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*Life Cycle and Market Impact  
Assessment of Waste  
Conversion Technologies  
Executive Summary*

*April 2004*



*Zero Waste—You Make It Happen!*

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# Executive Summary

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## **Background**

New technologies to convert organic and plastic wastes to fuels and electricity are rapidly emerging. To date, one such facility is scheduled for construction in Kings County, California. Assembly Bill 2770 (Chapter 740, Statutes of 2002) requires the California Integrated Waste Management Board (CIWMB or the Board) to prepare a report on these conversion technologies (CTs) to describe and evaluate their potential market and life cycle environmental impacts. These impacts are to be compared to those associated with the existing practice of disposal in landfills, as well as waste-to-energy (WTE) combustion and mixed municipal solid waste (MSW) composting.

CIWMB awarded a contract to an RTI International\* team to perform this work. The RTI team includes CT experts from National Renewable Energy Laboratory, MSW economics and financial experts from Hilton Farnkopf & Hobson, and MSW management and recycling experts from Boisson & Associates. The University of California at Riverside is working under a related contract to evaluate the entire range of different CTs for their feasibility for commercialization in California.

In general, our research sought to answer these primary questions:

1. What are the life cycle environmental impacts of CTs and how do these compare to those of existing MSW management practices?
2. What are the economic, financial, and institutional impacts of CTs on recycling and composting markets?

The focus of this study is on CTs as management alternatives for the *unrecovered* portion of the MSW stream, which is otherwise disposed of in landfills. The goal of this research is to better understand the potential environmental and market impacts that may result from the implementation of CTs, as well as to identify potential tradeoffs of using CTs as alternatives to existing MSW management practices. It is not intended to make definitive conclusions about CTs.

## **CT Descriptions and Scenarios Analyzed**

This study analyzed three CTs using a specified scenario for CT capacity in each of two regions. These are described in the following subsections.

### **CT Descriptions**

The selected CTs are concentrated acid hydrolysis, gasification, and catalytic cracking. These specific technologies were selected because they were identified by the Board as the most promising near-term CTs for MSW in California. Table 1 summarizes information about the technical feasibility, feedstock compatibility, facility integration, environmental burdens, and technology development status for each technology. It should be noted that none of these facilities currently exist in the United States for treating mixed MSW.

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\* RTI International is a trade name of Research Triangle Institute.

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**Table 1. Summary of CT Features**

<b>Feature</b>	<b>Acid Hydrolysis</b>	<b>Gasification</b>	<b>Catalytic Cracking</b>
Technical Feasibility	Yes	Yes	Yes
Feedstock Constraints	Carbohydrate fraction	Carbohydrate fraction, lignin, plastics	Polyolefin plastic only
Possible Product(s)	Ethanol, carbon dioxide (CO <sub>2</sub> ) Electricity, steam, lignin Gypsum	Electricity Heat	Low sulfur diesel Electricity
Environmental Impacts Air Water Solid	Combustion emissions Onsite wastewater treatment (WWT) required Ash, char, gypsum	Combustion emissions Minimal Ash and char	Combustion emissions Minimal rinse water Spent catalyst
Commercial Status	No commercial facilities Masada OxyNol received air permit for a NY facility	Numerous commercial facilities (none for MSW in the United States) Large demonstration facility in Australia	Facility in Poland Kings County, CA, facility in 2004 Several plastic pyrolysis plants in Europe and Asia
Featured Technology Vendor	Masada	Brightstar	Plastics Energy LLC

**Concentrated Acid Hydrolysis.** In acid hydrolysis, an acid (e.g., sulfuric acid) is used to convert carbohydrates (e.g., cellulose and hemicellulose) from waste into five- and six-carbon sugars that can be fermented into ethanol or other useful products. High (i.e., greater than 90 percent) conversions of carbohydrates are possible. Either concentrated or dilute acid can achieve the hydrolysis. Because the concentrated acid process is closer to commercialization than the dilute acid process, it was selected for this study.

The primary product from acid hydrolysis is ethanol. By-products include lignin solids, gypsum, and possibly carbon dioxide. Lignin can be burned in a boiler to create process steam and electricity for sale or process use. Gypsum may be sold for use in a variety of processes, such as wallboard production, road bed stabilization, landfill cover, soil amendment, or land/mine reclamation. If the gypsum cannot be reused, it is landfilled. A large market exists for carbon dioxide.

Two companies, Arkenol and Masada OxyNol™, LLC, are currently commercializing concentrated acid technology. Neither company has a commercial facility, but Masada was awarded an air permit for a facility to process 230,000 tons per year (tpy) of MSW and other wastes in Middletown, NY.<sup>1</sup>

**Gasification.** In gasification, feedstock is converted to syngas, primarily carbon monoxide (CO) and hydrogen (H<sub>2</sub>), in an oxygen-deficient atmosphere. Gasification is endothermic and requires a heat source, such as syngas combustion, char combustion, or steam. The primary product of

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gasification, syngas, can be converted into heat, power, or chemical products, or used in fuel cells. For this analysis, heat and power production are assumed to be the primary uses. The method of heat and power generation varies and can include gas engines, steam cycles, and complex biomass integrated gasifier combined cycle (BIGCC) systems. Numerous large scale biomass gasifiers have been developed and have completed demonstration-scale testing and/or commercial deployment. At least seven technologies were identified as commercially proven on a large scale and were considered for inclusion in this study. Because of the State of California's limiting definition of gasification, which specifies no oxygen introduction to the gasification process, only the Brightstar Environmental Solid Waste Energy Recycling Facility (SWERF) technology was included for further study.

