rate, the better. Shredding of the waste is recommended to reduce the density and provide consistency of the incoming waste stream. Shredding and compacting is not a requirement of the reactor, but the throughput will increase with looser waste and will extend the lifetime of the equipment. Metals would also need to be separated, however, if they are put into the equipment they can easily be taken out at the end.

Adaptive ARC has filed air quality permits with Monterey Air Quality District in Santa Cruz and the facility was covered under the CEQA documentation for the Eco-Park.

The Santa Cruz waste-to-clean-energy facility will operate in three phases.

1. Deployment of the first phase will include one reactor built by adaptiveARC, Inc., one gen-set, and a shredder. The reactor/gen-set pair will be deployed on the existing landfill area to minimize impact on the environment and adjacent property. The reactor gen-set pair will operate for 6-12 months during which time the system will undergo several tests, including;
    - Emissions
    - Ash by-product composition
    - Power consumption/output
    - Different waste streams as fuel feedstock
    - General technology validation

The reactor/gen-set will run intermittently for testing purposes. Santa Cruz County has the option of rejecting this phase at any point if certain milestones are not achieved.

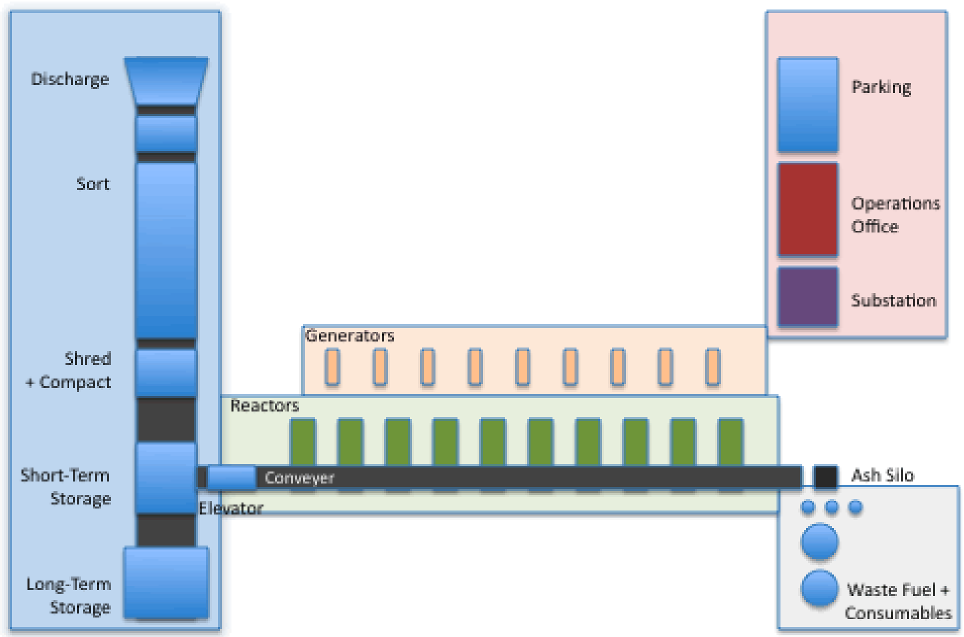
2. Deployment of the second phase will commence upon successful tests, permits, and milestones being achieved in the first phase. The second phase will include the addition of two more reactors, one more gen-set and the infrastructure to support processing of 200 tons of waste per day. The infrastructure includes shredding equipment, conveyor systems, ash silo, waste storage facilities, and support structures. The second phase will operate on a 24/7 basis for 12 months with minimal downtime. Certain criteria objectives will be created to validate the overall technology worthiness. Following the 12 months of continuous operations, the County may choose to accept or reject the technology. If the County chooses to accept the technology, the facility will be handed over as a turn-key operation to the County of Santa Cruz. Santa Cruz may choose to operate the waste-processing side of the facility on their own or subcontract the operation of the facility to adaptive ARC, Inc. and its partners.

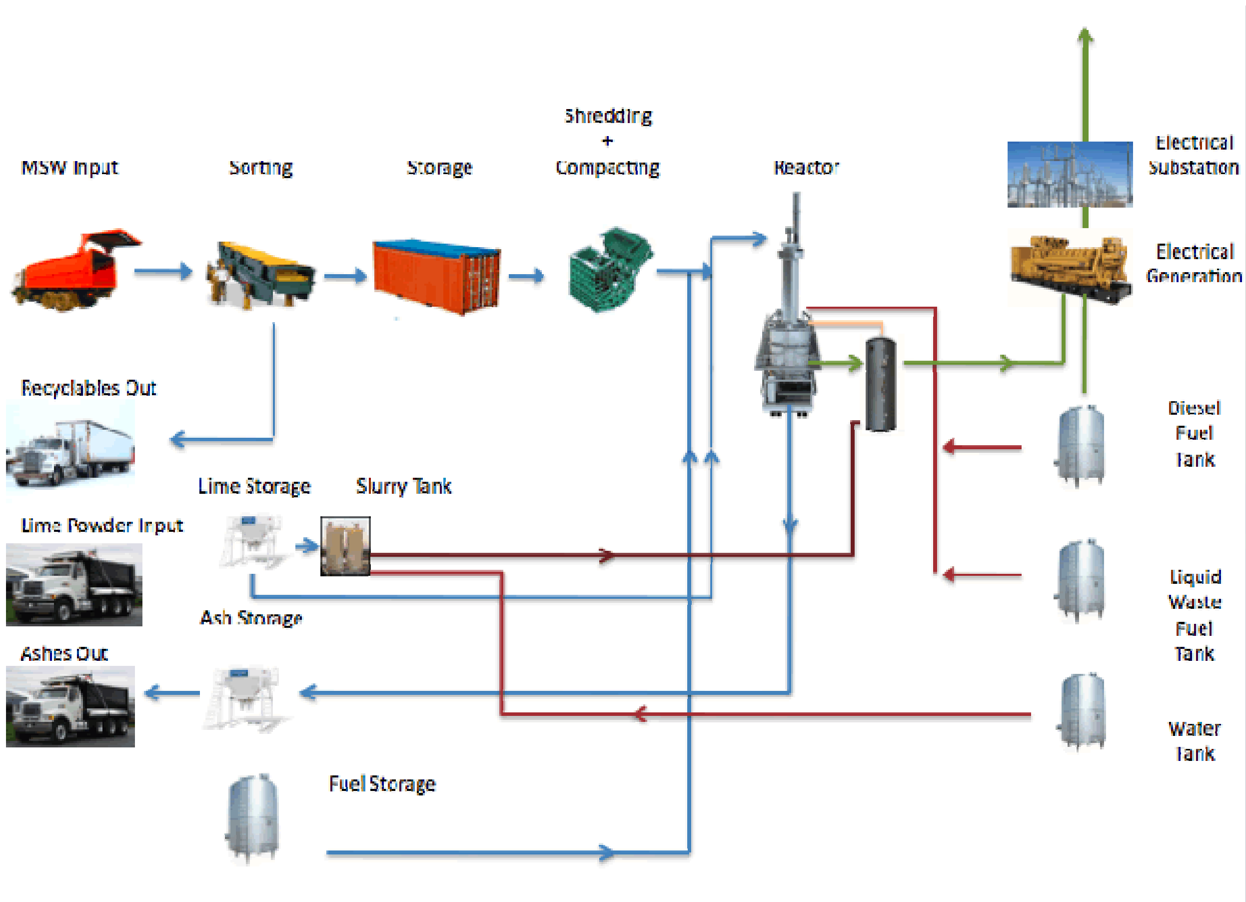
3. The final phase of the waste-to-clean-energy deployment will come upon completion of the "Eco-Park." This would happen within 4-6 years and would include moving the existing facility to its permanent "Eco-Park" home. The

modular/portable nature of the design will minimize moving costs and ensure minimum downtime. Santa Cruz may choose to upgrade the facility to processing 400 tons per day of waste.

The plasma reactor itself will require approximately 250kw of energy per reactor. The additional power required to operate the facility would be approximately 80kw for shredder, conveyor, and associated items. The reactor's gen-sets will produce 2000-3000 kw of energy per reactor, so the overall consumption of power will be approximately 10% of the power produced. This will fluctuate slightly based on waste input streams and moisture content of the incoming waste stream.

The final permanent facility at the Buena Vista landfill (phase 2) would include three reactors (one for redundancy) and two gen-sets (one for redundancy). A block diagram of what this might look like is shown below.





C3.7 GEM AMERICA

GEM Demonstration Facility
South Wales

GEM America (GEM), located in Summit, New Jersey, is the American subsidiary of GEM International, the owner and patent holder of the GEM Thermal Cracking System. GEM's thermal technology is capable of processing MSW and other types of waste, and has been tested on a variety of waste including MSW, commercial waste, wood waste and plastics. The GEM technology requires pre-processing to create a dried and shredded, prepared waste. The pre-processing equipment is not part of the patented GEM technology, but is included ahead of the GEM technology as part of an overall system and can be designed for the recovery of recyclables. GEM uses a pyrolysis technology, also called thermal cracking, to convert MSW into a synthesis gas that is combusted in a reciprocating engine to generate electricity. The process generates a carbon-based solid material, called char. The char may be potentially useable as a landfill cover material, but due to lack of identified markets is currently considered a process residue that requires disposal.

GEM's reference facility is a standard converter unit installed at a private landfill site in South Wales, U.K., which is the first, full-scale (commercial-sized) unit sold by GEM. While the reference facility represents a full-scale commercial installation under private ownership and operation, it operated intermittently for testing and inspection purposes, design modifications, and other reasons specific to the private facility owner and operator (e.g., to accommodate simultaneous testing and modification of an autoclave unit, intended for front-end separation of recyclables). Operation of the GEM converter was limited to four days per week, six hours per day, for a 12- to 18-month period. In this regard, GEM's reference facility is more representative of a full-scale demonstration facility of the converter unit than of a complete commercial facility capable of pre-processing and conversion.

The capacity of GEM's reference facility is approximately 40 tpd, which is the capacity of a standard GEM converter module. This capacity is the quantity of waste fed to the converter, after recovery of recyclables and drying of the waste. The owner's original plan was to expand to a total of three modules, but such expansion has not yet occurred. The demonstrated operating capacity at the reference facility is approximately 18.5 tpd, which is about half the design capacity. GEM reports that the facility has processed a total of approximately 1,375 tons of MSW over a one-year operating history. The facility is not currently operating, pending plans to re-locate the installation elsewhere.

GEM has been pursuing development of its first commercial facility in the U.S. (a private, industrial application in Ohio). This installation was scheduled to be operational in 2007, and may have recently achieved that status. The current status of this newest GEM installation is under investigation.

The primary output of the GEM technology is electricity, as described below, along with the potential recovery of recyclables:

- **Recyclables.** GEM has not completely developed a design concept for a front-end material recovery system. Only metal recovery is considered a routine part of the operation, with magnets and eddy current separators integrated with the waste shredding equipment. Glass would presumably be removed from the waste during pre-processing, but recovered glass has been considered by GEM to be residue requiring landfill disposal.

- **Energy.** Energy input to the GEM process comes from MSW. Fossil fuel (natural gas) is used during periods of startup, but is not used on a steady-state basis. Energy output is in the form of thermal energy and electricity. GEM proposes engines for conversion of syngas energy to electricity. For a commercial plant, the gross electricity output is stated to be 603 kWh of electricity per ton MSW received for processing. The technology requires approximately 70 kWh of electricity for internal (parasitic) use, resulting in net electricity generated for export (sale) of approximately 533 kWh per ton of incoming MSW. Additional thermal energy is reportedly also available for export (as heat, in the form of hot water). However, GEM has not sufficiently developed this concept for review and evaluation. Heat export, if viable, could provide additional revenue to a GEM project.

- **Other Products.** Except for energy, the GEM process does not generate products. The char, which is the solid byproduct of the pyrolysis process, may have potential use as a landfill cover material.

- **Residue.** The GEM process generates residue consisting of oversized material from pre-processing, glass, and char at an estimated rate of 28.4% by weight of the waste received for processing. The char consists of ash (inorganic material that escapes pre-processing) and residual carbon. The quantity of char will vary, depending on the characteristics of the waste processed in the GEM converter. For example, inert material that is not removed during pre-processing (e.g., glass, stones, metal) will pass through the converter and be mixed in with the char.

C3.8 INTERNATIONAL ENVIRONMENTAL SOLUTIONS (IES)

IES, located in Romoland, CA (Riverside County), is the developer of a pyrolytic gasification technology. This technology is currently under development for use with a variety of feedstocks, including MSW. IES's thermal technology centers on generation of a syngas by a retort reactor, followed by combustion of the syngas in a thermal oxidizer. The technology includes pre-drying of the waste and capture of the thermal energy using a heat recovery steam generator (HRSG). Because a dryer is integral to the process, as currently configured, the system can process sewage sludge and other organic wastes along with MSW. The process converts waste to useful energy in the form of electricity for net export. A small amount of residue, which will require disposal, is generated by the process.

IES has a reference facility, located in Romoland, CA, which is a demonstration facility (see photo). This facility has been used to process a variety of feedstocks since 2004. The Romoland facility has two pyrolysis units: one unit has an 8-tpd capacity, and the other has a 50-tpd capacity. A 125-tpd unit is under construction. This will be the standard module for commercial application.

IES Demonstration Facility
Romoland, California

The 50-tpd unit has been extensively stack tested while operating with MRF residuals as a feedstock. Except for several case-specific allowances made by the South Coast Air Quality Management District to enable extended test durations, the 50-tpd pyrolysis unit is generally limited by permit to operate less than a full day at a time. Therefore, the IES demonstration facility does not currently operate continuously.

Primary outputs of the IES process are described below:

- **Recyclables.** The IES design concept, to date, has been to accept MRF residuals, from which recyclables have already been removed. The IES technology does not include front-end recovery of recyclable materials. All of the MRF residual is processed through the retort vessel to produce syngas and char. The char has no appreciable recyclables that can be recovered.

- **Energy.** Electricity is produced by the combustion of the syngas in the thermal oxidizer for generation of thermal energy, which is then transferred to steam in the heat recovery steam generator, and finally converted to electricity by the steam turbine for both plant parasitic use and export.

- **Other Products.** The sole material product of the IES process is the syngas, produced by pyrolytic gasification. Currently, the only marketable product from the IES process is electricity. In addition to electric generation with the syngas, manufacture of fuel products, such as hydrogen, are actively under investigation by IES.

- **Residue.** The IES process generates residue requiring disposal from three sources: (1) the char from the retort vessel; (2) particulate matter collected by the cyclone; and (3) air pollution control system residues. Air pollution control system residues would include particulate matter, a caustic substance such as lime used for acid gas scrubbing, and a small amount of carbon injection used for mercury and dioxins/furans scrubbing. Approximately 5 percent by weight of the quantity of incoming MSW would need to be disposed.

C4.0 BIOLOGICAL PROCESSING

C4.1 ANAEROBIC DIGESTION

Anaerobic digestion is the reduction of carbon-based organic materials through controlled decomposition by microbes, accompanied by the generation of liquids and gases. In the anaerobic digestion of MSW, the biodegradable, organic components are metabolized by microorganisms in the absence of oxygen, producing a biogas (primarily methane and carbon dioxide), a solid byproduct (called "digestate", which is generally considered to be a compost), and reclaimed water. In an overview fashion, anaerobic digestion can be described by four primary steps: (1) pre-processing, or separation/preparation, of the MSW to obtain a prepared organic feedstock; (2) digestion of the prepared organic feedstock; (3) for some anaerobic digestion technologies, post-treatment of the digestate to produce a clean, mature compost, and (4) management and use of the biogas generated during the anaerobic digestion process. These primary steps are described below.

- **Pre-processing.** For mixed MSW, pre-processing or preparation/separation is necessary for separating biodegradable, organic materials from other waste components as well as for size reduction and preparation of the organic feedstock. Pre-processing can be accomplished using traditional, mechanical sorting processes, or it can employ more innovative and technology-specific approaches (e.g., the water-based preparation/separation system designed by ArrowBio.) Pre-processing will result in residue requiring disposal, generally consisting of broken glass and other inert materials present in the wastestream. Pre-processing can be combined with recovery of traditional recyclables that are not readily biodegradable and not of value in the digestion process. Recovered recyclables from pre-processing may include ferrous metal, aluminum, plastic, and glass. Recent initiatives are underway to sort paper and cardboard as recyclables, particularly when there are high market values for these materials. In general, maximizing the recovery of recyclables and the removal of non-degradable, inert materials during pre-processing will result in higher quality compost at the end of the process.

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

- **Post-processing.** Anaerobic digestion results in a solid byproduct, called "digestate." It consists of organic material that is not readily digestible, along with inorganic material that escaped pre-processing. Digestate is usually in the form of a slurry of varying consistency. Wet digestion technologies produce a digestate with a thinner, or wetter, consistency than dry digestion technologies. The digestate is commonly dewatered, with the liquid returned to the process or managed as a wastewater. The dewatered solids may be screened to remove inorganic materials, and are then aerobically finished, if necessary, to produce stable, mature compost, for sale as a product. The extent of post-treatment required to achieve a stable, mature compost, as well as the quantity of compost produced, varies based on the digestion technology used. Also, depending on the extent of separation and preparation conducted prior to the digestion process, some technologies require more post-processing than others (e.g., some technologies require screening of digestate prior to aerobic finishing, and/or screening of mature compost, in order to improve the quality of the resulting compost for purposes of beneficial use).

- **Biogas Management.** Anaerobic digestion results in a biogas, composed primarily of methane and carbon dioxide. Higher-quality biogas has a higher percentage of methane, with individual digestion technologies producing biogas with methane concentrations ranging from approximately 55% to 80%. Biogas may also include small amounts of contaminants, such as hydrogen sulfide (H_2S). The concentration of H_2S and other contaminants in the biogas generally depends on the characteristics of the MSW. Commercially available technologies may be utilized to remove contaminants and otherwise improve the quality of the biogas (i.e., achieve a higher percentage of methane), if such a step is necessary for a particular project. Often without any cleanup steps, the biogas can be beneficially used to generate electricity.

Two of the more advanced anaerobic digestion technologies for MSW are the Arrow Ecology ArrowBio process, and the Waste Recovery Systems Valorga process. These technology suppliers were reviewed and evaluated as part of comprehensive studies conducted by New York City and/or Los Angeles County. A summary is presented below.

C4.1.1 ARROW ECOLOGY AND ENGINEERING

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

ArrowBio
Tel Aviv, Israel

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

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

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

The separation and preparation subsystem of the ArrowBio technology is a water-based system, integrated with traditional mechanical sorting equipment. At the ArrowBio reference facility in Israel, incoming MSW is deposited directly into the water bath as it is received. Proposed Arrow facilities, including those currently planned for suburbs of Sydney, Australia, will likely include a receiving moving floor ahead of the water bath to allow for manual picking of bulky items from the waste as it is being moved to the water bath, and to allow for the recovery of paper and cardboard. Future facilities may also include a bag opener prior to the water bath, to allow for more efficient sorting. The need for an extended walking floor ahead of the water bath as well as the need for a bag opener are determined on a project-specific basis.

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

After material separation and organic preparation, biological treatment occurs in two types of bioreactors constructed in series: an acetogenic bioreactor, followed by a methanogenic bioreactor. Arrow's design uses two acetogenic reactors (in parallel) followed by one methanogenic bioreactor. In the acetogenic reactors, a specialized population of micro-organisms converts the organic material, by fermentation, into alcohols, sugars, and organic acids, which are then readily degradable in the second stage anaerobic reactor, the methanogenic reactor. Organic material must be sufficiently digested in the acetogenic reactor in order to pass through a fine screen into the methanogenic reactor. Fibrous material that is not very susceptible to microbial attack and that is not sufficiently digested cannot pass through this fine screen and is periodically removed from the acetogenic reactor as digestate.

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

The ArrowBio technology recovers recyclables, generates biogas that can be combusted to produce electricity, and generates a compost product, as summarized below:

- **Recyclables.** The ArrowBio process recovers traditional recyclables from the incoming MSW in the water bath. Materials that are recovered in the process include ferrous metal, aluminum, mixed film plastic, and glass.

- **Energy.** The ArrowBio anaerobic digestion technology produces biogas at a rate approximately equal to 11% of the incoming MSW by weight. The biogas produced in the ArrowBio process consists of methane, typically at a concentration of 70% to 80%, and carbon dioxide at a concentration of approximately 20% to 30%. Arrow also reports that trace amounts of hydrogen sulfide (i.e., less than 100 parts per million), oxygen, and nitrogen are present in the biogas.

  Arrow combusts the biogas in a reciprocating engine to produce electricity. The Arrow Bio facility in Israel utilizes a Caterpillar engine. Supplemental fuel (e.g., natural gas) is not used. The gross energy production rate for the ArrowBio technology is reported to be 300 kWh per ton of incoming MSW. The technology requires approximately 50 kWh for internal use, resulting in net electricity generated for export (sale) of approximately 250 kWh per ton of incoming MSW.

- **Other Products.** Compost is produced from dewatered digestate, with only passive aerobic finishing, if required (i.e., further stabilization of the digestate via on-site storage, with no active management to mix, turn or otherwise mechanically aerate the material). The compost production rate is approximately 14% of the incoming MSW (on a wet weight basis). No screening is conducted on the compost, reportedly because screening is not required.