**Catalytic Cracking.** In thermal cracking (e.g., pyrolysis) or catalytic cracking, waste plastics are converted into liquid and gaseous fuels. The addition of catalysts lowers the reaction time and temperature and can increase the selectivity of the products, but catalysts are generally expensive. H.SMARTech, Inc., has developed a commercial process for catalytic cracking of plastic wastes. After shredding, the plastic feedstock is melted and mixed with catalyst. The gaseous products are collected and oil is condensed. The oil is distilled into diesel and gasoline. Noncondensibles (e.g., propane) and gasoline are combusted in a gas turbine to provide process heat and electricity. The diesel fraction is shipped offsite. The catalytic cracking technology is designed for polyolefin plastics (e.g., grocery bags or agricultural film), a narrow spectrum of feedstocks. Other components (e.g., polyvinyl chloride [PVC]) must be removed before processing. H.SMARTech commercialized a polyolefin chemical recycling process in 1998 in Zabrze, Poland. The facility is the largest catalytic cracking plastics recycling plant in the world, with a capacity of 145,000 tpy of mixed plastics.<sup>2</sup> H.SMARTech formed Plastics Energy LLC to build a 50 ton per day (tpd) (expected to expand to 100 tpd) facility in Kings County, California, by the end of 2004.<sup>3</sup> Other companies (e.g., Ozmotech<sup>4</sup>) have plastics pyrolysis facilities in Europe and Asia.

### **CT Scenarios Analyzed and Key Assumptions**

The life cycle and market impact assessments are based on predefined future waste management scenarios in the greater Los Angeles and San Francisco Bay regions. These regions and scenarios were defined by CIWMB in the request for proposals for the study. Developing the most probable projected growth scenario for CT was not part of the study and should not be inferred from these scenarios.

CTs are incorporated at varying capacities from the base year of 2003 to 2010 as follows:

#### **2003 (Base Year)**

- Three 500 tpd acid hydrolysis facilities in each region (1,500 tpd total)
- Four 500 tpd gasification facilities in each regions (2,000 tpd total)
- One stand-alone 50 tpd catalytic cracking facility in each region.

#### **Years 2004 to 2010**

- One additional 500 tpd gasification plant built in each region in the year 2005
- Two additional 500 tpd acid hydrolysis plants built in each region in 2007
- One additional 500 tpd gasification plant built in each region in 2010.

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It is assumed that the CT facilities will be colocated at materials recovery facilities (MRFs). Other assumed transportation distances between various facilities included in the scenarios are shown in Table 2.

**Table 2. Transportation Distance Assumptions**

Type of Facility	Distance (miles)
<b>Waste Management Facilities</b>	
Collection to MRF/CT Facility	15
Collection to Transfer Station	15
Collection to Landfill or WTE or Compost	15
Transfer Station to Landfill or WTE or Compost	45
MRF/CT or WTE or Compost Facility to Landfill	25
<b>Remanufacturing Facilities</b>	
Aluminum	500
Glass	200
Paper	250
Plastic	250
Steel	500

**CT Feedstock Assumptions**

Table 3 summarizes the assumed annual capacities and incoming waste needs based on the composition (see Table 4) of waste landfilled in the Los Angeles and San Francisco Bay regions. The Greater Los Angeles region includes the counties of Los Angeles, Orange, Riverside, and San Bernardino. The San Francisco Bay region includes the counties of Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Solano, Marin, Napa, and Sonoma.

It is important to remember that CT facilities are handling waste material that is currently being (and will otherwise be) sent to landfills for disposal. Since the CT facilities can only accept certain materials in their process, they employ up-front material separation activities similar to those found in a mixed waste MRF (with the exception of a few pieces of specialty equipment, such as autoclaves and floatation separation systems). For this study, we assumed that 95 percent of the incoming unwanted materials were removed by the up-front separation and that 5 percent enter the CT process as contaminants. Of the material removed, we assumed the split between recovery for recycling versus landfill disposal as listed in Table 5.