- **Residue.** During front-end separation and preparation, recyclables and biodegradable organic materials are separated from inorganic and non-biodegradable material (e.g., grit, textiles, rubber, and composite packaging or consumer materials). The fraction that is not recyclable or biodegradable is considered residue requiring disposal at a landfill. For the ArrowBio process, up to approximately 23% of the MSW received for processing will be residue requiring disposal. This residue includes 2-3% glass that could potentially be recycled with development of a stable secondary market local to the facility. Unlike some other anaerobic digestion technologies, the ArrowBio technology does not generate residue after digestion. This is because the ArrowBio technology includes an extensive, water-based, hydro-mechanical separation and preparation process integral to, and preceding the digestion process, avoiding the need to screen the digestate or the finished compost after the digestion process.

C4.1.2 VALORGA INTERNATIONAL (URBASER)

Valorga (and its parent company, Urbaser) offer an anaerobic digestion technology. Valorga has been represented in the United States by Waste Recovery Systems, Inc. (WRSI) and, more recently, by Earthtech.

The Cadiz Plant
Spain

The Valorga process may be used for treatment of either mixed MSW, or for the source-separated organic fraction of MSW. In addition, sewage sludge or biosolids may be processed with MSW. The Valorga process is considered a "dry" anaerobic digestion process, since it processes organic feedstock with a solids content greater than 30%.

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

For processing mixed MSW, the Valorga digestion system would be coupled with a traditional materials recovery facility (MRF) at the front-end of the process, to recover recyclables and separate out non-biodegradable materials. The front-end processing would also include separation and size reduction equipment, to achieve a biodegradable organic fraction suitable as feedstock for the digester.

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

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

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

The Valorga technology recovers recyclables, generates biogas that can be combusted to produce electricity, and generates a compost product, as summarized below:

- **Recyclables.** Traditional recyclables would be recovered in a front-end MRF that is coupled with the Valorga technology. WRSI reports that approximately 88% of the metal and 28% of the plastic present in the waste would be recovered. Actual recovery rates would depend on the MRF equipment components and configuration.

- **Energy.** The Valorga anaerobic digestion technology produces biogas at a rate approximately equal to 15% of the incoming MSW by weight. The biogas produced in the Valorga process consists of methane, typically at a concentration of 55%, and carbon dioxide at a concentration of approximately 45%.

The Valorga facility in Barcelona, Spain is equipped with gas engine generators, for purposes of generating electricity from the biogas. Supplemental fuel (e.g., natural gas) is not used. The energy production rate is reported to be 218 kWh per ton of incoming MSW. The technology requires approximately 94 kWh for internal use, resulting in net electricity generated for export (sale) of approximately 124 kWh per ton of incoming MSW.

- **Other Products.** The compost production rate is approximately 24% of the incoming MSW (on a wet weight basis).

- **Residue.** For the Valorga process, an estimated 31% of the MSW received for processing will be residue requiring disposal. The front-end processing will generate an estimated 24% residue, and post-processing screening of compost will generate an estimated 7% residue.

C4.2 COMPOSTING

C4.2.1 INTRODUCTION

One alternative to landfilling that is particularly appealing due to its significant potential for waste diversion is in-vessel composting of municipal solid waste (MSW). Organic materials comprise the majority of MSW (typically 60-70%), so composting could play a role in achieving the waste reduction goals set by various States.

The technology features controlled oxygen, moisture, and temperature environments to accelerate the decomposition of organics. Each in-vessel stage is generally followed by a curing stage, which is either an aerated-static pile, or traditional windrow. There are four firms currently pursuing projects in the U.S.

Bedminster Bioconversion Corporation (marketed by Waste Options) has now developed 12 projects worldwide, including six in the U.S. (none in California) all handling mixed MSW and biosolids. New plants have come on line in the past few years, including the 700 TPD (designed to handle over 1,000 TPD) facility in Edmonton, Alberta. The company is now licensing the technology to others for project development. The Bedminster system is designed to handle MSW and biosolids together, usually a 2:1 mix. It is not designed to run on MSW alone.

Conporec is a French-Canadian company with a front-end technology similar to Bedminster. They operate a North American plant located north of Montreal in Tracy, Quebec that processes 35,000 TPY of mixed MSW (everything except Blue Box recyclables). They have also been awarded a 38,000 TPY facility in Delaware County, Delaware to process a mix of MSW and biosolids.

Herhof is a European technology with roughly 50 installations there (one in N. America). Historically, the Herhof system has focused on source-separated organics as a feedstock for production of compost. A more recent thrust has been the processing of MSW for the production of Stabilite, their patented fuel that is sold to WTE and conventional power plants. The company is proposing a modified system to process MSW and produce compost and Stabilite. Their one North American facility, in Peele, Ontario (outside Toronto) processes 16,000 tpy of mixed MSW for sale as compost.

ECS (Engineered Compost Systems) operates a 50 tpd MSW composting facility at West Yellowstone, MT, and another 50 tpd MSW composting plant in Mariposa County, CA. The latter system features an upfront MRF followed by eight composting vessels for primary composting and an aerated static pile (ASP) system for extended curing.

C4.2.2 HISTORY OF MSW COMPOSTING

- Municipal Solid Waste (MSW) Composting facilities struggled in the past with financial troubles, inconsistent results, and skepticism among market end-users.

- Primary challenges for the earlier facilities included competing with low-cost landfill tip fees, inadequate investment in odor control systems, and quality control of the feedstock and compost end-product.
- During the 1980s and 1990s MSW composting facilities were not very successful, however, new facilities have began to further develop process controls and operating procedures to control odors and improve compost quality.

C4.2.3 ECONOMICS

Cost and cost control are primary drivers with respect to solid waste management. Some of the key market influences for cost fluctuations include:

1. the costs of collection and hauling,
2. disposal (tipping fees),
3. labor and material and the availability of funding,
4. contractual arrangements,
5. level of service, and
6. regulatory compliance

The outstanding questions regarding MSW composting are the quality and marketability of the final product, and the overall cost. This net cost is strongly impacted by the cost of residue disposal and the value and marketability of the finished compost.

Typical tip fees for MSW compost facilities vary from $40 to $75 per ton. The best economic advantage for composting occurs when costs for recycling are factored into the overall solid waste management program. Composting facilities offer diversion rates between 60% and 75% of the incoming waste.

C4.2.4 FACILITIES

Currently, there are 13 mixed MSW composting facilities operating in the United States:

- Gilroy, CA
- Mariposa, CA
- Cobb County, GA
- Marlborough, MA
- Nantucket, MA
- Truman, MN
- West Yellowstone, MT
- West Wendover, NV
- Delaware County, NY
- Medina, OH
- Rapid City, SD
- Sevierville, TN
- Columbia County, WI

Table C1 provides summary information on these facilities. Source material for this report is excerpted *verbatim* from BioCycle November 2007, Vol. 48, No. 11, Page 22.

Gilroy, California: The Z-Best Composting site south of Gilroy was permitted in 1998 to accept up to 1,300 tons/day of curbside collected yard trimmings. In 2001, Z-Best was permitted to process municipal solid waste at the site as well. A sorting line was installed at the facility, which included hand sorting stations, as well as a Bulk Handling Systems (BHS) de-bagger, disc screen and a shredder. Materials passing through the 3-inch minus shredder were composted in Ag Bags. The company targeted “organics-rich” compactors, primarily from its commercial collection routes as well some residential. In addition to the compactor loads, the facility takes in screenings from a dirty MRF in Sunnyvale operated by a sister company, Zanker Material Processing Facility. “We receive about 280 tons/day of mixed waste, including the dirty MRF screenings, MSW

TABLE C1

Location	Owner/Operator	Project Start Date	System	Feedstock	Throughput (TPD)	Tipping Fee	Cost to Operate	Diversion %	Final Products
Gilroy, CA	Private/Z-Best Composting	2001	Enclosed ASP (Ag Bag, large plastic tubes)	Mixed waste, including dirty MRF screenings, residential MSW, commingled garbage and yard waste	280			70%	MSW compost only marketed to non-food related users
Mariposa County, CA	Municipal	2006	In-vessel (SV Composter - Engineered Compost Systems (ECS))	MSW from residents and businesses, and Yosemite National Park	60	$70/ton or $9.57/cy un-compacted and $19.14/cy compacted	Project totaled $8.3 million	50%	Daily Cover (ADC) at the County's landfill
Cobb County, GA	Municipal	1996	Rotating drum/aerated windrow (Bedmister)	MSW and treated biosolids	200			60%	Bio-Blend compost, offered free to residents, available for commercial sales
Marlborough, MA	Municipal/WeCare Environmental	1999	Rotating drum/aerated windrow (Bedmister with Allu turner)	MSW, biosolids, source separated organics	100 (with 5 tpd biosolids)			65%	30,000 cy of compost/year, 15% sold for $4 to $8/cy, the balance distributed at the cost of transportation
Nantucket, MA	Municipal/Waste Options, Inc.	2005	Rotating drum/aerated windrow (Bedminster) (Waste Options investigating use of pyrolysis)	Yard waste, MSW, biosolids	125 peak/30 off-peak (with biosolids)	$90/ton		80%	Topsoil and compost for sale (50% of compost sale goes to the Town), 1-6 cy is $35/cy, 7-16 cy is $30/cy, >16 cy is $25/cy
Truman, MN (Prairieland SWMB)	Municipal	1991	In-vessel (OTVD agitated bay composting system)	MSW	65	$75/ton			Portion of residuals are burned as refuse-derived fuel, rest is Class 2 compost (with a fee for trucking to haul to farmers)
West Yellowstone, MT	Municipal	2003	In-vessel (SV Composter - ECS)	MSW from Yellowstone National Park only, receive a lot of recylceable material that can't be recovered (stopped receiving biosolids in 2007) (planning to add bison road kill in 2008)	3,000 tons/year	$207/ton	$200/ton	50%	2,000 cy/year of compost sold in bulk for $15/cy
West Wendover, NV	Municipal		Rotating drum/aerated windrow	MSW and biosolids	25 (with biosolids)			70%	14 tpd of compost and 6 tpd of noncompostable garbage which is hauled to the landfill
Delaware County, NY	Municipal	2006	Rotating drum/agitated bays (Conporec/IPS - Siemens)	MSW, biosolids, select commercial/industrial organics from dairy farms	24,000 tons/year (with 6,500 tons/year biosolids)	no tipping fee	$50/ton	62%	Compost, mostly sold to a broker on a profit share basis, some direct sales from facility
Medina, OH	Municipal/Norton Environmental	1994	Windrow	Screend mixed organic waste from onsite "dirty" MRF, yard trimmings and wood	45				Compost used for landfill applications (ADC, slope cover)
Rapid City, SD	Municipal	2003	Rotating drum/agitated bays (Dano/IPS - Siemens)	MSW, biosolids	180 (with 12,000 gal biosolids)	$45/ton		27%	40 to 50 tpd of compost which is given away (may try to market to golf courses)
Sevierville, TN	Municipal	1992	Rotating drum/aerated windrow (A-C Equipment, Backhus turner)	Residential and commercial MSW, biosolids (not presently composting due to a major facility fire May 2007, plans to rebuild and expand)	250 (with 50 tpd biosolids)	$40/ton	$25.34/ton	60%	60% composted, 40% to an unlined demolistion debris landfill (in 2006 30,000 tons of compost was produced and sold to a marketing company for soil blending, topdressing and erosion control)
Columbia County, WI	Municipal	1992	Rotating drums/windrows	Residential MSW	70-80	$34/ton			3,000 tons/year of compost produced and given to local farmers at no cost

from residential sources and commingled garbage and yard waste," says Michael Gross of Z-Best Composting.

Z-Best is in the process of changing its operations at several of its recycling facilities in the San Jose region. As a result, it is dismantling the front-end processing plant at the Gilroy site. "All materials will go through our new MSW MRF in San Jose," adds Gross. "Processed material that has been cleaned will be hauled to Gilroy for composting. This way, we won't have to haul residuals back to our landfill. It is a better use of that composting site."

Mariposa County, California: The Mariposa County mixed waste composting plant began operating in the summer of 2006. The facility is designed to process 60 tons/day of material from residents and businesses in Mariposa County, as well as Yosemite National Park. Finished compost is used for daily cover at the county's landfill. Equipment at the plant includes a Bulk Handling Systems sorting line (including a de-bagger) and SV Composter vessels from Engineered Compost Systems (ECS). In the fall of 2006, there were some odor complaints that needed to be addressed. Part of the problem was traced to the biofilter, which wasn't functioning properly. ECS rewetted and reformed the media, added additional material and put an exhaust air humidifier that had been installed initially but wasn't in operation at that time, back in service. Odor emissions were significantly reduced both in frequency and severity, reports ECS.

Cobb County, Georgia: The Cobb County mixed waste composting plant opened in 1996 to process 300 tons/day of mixed waste with 100 tons/day of biosolids. As reported in last year's BioCycle, the facility is operating at 200 tons/day. Operations have not changed much during 2007. The compost is a mixture of MSW and treated sewage sludge, which enters rotating drums for three days, and then is screened and placed in aerated windrows for 28 days. After a second and final screening, its Bio-Blend compost is offered free to residents for individual use, and is available for commercial sales by appointment.

Marlborough, Massachusetts: Starting its eighth year of operation this fall, this 120 tons/day rotary drum co-composting facility processed 34,000 tons of mixed MSW, 12,000 tons of biosolids and 8,000 tons of source separated organics. According to Chris Ravenscroft, President of WeCare Environmental, owner and operator of the facility under contract to the City of Marlborough to process its MSW, it had to reduce the quantity of biosolids processed through the facility and have continued to identify new, clean sources of organic wastes, such as supermarkets.

The facility produces approximately 30,000 cy of compost per year, with 15 percent sold for $4 to $8/cy, and the balance distributed at the cost of transportation. Compost is used for topdressing existing lawns and athletic fields, as well as to manufacture topsoil. The compost is screened through a 3/8-inch

McCloskey trommel screen. "We find that the markets have a very low tolerance for contamination," says Ravenscroft. The residue rate from material processed through the composting system is approximately 35 percent.

Nantucket, Massachusetts: On the Island of Nantucket off the coast of Cape Cod, Waste Options, Inc. continues to operate the 125 tons/day MSW and biosolids co composting facility under a 25-year contract with the Town of Nantucket. The last two years have focused on compost marketing, and Whitney Hall, President of Waste Options, reports that demand for the compost and organic topsoil continues to grow. "Landscapers who bring in yard waste are our largest customers, and we sell more topsoil than straight compost," he says. "We also have some distributors who take bulk deliveries and market the product."

The MSW compost is refined with a bivi-TEC screen and a destoner to remove glass, and then blended with ground yard trimmings for further curing. One modification to the blending recipe has been to cut back on the amount of chipped wood and brush and use more leaves and wood fines. Hall explains that this results in less wood and sticks to screen out of the final product. "Instead of using a 3/8-inch screen in the McCloskey trommel, we are using a one-half inch screen," he notes. Waste Options has a sliding scale price for the organic topsoil, with discounts for larger quantities - 1-6 cy is $35/cy; 7-16 cy is $30/cy; and >16 cy is $25/cy. Fifty percent of compost sales revenues go to the Town.

As for possible changes at the facility, Hall says Waste Options is investigating the use of pyrolysis, a high temperature process that would extract combustible gas from the compost facility residuals, and construction and demolition debris. The gas would be used to generate electricity to power the plant. "I have looked at two operating pyrolysis facilities and have discussed it with the Town and the Massachusetts Department of Environmental Protection (DEP)," he says. "It appears that the process could be permitted by the DEP. A quick look at the economics indicates that it could be viable, so the Town is forming a committee and hiring a consultant to assist with a feasibility study."

Truman, Minnesota: The Prairieland Solid Waste District steadily processes 65 tons/day in its OTVD agitated bay composting system, with no plans to expand capacity. A portion of the residuals from the process are burned as refuse-derived fuel (RDF). According to the facility's director, Mark Bauman, if demand for RDF expands, the District might install an additional shredder to produce more fuel. It still produces 3,000 tons/year of compost, and will land spread it for no charge. A fee for trucking is charged to haul compost to farmers, and eventually, when demand increases, a small fee will be charged for the compost. In the last year, there has been growing demand for the end product to use in animal mortality composting, particularly with the swine industry. Pork producers use the compost as an amendment to process piglet mortalities, and the occasional sow. What does it mean to process a pig mortality? Bury it? The facility's tipping fee is currently $75/ton. A bivi-TEC is used to screen the compost to five millimeters. Due to fluctuating levels of lead, the District's compost is usually Class 2. “We landfill some residuals that could be used for fuel, but just don't have capacity in area to burn it at this time,” says Bauman.

West Yellowstone, Montana: The West Yellowstone Compost Facility, operated by the Hebgen/West Yellowstone Refuse District, is designed processes 3,000 tons/year of mixed MSW. It uses an in-vessel composting system supplied by Engineered Compost Systems. “We accept mixed MSW from Yellowstone National Park only,” explains Kathy O'Hern, facility manager. “The Park's waste stream includes a small amount of residential material. The remaining waste stream consists of waste generated in campgrounds, concessionaire restaurants and hotels, roadside bins and the Park's trade shops, e.g., electrical, plumbing and woodshops.”
The plant opened in July 2003. Initially, it also accepted biosolids from the park. “The only change we made to our operations in 2007 was to stop accepting biosolids,” adds O'Hern. “Although we are permitted to handle biosolids, we found that this material does not work well in our incline coreless auger conveyor.” During 2008, the facility is planning to add a road kill composting program for the bison hit on local highways.

About 2,000 cy/year of compost are produced. It is sold in bulk for $15/cy. The facility has a bivi-TEC screen and a Forsberg de-stoner to remove contaminants from the compost. “About 95 percent of the contaminants are removed,” she says. “The final compost continues to contain small flecks of colorful plastic picnic ware.” Overall, residue from operations accounts for about 50 percent of the total incoming waste stream. “We receive a large amount of recyclable materials that cannot be recovered with our existing system,” adds O'Hern. Tipping fee at the facility is $207/ton; cost to operate, including loan repayment, is $200/ton.

West Wendover, Nevada: The City of West Wendover's composting facility accepts up to 25 tons/day of MSW, which is mechanically sorted and combined with up to five tons/day of biosolids (generated by the nearby wastewater reclamation facility). The compostable mix is then loaded into cement kilns, which operate as rotary drums. The end result is 14 tons/day of compost, and six tons/day of non-compostable MSW such as glass and C&D debris, which is hauled to the landfill for disposal. By combining the MSW and biosolids, West Wendover is achieving a 70 percent recycling rate, notes a statement on its website.

Delaware County, New York: “This year has been a good one for our compost facility, and I have to say we are successfully producing a quality product with minimum down time,” reports Susan McIntyre, Solid Waste Director for the

Delaware County Department of Public Works. The facility, which is owned by the county, came on line in May 2006. Its processing line includes a Conporec rotary drum and Siemens/IPS agitated bays (14 in total). The plant is processing 24,000 tons/year of MSW, 6,500 tons of biosolids and 2,800 tons of select commercial/industrial organics from local dairy plants.

McIntyre describes a number of minor changes made in the plant over the last year as part of fine-tuning the operation. "We made some adjustments to the bioreactor's interior for better waste tumbling and mechanical separation," she says. "We also added chains and paddles to the trommel screen interior to improve organics separation and screen cleaning. A leveling bar was added to the infeed conveyor to the pulverizer that crushes glass in the final compost product." The county instituted a two-week preventive maintenance shut down, a practice it plans to continue.

Operationally, the most significant change has been a more aggressive effort to divert problematic waste items such as hose, tubing, strapping, carpet and other bulky objects that contribute to generation of large "hair balls" inside the drum. "We are working with the private haulers who collect the MSW, and are making progress," adds McIntyre. "Our crane operators have gotten more skilled at removing these materials from the tip floor prior to loading into the bioreactor. Once the operators extract a few hair balls out of the discharge end they tend to get more discriminate as to what they load in the front end!" To help with removing the hair balls that still are created, the county installed a permanent winch with custom designed logging grapples to hook onto the balls and pull them out.

Total residuals from the composting facility are 38 percent by weight, and 20 percent by volume, a more important number to Delaware County since all residuals go to its adjacent lined landfill. Landfill staff has found that disposal of wet residuals (about 55 percent moisture) has advantages over the drier MSW they used to bury since it is easier to handle and has less wind-blown litter. Recyclable materials are diverted through a separate MRF prior to MSW being delivered to the composting facility. The MRF is located on the same site. The facility does not charge a tipping fee, but McIntyre reports that operating costs and debt service are in the low to mid $50/ton. The County sold approximately 7,500 cy of compost in the first three quarters of 2007. Most is sold to a broker on a profit share basis, with limited direct sales from the facility. Testing has repeatedly shown that the compost contains less than one percent foreign particles by dry weight. "We have a dedicated staff that is committed to what we are doing, and believe in it, and that is an important contribution to our success thus far," says McIntyre.

On the regulatory front, the New York State Department of Environmental Conservation recently determined that the facility must register as a minor air emission source due to its biofilter. Using data from comparable composting facilities and their biofilters, the county was able to demonstrate that the facility is in the state's lowest regulatory threshold for emissions of NOx and SOx. As for odor complaints, McIntyre says that when the occasional complaint comes in it is usually the adjacent landfill. “It's a different odor from the composter, and we can recognize it too,” she says.