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**Table 3. Assumed Annual Capacities and Incoming Waste Needs**

<b>Technology</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>
<b>Tons Per Year (based on 329 operating days per year)</b>								
Acid Hydrolysis	493,500	493,500	493,500	493,500	822,500	822,500	822,500	822,500
Gasification	658,000	658,000	822,500	822,500	822,500	822,500	822,500	987,000
Catalytic Cracking	16,450	16,450	16,450	16,450	16,450	16,450	16,450	16,450
Total	1,167,950	1,167,950	1,332,450	1,332,450	1,661,450	1,661,450	1,661,450	1,825,950
<b>Required Incoming Tonnage Before Sorting—Greater Los Angeles Area</b>								
Acid Hydrolysis	630,176	629,260	629,260	629,260	1,048,766	1,048,766	1,048,766	1,048,766
Gasification	737,681	734,863	918,579	918,579	918,579	918,579	918,579	1,102,294
Catalytic Cracking	1,092,230	1,092,230	1,064,427	1,064,427	1,064,427	1,064,427	1,064,427	1,064,427
Total	1,367,857	1,364,123	1,547,839	1,547,839	1,967,345	1,967,345	1,967,345	2,151,060
<b>Required Incoming Tonnage Before Sorting—San Francisco Bay Area</b>								
Acid Hydrolysis	641,780	643,525	643,525	643,525	1,072,542	1,072,542	1,072,542	1,072,542
Gasification	754,643	754,475	943,093	943,093	943,093	943,093	943,093	1,131,712
Catalytic Cracking	1,078,636	1,078,636	1,118,529	1,118,529	1,118,529	1,118,529	1,118,529	1,118,529
Total	1,396,423	1,398,000	1,586,618	1,586,618	2,015,635	2,015,635	2,015,635	2,204,254

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**Table 4. Assumed Percent Composition of Waste Sent to CT Facilities<sup>a</sup>**

Component	Los Angeles		San Francisco	
	2003	2004–2010	2003	2004–2010
Paper	32.5	31.5	32.2	31.6
Plastic	11.5	11.7	10.8	11.1
Metals	7.6	7.3	9.6	9.6
Glass	3.8	3.7	3.9	3.9
Organics	42.8	43.9	41.6	41.9
Miscellaneous	1.9	1.8	1.9	1.9

<sup>a</sup> It was assumed that construction and demolition, industrial, and hazardous waste would not be sent to CT facilities.  
 Note: values may not sum to 100 percent due to rounding.

**Table 5. Assumed Percent of Material Recovered for Recycling and Landfill Disposal**

Disposition	Glass	Paper	Plastic	Metals
Recovered and Recycled	50	50	50	70
Removed and Landfilled	45	45	45	25
Unremoved (Process Contamination)	5	5	5	5

## **LIFE CYCLE ASSESSMENT**

AB 2770 included the requirement that CIWMB’s report on CTs “describe and evaluate the life cycle environmental and public health impacts of CTs and compare them with impacts from existing solid waste management.”

To meet this requirement, a life cycle assessment (LCA) was conducted for the selected CTs. Our general approach was to develop mass balance and life cycle inventory (LCI) modules for the selected CTs and use RTI’s Municipal Solid Waste Decision Support Tool (MSW-DST) to capture the other life cycle components (e.g., collection, transfer, materials recovery, compost, combustion, landfill), energy production, transportation, and materials production activities.

An LCA is not a risk assessment, but rather shows the difference in total energy consumption and emissions of proposed CT scenarios as compared to baseline scenarios of landfill disposal and WTE. Concentrations of pollutants at a given time and location are not captured by an LCA. A study to identify concentrations would need to be site-specific and is outside the scope of this effort.