Medina, Ohio: Medina County has operated a mixed municipal solid waste processing facility (“dirty MRF”) since 1993. Between 140,000 and 150,000 tons/year of MSW is tipped at its Central Processing Facility. Recyclables are removed via manual and automated sorting. Screened two-inch minus fines (the mixed organic waste fraction) are composted with yard trimmings and wood. Compost is used for various landfill applications. Recently, the facility began producing refuse derived fuel pellets from shredded paper and film plastic.

Rapid City, South Dakota: The mixed waste composting plant in Rapid City will celebrate its fifth year of operation next May. The plant has two rotary drums, followed by a nine-bay Siemens/IPS composting system. “We currently process 180 tons of MSW/day, down from 200 tons/day last year,” says Mike Oyler, plant manager. “Our goal is to get a better breakdown of the organic fraction by putting less material through the drums. We are finding that by not overloading the drums, we are getting better separation of the MSW as it has more room to tumble.” The facility co composts the MSW with about 12,000 gallons/day of biosolids. Retention time in the bays is 28 days, followed by secondary composting in aerated piles in an adjacent building. “We decreased the height of these piles, as well as piles of finished compost outside, to 6-feet,” adds Oyler. “That eliminated a lot of odors. We think the piles were going anaerobic.” On occasion, material is put back through the bays for a total retention time of 56 days. “That compost is much darker in color and when we screen it, it looks like wet coffee grounds.”

The media in the biofilter was changed earlier this year; staff decided to use compost screen overs instead of wood chips only. In addition, the biofilter sprinklers were changed from a rotating head with a 30-foot pattern to umbrella head sprinklers that cover a 10-foot area, providing better overall coverage. In addition, operators are building a screen to further refine the finished compost. “We've designed a small vibration unit with a 1/8-inch screen,” says Oyler. “We'd like to market this compost for use on golf courses and to top-dress lawns.” Roughly 40 to 50 tons/day of compost is produced using a 1/8-inch screen. Finished compost is given away. “We are getting great testimonials from area residents who are using the compost on their lawns and gardens,” he adds.

Sevierville, Tennessee: Sevier Solid Waste Inc.'s 15 year-old MSW co composting facility, the largest operating plant in the U.S. in 2006, burned to the ground on May 31, 2007, completely destroying the 102,000 square foot building that housed the tip floor and compost hall. As fully described in the accompanying article, the five rotary drum compost vessels and their hydraulic rams were saved by the Pigeon Forge Fire Department. Pending final terms of the insurance settlement, Sevier Solid Waste Inc. plans to rebuild the facility, expanding it to 180,000 square feet and making significant changes to the materials flow process.

Prior to the fire, the facility was processing 250 tons/day of MSW and 50 tons/day of biosolids. A new Backhus windrow turner had been purchased and was being used to turn and aerate the compost piles; the forced aeration system had been turned off. According to Tom Leonard, Solid Waste Director, the aeration trenches had been a continual maintenance challenge due to clogging of the specially manufactured plastic grates developed by Bedminster Bioconversion when it built the facility. The grates were also prone to being dislodged by the loader bucket as it was turning the piles, and had to be continually replaced.

All of the residential and commercial MSW generated in Sevier County was being processed at the facility, with 60 percent of the total tons converted to compost. The remaining 40 percent residue, mostly plastic, glass and metal, goes to an unlined demolition debris landfill operated on an adjoining parcel of land, thereby diverting the residue from a lined landfill. There is no upfront sort line for recyclables, and after discharge from the digesters the recyclables are too dirty for marketing. In the early years, the facility utilized a belt magnet to pull metals off the residuals, as well as an eddy current separator to extract aluminum. Both streams were shredded and screened to remove dirt. However, neither metal product was sufficiently clean for recycling markets. In 2006, notes Leonard, the facility produced almost 30,000 tons of 1/4-inch screened compost. All of it was sold to a company that markets the materials for soil blending, topdressing and erosion control. The tip fee at the facility is $40/ton, with total costs to process MSW and biosolids, as well as dispose of residue, estimated at $25.34/ton.

Columbia County, Wisconsin: The Columbia County Recycling and Waste Processing Facility has been operating since 1992, and continues to process between 70 and 80 tons/day, although the flow is a bit higher in the summer. There are two rotary drums, each loaded with five yards of material at a time, with a daily capacity of 40 tons (maximum capacity of 250 tons per drum). After five days in the drum, the compost goes through a 15-foot long screen with 3/4-inch holes. The compost is then put into windrows for eight weeks, and is finally screened to 3/8-inch. About 3,000 tons/year of compost is produced. It is given away at no cost to local farmers.

According to Bill Casey, the facility manager, national waste companies have been purchasing the independent haulers in the county, including those servicing municipalities. These companies also own the landfills, and with an inside market, they are able to undercut the $34/ton tip fee at the MSW composting facility, making it increasingly difficult to maintain the throughput. "We had to go out and do our own collection; we offer curbside collection in certain areas," says Casey.

C4.2.5 CONCLUSION

MSW composting continues as a "niche" type conversion technology, gaining hold in smaller communities, by and large, and one with a certain environmental ethic. The difficulty in providing a final product of high quality, free of contamination continues to be an issue. Likewise, overcoming the negative public perception regarding products derived from MSW has proved difficult. Economics have been adversely affected by this inability to build final product value.

However, the simplicity of these systems still continues to amaze and should stronger markets develop over time, MSW composting could realize a resurgence.

C5.0 HYDROLYSIS

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

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

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

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

Hydrolysis of cellulosic feedstocks, including MSW, is not commercialized yet in the U.S. However, several major companies are pursuing these technologies for use primarily with feedstocks such as: energy crops (i.e., switchgrass), agricultural residues (i.e., corn stover), forest residues, and greenwaste and woodwaste from the MSW wastestream.

Most notable of these locally is BlueFire Ethanol who just received their Land Use Permit and CEQA clearance for a plant near Lancaster, CA. This plant will convert 200 tpd of low-grade greenwaste and woodwaste into 3.2 million gallons per year of fuel grade ethanol.

C5.1 MASADA OXYNOL

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

Masada's owner, who closely managed the OxyNol business venture and the Middletown, NY plant development passed away in 2005. Further development work was suspended while the company sought strategic investors and management support. Subsequently, ownership issues were resolved and the project began to move forward. Significantly, the New York State Part 360 Solid Waste Permit and the Title V Air Operating Permit, which were obtained during project development and allow construction of the facility, were renewed. Construction of this facility is planned to start in 2008. Masada is also pursuing international projects. In November 2007, Masada entered into a joint-venture agreement with a privately-owned group of waste management companies in the Dominican Republic, and has proposed at least one project in that Country.

C6.0 MECHANICAL PROCESSING

C6.1 INTRODUCTION

Autoclaving of medical waste for sterilization before disposal has long been practiced throughout the U.S. However, in recent years, a much broader, larger, and innovative application has emerged as a process for MSW. Mixed residential and commercial MSW or post-MRF residue is "pressure cooked" with steam in large, rotating super drums up to 25 ft in diameter and 100 ft long. This facilitates subsequent separation of organic biomass (processed paper, cardboard, foodwaste, etc.) from inorganic (glass, metal, plastic, textiles, etc.).

Autoclaving can be viewed as a "pre-processing" step for following conversion technologies (CT). The importance of producing a high-quality, homogeneous organic feedstock for CT plants, all of which focus on the organic component of MSW, should not be overlooked. In fact, one of the greatest challenges facing the application of CT to MSW and MRF residuals is feedstock preparation.

Overall diversion of 70-90% can be achieved depending on the quality of the MSW feedstock and ability to market all the products.

The process involves the following steps:

- Autoclaving of "as received" or "post MRF" MSW (no shredding or pre-processing is necessary except removal of bulky items)
- Screening to separate organic and inorganic fractions
- Sorting of traditional recyclables
- Further processing of biomass (several alternatives listed below)
    - Cleaning to recover paper fiber for recycling at paper mills
    - Anaerobic digestion for power, fuel and compost production
    - Gasification for heat and power generation
    - Hydrolysis for ethanol production
    - Wastewater treatment and discharge to sewer

Three firms are currently active in the U.S.:

- Comprehensive Resources (CR3) (Salinas, CA)
- CES Autoclaves (University of Alabama)
- Tempico (Hammond, LA)

A fourth developer, World Waste International (WWI), actually constructed a 500 tpd autoclave plant at the CVT Transfer Station in Anaheim, CA. This plant featured two 12-ft diameter autoclaves designed to process up to 500 TPD of mixed commercial and "post MRF" residue that was disposed at the Olinda Landfill in Brea, CA. The recovered paper fiber was dewatered to "wet lap" quality and sold to a local paper mill for manufacturing into new paper products, predominantly corrugated medium. WWI has since changed strategies and is pursuing thermal processing for power generation. The autoclaves are no longer part of their plans.

C6.2 COMPREHENSIVE RESOURCES (CR3)

CR3 ran a demonstration plant in Reno, NV for several years. This setup included not only the autoclave, but a biomass cleaning system to recover clean paper fiber. In 2006-2007, the autoclave was moved to the Crazy Horse Landfill in Salinas, CA for further demonstrations under the auspices of the Salinas Valley Solid Waste Authority. The autoclave started operating there in late 2007 and conducts demonstration runs approximately once a month. It is currently undergoing air emissions testing.

The 6-ft diameter rotating and articulating autoclave can process over one ton of MSW over a two hour cycle. The focus now is on processing MSW and agricultural wastes with the intent of hydrolyzing the resultant biomass to make fuel-grade ethanol. This is a change from the original strategy of pulp recovery for sale to paper mills. The autoclave team is participating in a comprehensive R&D agreement with the Department of Agriculture lab in Richmond, CA where the biomass hydrolysis work is being conducted.

One future plan includes the development of a full-scale commercial autoclave plant (2,000 TPD) at the Johnson Landfill in Salinas County, where it would be part of a "Resource Management Park".

StereCycle was granted the CR3 license for the UK and portions of Europe. They have secured substantial investment capital from Goldman Sachs and others totaling over 70 million British pounds. They have constructed two 9-ft diameter autoclaves and are pursuing several locations for projects in the UK. The autoclaved, screened, and dried biomass would be used for soil conditioner and boiler fuel.

C6.3 CES AUTOCLAVES (UNIVERSITY OF ALABAMA)

CES is a new company formed from World Waste International participants by the original MSW steam autoclave developer, Professor Michael Eley of the University of Alabama. CES is currently working with Rainbow Disposal of Huntington Beach, CA to construct a 10 TPD pilot plant at Rainbow's MRF/transfer station. The focus of the process is to convert MRF residual now going to landfill disposal into a biomass feedstock for conversion to ethanol. The latter technology will be supplied by Clean Earth Solutions, a dilute 2-stage acid hydrolysis process.

Rainbow anticipates the pilot plant will be operational in the summer of 2008.

C6.4 TEMPICO (HAMMOND, LA)

Tempico, Inc. was formed in 1990 to commercialize patented technology utilizing pressure and steam within a rotating autoclave registered as the ***Rotoclave*®.** The technology is being used in the medical waste processing field currently, with other exciting applications underway. Over 110 Rotoclaves are operational worldwide processing medical waste.

The *Rotoclave*® technology offers the opportunity for volume reduction of Municipal Solid Waste (MSW) to landfills, potentially reducing the volume by approximately 50% without the need for grinding. Beyond volume reduction, the Tempico system provides the ability for further biomass processing as described earlier in this appendix section.

The Rotoclave® system utilizes a pressure vessel with a unique rotating internal drum that accepts waste materials and subjects them to agitation, heat, and moisture. The combination of high temperature, pressure and moisture, in conjunction with the unique method of agitation ensures all materials will contact the necessary sterilizing steam.

The Company is hopeful that its first system of four 12' diameter, 50' long vessels for processing MSW will be contracted for installation in the Dominican Republic sometime in the 1st quarter 2008. A project in New Jersey is also in development.

Tempico has chosen to remain "technology neutral" and is working with cellulosic ethanol, gasification, recycle fiber and cellulosic-derived specialty chemical vendors on one front while developing long term sources of MSW on another. The company has performed tests relative to recycle fiber with major paper companies since the early 1990s and more recently with other conversion technology vendors.

Tempico has a commercial dilute acid hydrolysis cellulosic ethanol facility teaming opportunity under way, and will be setting up a 1,000 pound per batch Rotoclave and associated downstream recycling equipment at a landfill in the next two or three months in order to produce MSW derived pulp for testing over a long period of time.

C6.5 CONCLUSION

At present, there are no commercial scale MSW autoclave systems in the U.S. The one such plant that was constructed, WWI in Anaheim, has since been closed down due to a change in corporate focus and strategy. The main reason given is that it was not cost effective to recover fiber for sale to paper mills, which are in decline in the U.S. However, WWI states that the autoclaves themselves worked.

From the current direction of all three autoclave companies it is clear that the focus is on production of fuels and energy from the biomass, and that the autoclave is functioning as a "feedstock processing" system. This is not to be taken lightly, as feedstock preparation is one of the critical elements for any type of MSW conversion.

One issue which faces developers of the autoclave is conflicting patent claims, which have loomed in the past, and may become more complex and difficult when the first commercial plants go into development.

C7.0 CHEMICAL PROCESSING

Chemical processing technologies use one or a combination of various chemical means to convert MSW into usable products, often uniquely encompassing aspects of other conversion processes such as digestion and gasification. An example of a chemical processing technology is depolymerization, which is the permanent breakdown of large molecular compounds into smaller, relatively simple compounds.

Depolymerization is thermal in nature, but instead of a single thermal reaction step it involves a number of complex and interrelated processing steps, some similar to petroleum refining. In simplified terms, the process is an advanced thermal process that utilizes water as a solvent, converting the organic fraction of MSW into energy products (steam and electricity), oil and specialty chemicals. Following up-front sorting to remove recyclables and inorganics, the major steps of the depolymerization process are: (1) pulping and slurrying the MSW with water; (2) heating the slurried MSW under pressure; (3) quickly lowering, or "flashing" the slurry pressure to release and recover gaseous products (which can be converted to light hydrocarbons or used to generate electricity); (4) reheating the slurry to drive off water and light oils from the solids; and (5) separating the light oils from the water. Further processing of the oils (e.g., distillation, solvent extraction, cracking) can be used to produce higher-value oils, equivalent to #4 and #2 oil products. The process also generates carbon solids, which could be activated and used as a filter medium or as a soil amendment.

A company that offers thermal depolymerization is Changing World Technologies (CWT). CWT is headquartered in West Hempstead, New York, and is the developer of a conversion technology that creates renewable diesel fuel from feedstocks that are ordinarily considered to be wastes. The CWT technology was first developed to make useful energy products from animal and food processing wastes. CWT has also invested in significant research and development work to evaluate the feasibility of processing auto shredder residue and components of municipal solid waste (MSW). The system can in theory co-process sewage sludge along with other wastes, although there may be limitations on the proportionate quantity that would make technical and economic sense in a multi-waste feedstock to a CWT facility. CWT is actively pursuing development of commercial scale plants using food processing wastes as feedstocks in other locations. Concurrently, major development investment is being made to advance experience with auto shredder residue and mixed MSW.

CWT has two reference facilities. The larger facility (248 tpd) is located in Carthage, Missouri and has been operated by Renewable Environmental Solutions, LLC (RES) since the year 2005 with poultry processing waste as a feedstock. The smaller, pilot facility (7 tpd) is located in Philadelphia, Pennsylvania, and has been used for research and development activities since the year 2000. The pilot facility is operated by Thermo Depolymerization Process, LLC (TDP).

C8.0 LOCAL CONVERSION TECHNOLOGIES VENDORS

Several local companies have approached the City of San Diego with Conversion Technologies for consideration under the long-term strategic planning process. These companies are:

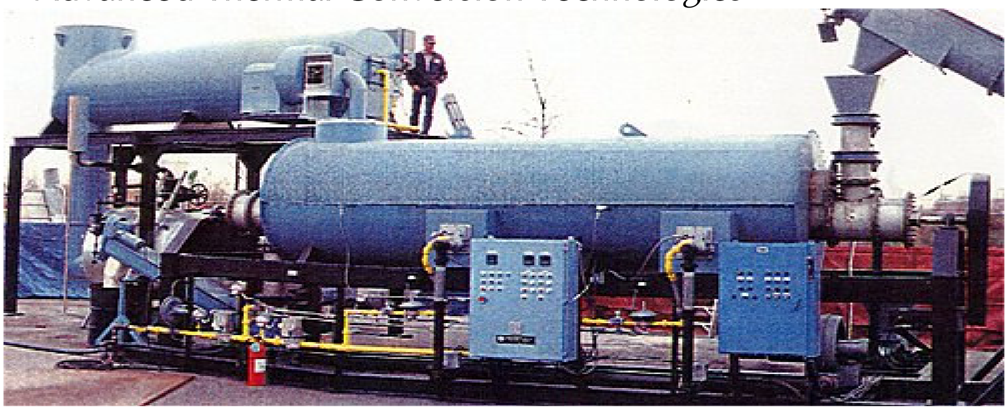
- AdaptiveARC (formerly AdaptiveNRG)
- Balboa-Pacific Corporation
- Envirepel Energy
- Max Products
- Reg Renaud (STI Engineering)
- World Waste International

Brief discussions of each of these vendors are given below.

C8.1 AdaptiveARC (Kris Skrinak, Managing Partner (858) 525-1133)
See Section C3.6 for a discussion of the plasma arc technology and their current primary project in development, a demonstration plant in Santa Cruz, CA. The company also met with LRMO team representatives discussing the possibility of a sole source 200 TPD project that would be constructed by AdaptiveARC and owned and operated by the City of San Diego.

C8.2 BALBOA PACIFIC CORPORATION (JAMES O. BOYLAN, CEO (858) 259-7621) [WWW.BALBOA-PACIFIC.COM]

"Advanced Thermal Conversion Technologies"



Pyrolytic Gasification

Balboa Pacific Corporation has developed the Bal-Pac Thermal Conversion Pyrolytic Gasification System shown above. It works as a continuous feed waste treatment technology that causes the destructive distillation of toxic or non-toxic organic material, either solid or liquid substances, reducing the feedstock to a sterile ash and hot exhaust gases. Balboa's Pyrolytic Gasification destroys 99.9 percent of the toxic elements found in any feedstock and is cost effective in its application to waste management. The emissions and leachate are non-hazardous and non-toxic. Balboa has received acceptance of its technology by the Environmental Protection Agency (EPA) and the South Coast Air Quality Management District (AQMD), based on past operations. They do not currently have a facility operating.

Balboa's gasification system can use a variety of waste streams for power production once they have been modified to a certain size and form. For example, whole tires must be shredded into two-inch chips prior to introducing into the system. The moisture content in sewage sludge and other toxic liquids or waste materials having high oxygen content will need to be dehydrated prior to system introduction. A Material Recovery Facility (MRF) that utilizes this system will need to be *waste-stream* specific in design.

For several years back in the 1980's, Balboa Pacific operated a demonstration plant in Santa Fe Springs, CA that processed primarily hazardous waste. This plant was closed down years ago, however, while it was running and during subsequent pilot demonstrations, various aspects of the operation were validated by independent engineering firms including Dames & Moore and Pacific Environmental Services. See the Balboa Pacific website for details.

The company has recently re-surfaced with new management, new focus and new backing. In a meeting with LRMO team representatives, Balboa Pacific proposed to the City of San Diego to build and operate a 50 TPD MSW pyrolysis facility at the Mirimar Landfill at their own cost. The facility would process material excavated from an existing cell at the landfill, including the dirt. The facility would require about 5 acres and would generate about 1 MW of power as well as a carbon char by-product that would be sold, and which would also produce carbon credits.

C8.3 ENVIREPEL ENERGY, INC.
www.envirepel.com

Envirepel Energy Inc.'s business plan focuses on a combination of small local biomass gasification facilities in combination with larger regional facilities. They are in the process of developing, permitting and constructing their “Max Power" combustion system, which will generate clean renewable energy from wood waste and green waste for sale to San Diego Gas & Electric Company. Technically, this is not a “Conversion Technology” as their feedstock is not MSW, but separated and ground greenwaste and woodwaste. There are roughly 20 such facilities already operating in California by other companies.
Roughly 250 MW of renewable energy would be generated in San Diego County at Envirepel’s two proposed sites.
Kittyhawk (Vista, CA) is a demonstration facility that will serve as a testing, financial and operating model for future projects. The project requires the delivery of pre-ground wood chips and greenwaste from various waste haulers located outside of the City of Vista. The facility is anticipated to consume approximately 96 tons of green and wood waste in a 24- hour period, or 672 tons per week. The plant will generate 1.75 MW of power which could provide electricity to over 1,000 homes. The plant is anticipated to begin operation in the Spring of 2008.
The Company anticipates that the electricity produced at the Facility will be used to operate some of the ceramic curing ovens and other manufacturing equipment, with the surplus sold to San Diego Gas and Electric Companies on an "as available" basis. This allows the use of the Facility as a true "cogeneration" unit for the manufacturing of ceramics for other combustion units, at effectively one-third the cost for electricity. The Facility is designed to export to the local service (12 KV) grid approximately 1.5 MW on a continuous basis with only minor down time (95% uptime). The Kittyhawk Renewable Energy Facility is also certified under the State of California's Renewable Portfolio Standard.

The Facility is being constructed in one half of the Company's 42,000 square foot industrial location in Vista, California. The City of Vista issued a special use permit for the commercial operation of the Facility (selling electricity to SDG&E), with the manufacturing and construction of the system as an allowed use under the existing industrial zoning codes.