### **Life Cycle Inventory Modules for CTs**

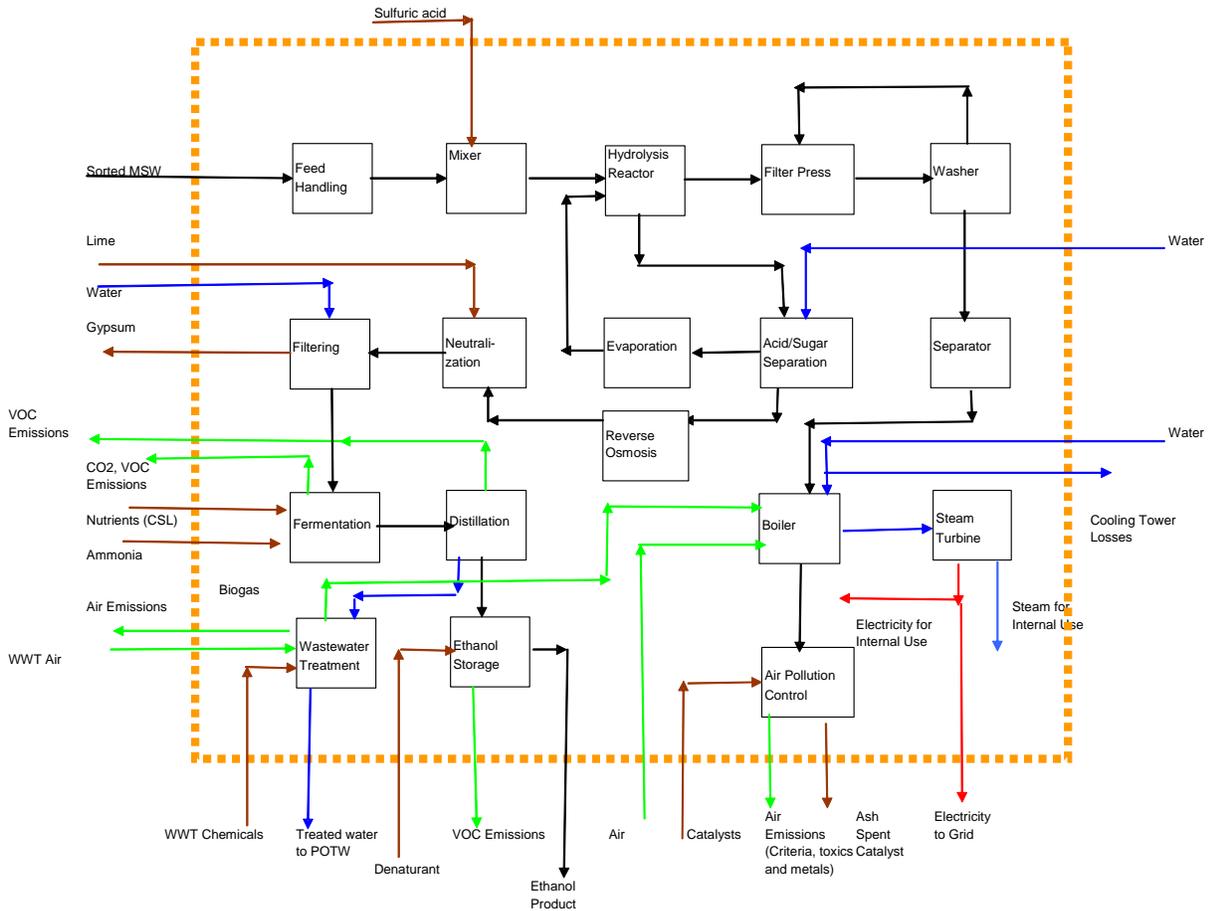
The life cycle boundaries for each CT include not only the inputs and outputs to the technology, but also processes that supply inputs to those operations, such as fuels, electricity, and materials production. Likewise, any useful energy or products produced by the CT system are captured by the inventory. In selecting parameters to include in the inventory, our goal was to identify all relevant inputs and outputs to each technology. No primary data collection was conducted for this study, because CT facilities for MSW do not currently exist in the United States. Therefore, we relied on publicly available sources of information about planned U.S. facilities or existing foreign facilities, as well as direct communication with the technology vendors.

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Process flow diagrams and descriptions were developed for the selected CTs based on designs used by specific vendors: concentrated acid hydrolysis is based on the Masada OxyNol™ technology, gasification is based on the Brightstar Environmental SWERF technology, and catalytic cracking is based on the Plastics Energy LLC/H.SMARTech technology. These are described in more detail below.

**Concentrated Acid Hydrolysis.** Concentrated acid hydrolysis, illustrated in Figure A, is the most complex of the three processes evaluated. This process consists of seven major process areas: feed handling, hydrolysis, acid recovery and recycling, fermentation, ethanol recovery, wastewater treatment, and power production.

The presorted feed is dried to 10 percent moisture and ground to less than 1 inch. It is then mixed with 70 percent sulfuric acid and heated. The solids are washed and separated from the sugar/acid mix. After another washing, the solids are sent to the gasifier and the wash water is recycled in the process. The sugar/acid mix is cooled before being sent to an ion exchange column. The



**Figure A. Concentrated Acid Process Flow Diagram**

The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the CT is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

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recovered sugar is further concentrated using a reverse osmosis system. It is then neutralized and any solids are removed. The concentrated, cleaned sugar stream is sent on to fermentation, and the acid is sent to acid recovery.

The acid recovery system is composed of an ion exchange bed, which will elute the acid and sugar at different times. The acid/water mix is sent to evaporation to concentrate the acid before recycling to the hydrolysis steps. The sugar solution is neutralized with lime, any gypsum formed is separated out, and the sugar is sent to fermentation. Ethanol is recovered from the fermentation product stream via distillation and dehydration.

Non-MSW inputs to the process are water, sulfuric acid, lime, denaturant (gasoline), ammonia, and catalysts. The process generates all of its own heat, steam, and electricity. Outputs consist of the ethanol and electricity products, volatile organic compound (VOC) emissions from storage, combustion emissions, ash, gypsum, treated wastewater, and spent catalysts. The gasifier will require air pollution control. Ammonia injection was assumed for control of nitrogen oxides (NO<sub>x</sub>). The ethanol and denaturant storage tanks may also require controls to minimize losses. Inert feedstock constituents for acid hydrolysis include glass, plastics, and metals. In addition, lignin and other noncarbohydrate fractions of the MSW will not be converted to ethanol.