All fuel for the Facility is expected to come from a radius of less than 20 miles. The Company believes that approximately 60,000 tons of suitable fuel material will be available for the Facility each year in this small radius. This fuel is typically from tree trimmings and clean wood sources. Kittyhawk is not permitted to run on grass clippings. The fuel material can be delivered to the Facility as opposed to the surrounding landfills, allowing existing landfill space to be utilized for materials that are truly not recyclable, thereby extending the life of the landfill.

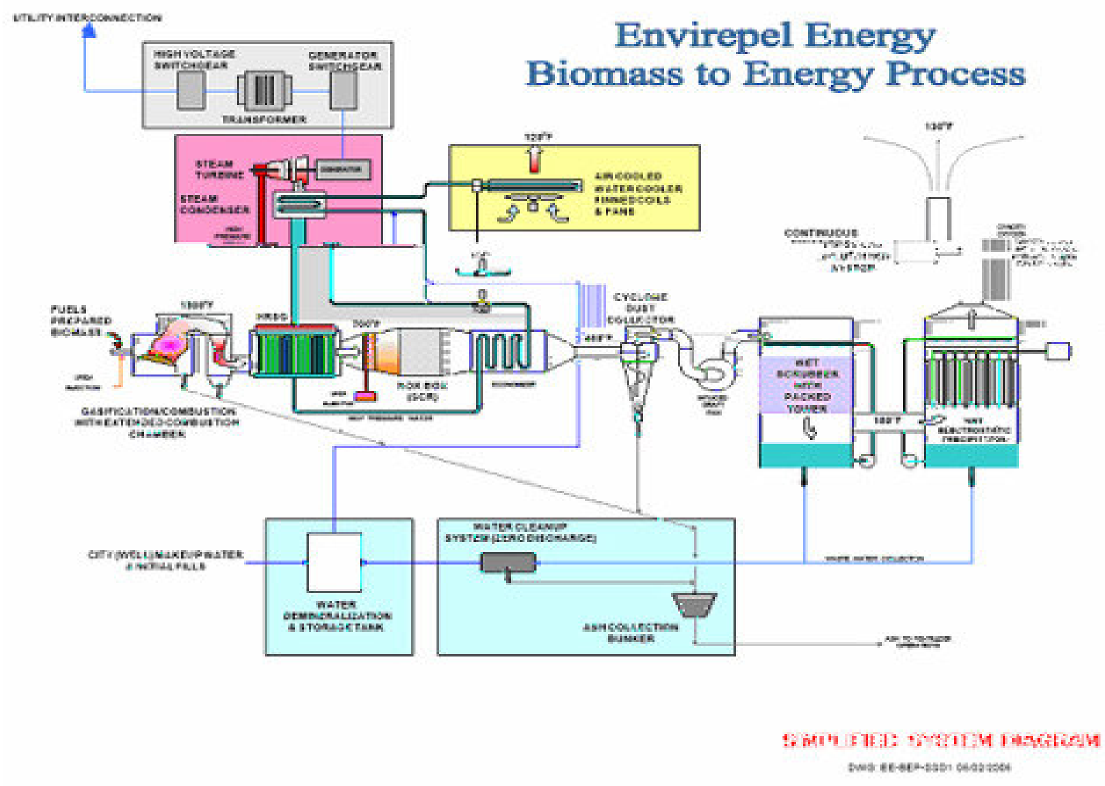
The Fallbrook Renewable Energy Facility (FREF) (Fallbrook, CA) will convert biomass materials that would normally go into landfills, into thermal and electrical energy through a combustion and gasification process The facility is designed to export to the grid approximately 67 MW on a continuous basis.

The FREF Facility is planned to have 12 individual combustion units. Ten will be active and two will be spares for maintenance rotation and reliability purposes. The combined rating for the twelve boilers and twelve combustion units is approximately 1,000,000 lbs. per hour of 650 psig steam. These units will generally operate in the range of 60%-100% of capacity, which the Company believes will ensure the low emissions desired for this overall effort. The steam will be used to turn three identical 30MW generators.

Artist Rendition

As with any steam/electric generating system there is a considerable amount of thermal energy available that cannot be converted into electricity. This otherwise wasted thermal energy will be captured in a water heating system. This water heating system will provide thermal energy to aid in growing organic crops in an agricultural complex that is to be adjacent to the biomass energy facility.

The fuel for this facility and all subsequent energy production will be from the surrounding community. The fuel will be biomass related materials that are presently going into nearby landfills. All fuel for this facility will be drawn from the greater San Diego County area. There is approximately 1.1 million tons a year of sustainable fuel materials available to this facility in the San Diego County Area.



Envirepel Energy plans to be the first company in the State of California to design, construct, and operate a commercial scale thermal conversion facility when they build the MSW- fueled Ramona Renewable Energy Facility (RRFF) at the Ramona Landfill. RREF is designed to generate electrical energy from onsite waste streams including MSW, agricultural and residential green waste sources, construction and demolition materials, and non-recyclable plastics/paper and wood waste.

C8.4 MAX PRODUCTS

Max Products has plans to process landfill gas into methanol for vehicle fuel additive. Contact information was unavailable for this company.

C8.5 REG RINAUD (STI)

STI proposes a steam injection system for enhanced landfill gas recovery and to accelerate material decomposition and ultimate stability of the Miramar Landfill. A demonstration test was recently performed at the landfill. Results showed that at this time the process is not economically feasible as the dry landfill material required substantially more steam than originally calculated. The Phase I Long-Term Resource Management Options Strategic Planning report for the City of San Diego discusses the project in more detail.

C8.6 WORLD WASTE INTERNATIONAL, INC. (John Pimintel, CEO, (650) 269-8933)
www.worldwasteintl.com website

World Waste International (WWI) began in 2002 focused around an autoclave technology that recovered paper fiber from mixed MSW and MRF residue. The Company was successful in raising over $20 million in capital to build the first commercial autoclave plant in the U.S. at the CVT transfer station in Anaheim, CA. Construction was completed in 2005.

This plant featured two 12-ft diameter autoclaves designed to process up to 500 TPD of "post MRF" residue that was being disposed at the Olinda Alpha Landfill in Brea, California. The recovered paper fiber was dewatered to "wet lap" quality and sold to local paper mills for manufacturing into new paper products, predominantly corrugated medium.

Through operation of the plant, WWI realized that it was not economical to recover fiber so they shut the plant down in late 2006. Since then, they have changed strategies and are pursuing thermal processing of biomass for power generation (gasification, pyrolysis, plasma arc). They are currently performing due diligence on a variety of thermal technologies. The autoclaves are no longer part of their plans.

Several large New York investment firms have invested in WWI, with more than $50 million raised for facility development. In the future, the company plans to further enhance project economics by converting biomass into fuel-grade ethanol; however, their research shows that technologies for power generation are currently more mature and thus offer better near-term prospects.

C9.0 ECONOMIC REVIEW OF ADVANCED CONVERSION TECHNOLOGIES

A key consideration in determining the commercial viability of any conversion technologies, and their feasibility as alternatives to continued landfilling, will be the tipping fees. Tipping fees, in turn, are highly sensitive to project-specific and site-specific factors such as site development costs, local construction market conditions, regulatory and permitting requirements, residue transportation and disposal costs, the strength and stability of electricity and local product and material markets, and transportation costs for delivery of products to final locations. For purpose of this review, the following factors relating to economics have been considered:

- **Information Sources.** In the past few years, several studies have generated cost and revenue data regarding advanced conversion technologies (specifically, thermal processing and anaerobic digestion technologies), for both small- and large-scale demonstration and commercial facilities in the United States. Information from ARI's September 2004 and March 2007 studies and reports for New York City and from ARI's October 2007 study for

Los Angeles County, CA (Los Angeles County Conversion Technology Evaluation Report - Phase II), which represents some of the most current information that is publicly available, is summarized in this report, along with other published information.

- **Planning Perspective.** Since the technologies considered in this report are not yet in commercial operation in the United States, information on capital and operating costs is generally available only on a planning-level basis. While such estimates are only at a level of detail and accuracy commensurate with planning efforts or initial feasibility studies, the information is instructive to the degree that the analyses result in order-of-magnitude cost and tipping fee estimates. Although such estimates should not be considered as definitive as those that would result a formal procurement or from in-depth project-specific feasibility studies, they are useful in providing estimates of what reasonably could be expected of individual technologies and, in the first instance, can serve as one factor in determining which technologies or categories of technologies may be appropriate for further consideration in subsequent comprehensive planning work.

- **Analytical Assumptions.** In the studies referenced above (i.e., New York City and Los Angeles County), the participating technology suppliers were asked to provide capital and operating cost estimates, as well as performance data such as net energy produced for sale and the types and volumes of materials that could be recovered and sold. The amount of electricity generated and the volume of materials recovered for each technology were confirmed through ARI's independent reviews of the mass and energy balances that were provided by technology sponsors. Based upon these analyses, the amounts of products (i.e., the energy generated and the secondary materials recovered) - - and therefore project economics - - vary between the technologies, depending upon technology-specific considerations.

- **Cost/Benefit Considerations.** In considering alternatives to landfilling, it can be expected that direct costs would be only one aspect of an overall cost/benefit analysis, which might take into account additional considerations such as:

    - statutory imperatives and local policies and objectives regarding environmental concerns, particularly regarding recycling, renewable energy generation and waste diversion from landfills;

    - the long-term reliability of any advanced conversion technologies that might be considered for an identified project;

    - the actual costs that might result from formal, guaranteed price proposals solicited through a procurement, when compared to planning-level estimates;

- the long-term outlook for energy and materials markets and the affect of market uncertainties on project economics; and,
- the prospect for the continuation of landfilling long-term, as influenced by regulatory, economic and policy matters.

The following subsections provide summaries of estimated project costs and resulting tipping fees, as derived from information provided by various technology suppliers. As summarized below, there is significant variation in capital and operating costs, both within individual technology types and between disparate technology types.

C9.1 THERMAL PROCESSING

Economic information for thermal processing technologies has been published as a result of studies conducted by New York City (ARI, March 2007) and Los Angeles County (ARI, October 2007). New York City data was based on cost and revenue information in 2005 dollars, with a projected first-year tipping fee for the year 2014. This planning-level analysis is summarized in Table C9-1. Los Angeles County data was based on cost and revenue information in 2007 dollars, with a projected first-year tipping fee for the year 2007. This planning-level analysis is summarized in Table C9-2.