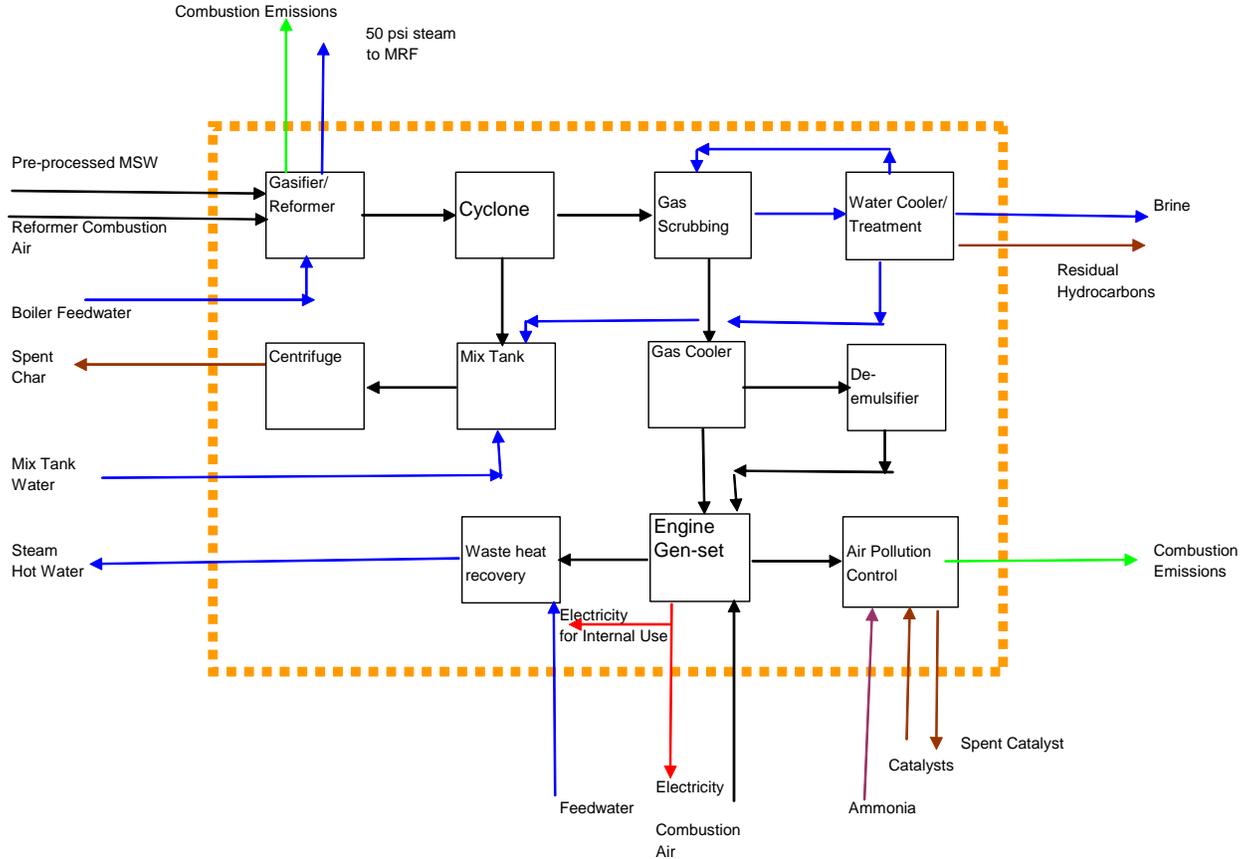
Hydrolysis technologies have air, solid, and water releases. Air emissions are generated primarily from lignin combustion with small amounts of ethanol emitted from the fermentors, storage tanks, and distillation columns. Concentrated acid hydrolysis will generate large quantities of gypsum, which may be sold, depending on market conditions. However, in some cases, the plant would have to pay to haul the excess gypsum away. If lignin is combusted onsite, ash will also be generated for disposal. Wastewater releases will occur from boiler and cooling tower blow down as well as process wastewater. Due to the relatively high potential BOD content of the process wastewater, it will be treated on-site before release to a POTW.

**Gasification.** The process for waste gasification is illustrated in Figure B and described below. Following preprocessing in the adjacent MRF, the feedstock is sent to the main gasification area. Here, the feedstock is heated, pyrolyzed and reformed into syngas, bio-oils and char. The char is recovered from the other products via a cyclone, cooled with a water quench, and sent offsite. The syngas and bio-oils are scrubbed and cooled to recover the bio-oil. Heavy bio-oils and some of the syngas are recycled to the reformers, where they are combusted to fuel the reformer. The majority of the syngas and the light bio-oils are combusted in reciprocating engines to generate electricity. Waste heat from the engines is converted to steam and hot water for use in the process and for export to MSW processing (i.e., the autoclave). The engine exhaust will be subject to air pollution controls. At a minimum, CO, NO<sub>x</sub>, and VOC control will likely be required. For large facilities (e.g., greater than 2 megawatts [MW]) such as the one proposed, a combination oxidation catalyst and selective catalytic reduction (SCR) is used.

Process inputs are composed of MSW, combustion air, water, ammonia, and catalysts. Electricity, wastewater, spent catalysts, char, emulsified bio-oil, and combustion emissions are the process outputs.

Gasification is compatible with the organic fraction (e.g., yard wastes, wood wastes) and plastic fraction of the MSW feedstock or refuse-derived fuel (RDF). Metals, glass, and other recyclables should be removed in the MRF. Power produced by the facility can be readily integrated into the power grid.

Gasification produces air pollutants (e.g., NO<sub>x</sub>) and greenhouse gases (e.g., CO<sub>2</sub>) from the gas engines and the reformer. However, all emissions are expected to be controlled with SCR and



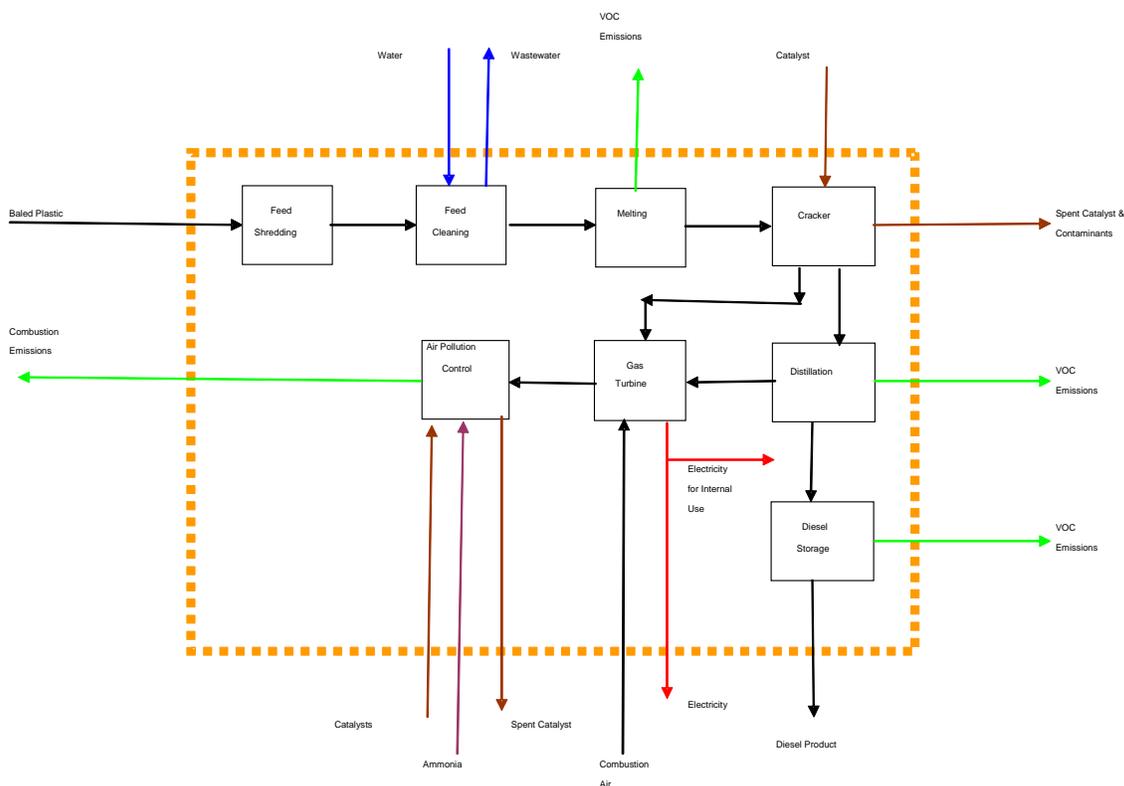
**Figure B. Gasification Process Flow Diagram**

The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the CT is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

oxidation catalysts. Air toxics such as metals and dioxins are expected to be minimal. In fact, all air pollutant concentrations in the exhaust gas from the reciprocating engines at the Brightstar Wollongong (Australia) facility were shown to be at or below the European Waste Incineration Directive.<sup>5</sup>

Ash and char will also be generated. Toxicity Characteristic and Leaching Procedure (TCLP) data from RDF combustion ash and gasification by-products showed results that were significantly below applicable limits.<sup>6, 7</sup> Wastewater releases (e.g., boiler blow down) will be minimal. The Brightstar gasifier in Wollongong was licensed for 30,000 tpy MSW.<sup>8</sup> It has not yet achieved its nameplate capacity, but has operated as a demonstration plant for about two years.<sup>9</sup>

**Catalytic Cracking.** The major process areas for catalytic cracking are shown in Figure C and include feed handling, cracking, distillation, and power production. Baled plastics are sent to a feed shredder to reduce the material to less than 3 inches. The material is then cleaned with water and dried. Wastewater from the washing step, containing primarily dirt and paper, is collected and sent offsite to a publically owned treatment works (POTW). The shredded and cleaned feed is sent to a vessel where it is heated to 185 °C to melt the plastic.