TABLE C9-1
THERMAL PROCESSING - SUMMARY OF PROJECTED FIRST-YEAR TIPPING FEES FOR NEW YORK CITY (2014)

Technology Supplier	Facility Capacity (tpd)	Construction Cost ($2005, millions)	Annual O&M Cost ($2005, millions)	Annual Revenues ($2005, millions)	Projected Tipping Fee ($/ton, 2014)	
					Private Ownership and Financing	Public Ownership and Financing
Ebara	2,959	$762.6	$31.5	$43.8	$141	$96
GEM	2,758	$468.2	$52.2	$54.1	$134	$104
IWT	2,612	$405.7	$51.1	$46.7	$103	$76
Rigel	2,729	$876.5	$166.8	$203.8	$165	$129

TABLE C9-2
THERMAL PROCESSING - SUMMARY OF PROJECTED FIRST-YEAR TIPPING FEES FOR LOS ANGELES COUNTY (2007)

Technology Supplier	Facility Capacity (tpd)	Capital Cost ($2007, millions)	Annual O&M Cost ($2007, millions)	Annual Revenues ($2007, millions)	Projected Tipping Fee ($/ton, 2007) Private Ownership and Financing
IES	242.5	$30.1	$2.7	$3.3	$56
IWT	312	$75.2	$11.0	$7.9	$131
IWT	623	$126.4	$16.9	$19.6	$71
IWT	935	$170.4	$24.6	$29.4	$59
Entech	413	$56.6	$6.8	$6.3	$55

C9.2 ANAEROBIC DIGESTION

Economic information for anaerobic digestion technologies has been published as a result of studies conducted by New York City (ARI, March 2007) and Los Angeles County (ARI, October 2007). New York City data was based on cost and revenue information in 2005 dollars, with a projected first-year tipping fee for the year 2014. This planning-level analysis is summarized in Table C9-3. Los Angeles County data was based on cost and revenue information in 2007 dollars, with a projected first-year tipping fee for the year 2007. This planning-level analysis is summarized in Table C9-4.

TABLE C9-3
ANAEROBIC DIGESTION - SUMMARY OF PROJECTED FIRST-YEAR TIPPING FEES FOR NEW YORK CITY (2014)

Technology Supplier	Facility Capacity (tpd)	Construction Cost ($2005, millions)	Annual O&M Cost ($2005, millions)	Annual Revenues ($2005, millions)	Projected Tipping Fee ($/ton, 2014)	
					Private Ownership and Financing	Public Ownership and Financing
Arrow	586	$43.3	$4.2	$7.3	$56	$43
WRSI	500	$41.0	$2.9	$3.3	$80	$65

TABLE C9-4
ANAEROBIC DIGESTION - SUMMARY OF PROJECTED FIRST-YEAR TIPPING FEES FOR LOS ANGELES COUNTY (2007)

Technology Supplier	Facility Capacity (tpd)	Capital Cost ($2007, millions)	Annual O&M Cost ($2007, millions)	Annual Revenues ($2007, millions)	Projected Tipping Fee ($/ton, 2007) Private Ownership and Financing
Arrow	300	$20.9	$1.9	$3.0	$50

Regarding Aerobic Digestion (composting) of MSW, tipping fees vary widely depending on key market influences including:

1. the costs of collection and hauling,
2. disposal tipping fees,
3. quality of feedstock,
4. cost of labor and materials
5. availability and cost of funding,
6. market size and pricing for final product, and
7. regulatory compliance costs

The outstanding questions regarding MSW composting are the quality and marketability of the final product. The net cost is strongly impacted by the cost of residue disposal and the value and marketability of the finished compost.

Typical tip fees for MSW compost facilities in the U.S. vary from roughly $35 to $90 per ton, with most in the $40 to $75/ton range.

C9.3 HYDROLYSIS

Hydrolysis technologies are not yet in commercial operation for MSW. However, the technology is advancing to commercial application in the United States, with a waste-to-ethanol hydrolysis facility under development in Middletown, New York. A limited review of Masada's technology was provided based on information reported by Masada for the New York City Phase 2 Study (ARI, March 2007). The facility under development is proposed to process 230,000 tpy of MSW and 422,000 tpy of sewage sludge, along with significantly smaller amounts of other waste materials (i.e., waste paper, septage, and leachate). The project delivery approach is design/build/own/operate (DBOO) with a guaranteed waste supply and tip fee provided by contracted municipalities. The negotiated tipping fee for 2004 was $65 per ton of MSW supplied, escalated at 64% of the Consumer Price Index (CPI). Masada has assumed full responsibility for the marketing of the ethanol and its quality.

C9.4 MECHANICAL PROCESSING

The only commercial autoclave plant to operate on MSW in the U.S. was the 500 tpd WWI facility in Anaheim, CA. While it was operating, the facility received a tipping fee of $35/ton for MRF residual material. This was the rough equivalent of the hauling and landfill disposal cost. However, the plant as designed for recovery of paper pulp was not economically viable, so it is not possible to assess the realistic tipping fee for the Company to have been profitable, but clearly it is well above $35/ton. Other autoclave systems are still in the demonstration phase and do not represent full scale production O&M costs.

With the recent meteoric rise in fuel prices, it is realistic to assume that autoclave O&M costs are likely significantly higher than they would have been just a year ago. The key to the system is to run the autoclaves in pairs, so the heat from the cooling unit can be used to warm to the other. Theoretical calculations at the demo plants show this can save up to 50% of the energy for the system.

In addition, if coupled with thermal Conversion Technologies, the waste heat from that thermal process can be used to pre-heat the autoclaves, thus conserving a significant amount of energy and lowering the cost.

C9.5 CHEMICAL PROCESSING

Changing World Technologies (CWT) is one of the more advanced chemical processing technologies pursuing applications for MSW, but its experience with MSW is limited. As previously noted, CWT has a small (7-tpd) pilot facility that has tested various feedstocks, and a 248-tpd commercial facility with poultry processing waste as a feedstock. CWT provided economic information for a conceptual, 200-tpd demonstration facility for the Los Angeles County Phase II Evaluation (ARI, October 2007), which would process a combination of MSW, auto shredder residue, and fats/oils/grease. Based on information provided by CWT ($2007), capital costs for a 200-tpd demonstration facility would be approximately $35 million, and operating costs would be approximately $9 million per year. Revenues would be derived primarily from the sale of biodiesel, the primary product, and also from the sale of recovered metal and other secondary products. CWT estimated revenues would be on the order of $8.4 million per year. CWT estimated a tipping fee of $60 per ton for MSW and sludge, and $20 per ton for fats, oils, grease and used oil. However, the company projected there would be an annual loss using the estimated tipping fee for the proposed demonstration facility. CWT projected that profitable economics would be achieved with a 1,000-tpd commercial facility.

C10.0 PRELIMINARY SCREENING OF CONVERSION TECHNOLOGIES

Based on information published in recent studies and summarized in this report, a preliminary screening of conversion technologies has been conducted. This preliminary screening has been conducted by category of technology, and not by individual technology supplier. The screening is based on application of the following, project-specific criteria applied to all options considered under the LRMO Strategic Plan:

- **Financial Viability.** Options provide financial support for the City's environmental programs; are economically viable for the City of San Diego and are reasonably competitive with future alternatives.

- **Technical Viability.** Options are technically sound with a proven track record at needed volumes.

- **Regional Viability.** Options and/or technologies are viable (legal, compliant with regulations, and socially acceptable) in the San Diego region and address local needs. Options should consider existing assets, civic structure, geology and climate.

- **Environmental Viability.** Options have minimal impact to CEQA/NEPA environmental parameters and are environmentally beneficial such as providing green energy, renewable fuels, and reduced greenhouse gas emissions.

- **Capacity Optimization.** Options minimize disposal demand and optimize remaining landfill capacity at Miramar.

- **Sustainability.** Options provide for the highest and best use of material generated by the City's residents and businesses.

Table C10-1 presents the results of the screening process.

TABLE C10-1
PRELIMINARY SCREENING OF CONVERSION TECHNOLOGIES

Conversion Technology	Financial Viability	Technical Viability	Regional Viability	Environmental Viability	Capacity Optimization	Sustainability
Gasification & Pyrolysis	Tipping fee ranging from $60-$100/ton	Commercial overseas for MSW in >20 applications; capacities up to 600 tpd	Viable option but public acceptability subject to site-specific determination	Generates electricity and/or fuels; reduces greenhouse gas emissions; low air emissions profile associated with combustion of pre-cleaned synthesis gas	Potential for high diversion from landfill disposal (85% to 100% diversion by weight))	Converts post-recycled MSW and MRF residuals that would otherwise be landfilled into electricity and/or fuels, aggregate, and other products; moderate to high certainty of marketing non-energy products
Anaerobic Digestion	Tipping fee ranging from $40-$60/ton	Commercial overseas for MSW in >10 applications; capacities up to 900 tpd	Viable option but public acceptability subject to site-specific determination	Generates electricity and/or fuels; reduces greenhouse gas emissions; low air emissions profile associated combusting methane-based biogas	Potential for moderate to high diversion from landfill disposal (65% to 85% diversion by weight)	Recovers recyclables and converts post-recycled MSW and MRF residuals that would otherwise be landfilled into electricity and/or fuels and compost; low to moderate certainty of marketing compost for higher uses than alternative daily landfill cover
MSW Composting	Tipping fee ranging from $35-$90/ton	13 plants operating in U.S., mostly in small communities	Issues with marketability of final product, and acceptability related to potential odor	Odor an issue at some facilities. Final product quality and marketability also an issue.	Facility range: 50-250 tpd; high diversion as long as final product can be sold.	Recovers and converts organics for soil amendment. Product marketability and value are key issues.
Mechanical Processing (Autoclave)	Commercial tipping fee not yet established	No commercial plants in operation in U.S.	Shift in focus from pulp recovery to energy generation would be good regional fit.	Minimal impacts in exchange for good pre-processing capability for follow on conversion technologies	WWI plant in Anaheim, CA operated at 500 tpd with 2 autoclaves.	Can process mixed MSW into feedstock for follow-on conversion. Waste heat from a following thermal process can pre-heat autoclaves.
Hydrolysis	Tipping fee ranging from $65-$75/ton	Not yet commercially demonstrated for processing MSW	Viable option but public acceptability subject to site-specific determination	Generates fuel-grade ethanol (a vehicle fuel) and electricity; reduces greenhouse gas emissions; low emissions profile expected from gasification of lignin (a side process)	Potential for high diversion from landfill disposal (90% diversion by weight)	Recovers recyclables and converts post-recycled MSW and MRF residuals that would otherwise be landfilled into fuels and gypsum; moderate to high certainty of marketing non-energy products (gypsum)
Chemical Processing (Depolymerization)	Tipping fee ranging from $50-$90/ton	Not yet commercially demonstrated for processing MSW	Viable option but public acceptability subject to site-specific determination	Generates a synthetic diesel fuel and a byproduct carbon fuel; reduces greenhouse gas emissions; low emissions profile expected for auxiliary boiler used to generate process heat	Potential for high diversion from landfill disposal (90% diversion by weight)	Recovers recyclables and converts post-recycled MSW and MRF residuals that would otherwise be landfilled into fuels; moderate to high certainty of marketing fuels