**Figure C. Plastics Catalytic Cracking System Diagram**

The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the CT is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

The melted plastic is mixed with catalyst and reacted in the cracker. Cracked gas components leave the reactor and are sent to the distillation area. The liquid fractions (diesel and gasoline) are condensed and separated via distillation. The diesel fraction is sent to product storage. The gasoline fraction is sent to the gas turbine along with the light ends (e.g., butane and propane) from the cracking process. Plastics Energy LLC will use the H.SMARTech process and a proprietary metal silicate catalyst to crack the plastics, resulting in yields of 83 percent for diesel, 14 percent for gasoline, and 3 percent for light gases.<sup>10</sup>

The rest of the process is similar to a gas turbine facility. The gaseous and gasoline fractions are combusted in the turbine to generate electricity. The hot exhaust gas from the turbine is used to provide process heat. SCR reduces NO<sub>x</sub> emissions in the turbine exhaust. SCR will require ammonia injection and an SCR catalyst.

As shown in the diagram, the system has only three inputs besides the feedstock: catalyst, water, and air. The cracking catalyst is a metal silicate; its exact formulation is proprietary. The SCR catalyst may be a zeolites or vanadium-based catalyst. The process will be almost self-sufficient in energy, requiring only 500 kilowatts (kW) from the grid.

In addition to the diesel and electricity products, the process will have combustion emissions (criteria pollutants and toxics), VOC emissions from organic storage and drying operations,

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wastewater, and spent catalysts. The largest source of air emissions will occur from the gas turbine, but these emissions should be well below acceptable limits because of the clean fuel. Limited amounts of miscellaneous organic air emissions will also likely occur from other processing points (e.g., valves, storage tanks). Wastewater releases will be low and will be composed of rinse water and cooling tower blow down. Solid waste, composed of feedstock inerts and spent catalyst, will also be generated.

Yield losses may occur from inert fillers or pigments. The catalytic cracking technology is designed for a narrow spectrum of feedstocks (polyolefin plastics, e.g., grocery bags). Other components (e.g., PVC) must be removed in the MRF before processing. Although the technology is narrowly focused, this waste stream currently has limited other recycling avenues.<sup>11</sup>

### **Life Cycle Results for Scenarios Analyzed**

The results of the life cycle study are presented for the Los Angeles and San Francisco Bay regions for the CT scenarios as compared to scenarios using existing MSW management practices across a time period of 2003 to 2010. The complete set of scenarios consists of the following:

1. Landfill with no gas collection (worst landfill case)
2. Landfill with gas collection and flaring (average landfill case)
3. Landfill with gas collection and energy recovery (best landfill case)
4. WTE
5. Organics composting
6. CTs.

Landfill, WTE, and composting are included as reference cases. For each scenario, the results for selected life cycle parameters for CT-based management are shown in Figures D through K. The life cycle parameters include net annual energy consumption, sulfur oxides (SO<sub>x</sub>) emissions, NO<sub>x</sub> emissions, and carbon equivalents. A positive value represents a net life cycle burden. A negative value represents a net life cycle savings or avoidance for that parameter. In effect, a negative values indicates that energy and materials offsets from any particular scenario are less than those associated with the processes included in the scenario.

### **Key Findings from the Life Cycle Study**

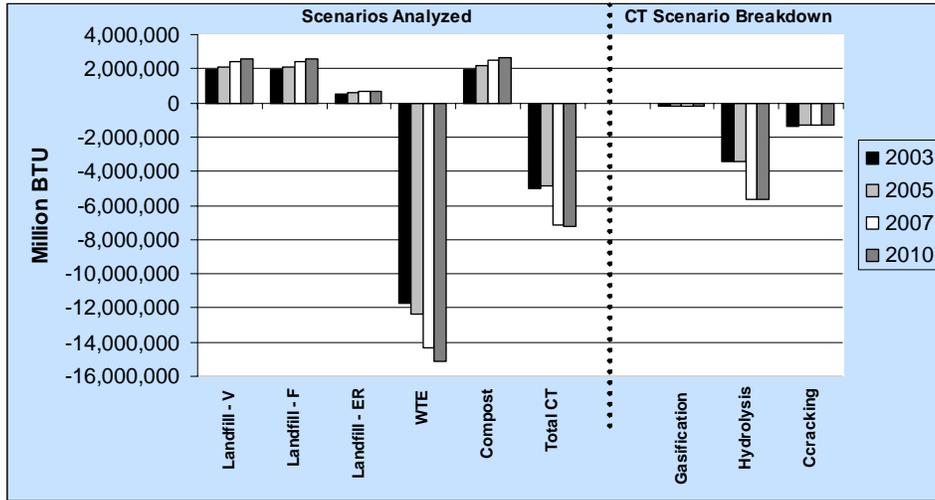
Although we used the best available information to characterize the CTs, they do not yet exist in California, and thus we had to make a number of assumptions about their design and operating characteristics. Therefore, the results and findings from this study need to be taken in context and considered as general directional results rather than absolute results. Further research will be needed to test and evaluate operating facilities.

***Finding #1: The amount of energy produced by the CTs is significant. Although significant, the energy offset related to the CTs is less than the potential amount of energy saved through the additional recycling achieved by the CT scenarios.***

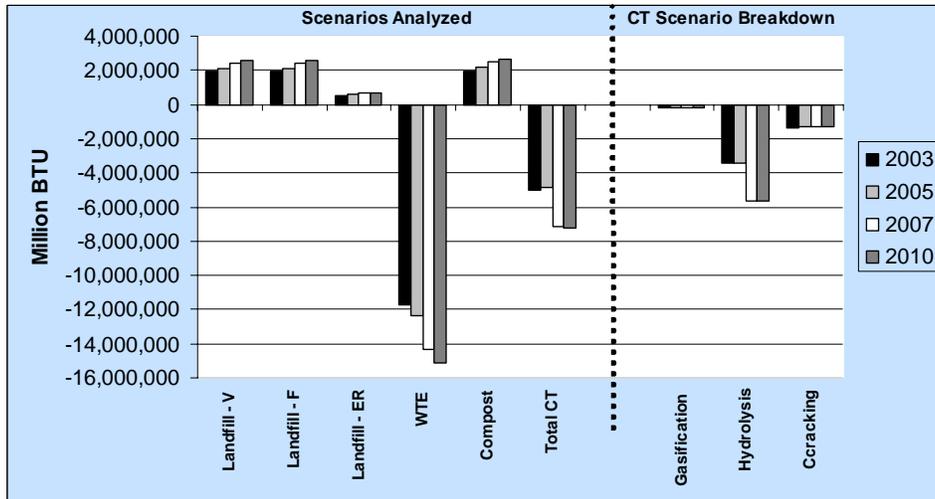
Energy is consumed by all waste management activities (collection, MRF, transportation, treatment, disposal), as well as by the processes to produce energy and material inputs to the CTs. Energy offsets can result from the production of fuels or electricity, as well as from the recovery and recycling of materials. As shown in Figures D and E, the CT scenarios range from about 7 to 10 times lower in net energy consumption as compared to the landfill scenarios and are net energy savers. The energy savings attributed to the CTs result from a combination of electricity,

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fuel, and materials (recycling) offsets. It is interesting to note that the energy-savings potential resulting from the additional materials recycling is significantly greater than the net energy production potential. Even the best-case landfill scenario (with gas collection and energy recovery) is significantly higher in energy consumption than the CT scenario. The WTE scenario significantly outperformed all other scenarios for net energy consumption. The factors that lead to WTE's high net energy savings include high electricity production and some steel recycling offsets.



**Figure D. Los Angeles Region, Annual Net Energy Consumption**



**Figure E. San Francisco Region, Annual Net Energy Consumption**

**Finding #2: For criteria air pollutants, the CTs are not necessarily better than existing options. The cases of NO<sub>x</sub> and SO<sub>x</sub> are described.**

NO<sub>x</sub> emissions result largely from the combustion processes, and thus NO<sub>x</sub> offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production. As shown in Figures F and G, the CT scenarios appear to produce about the same levels of net NO<sub>x</sub> emissions than the landfill scenarios, without energy recovery. The landfill scenario with gas collection and energy recovery has about one-third the level of net NO<sub>x</sub> emissions as the CT scenario. Note that there is a higher level of uncertainty regarding air pollution control requirements for CTs. We used conservative estimates for NO<sub>x</sub> production. With additional controls, NO<sub>x</sub> could be lowered. The WTE scenario resulted in the lowest amount of NO<sub>x</sub> emissions and was the only scenario that resulting in a net NO<sub>x</sub> savings.

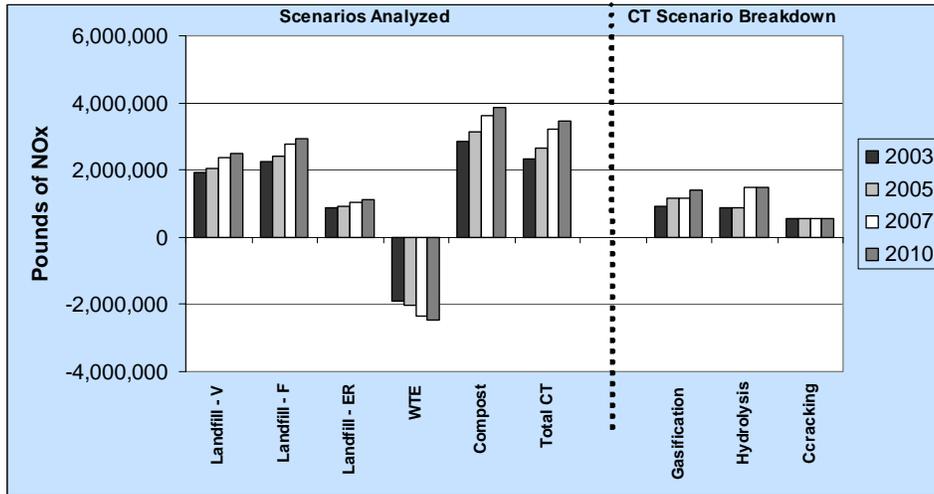


Figure F. Los Angeles Region, Annual Net NO<sub>x</sub> Emissions

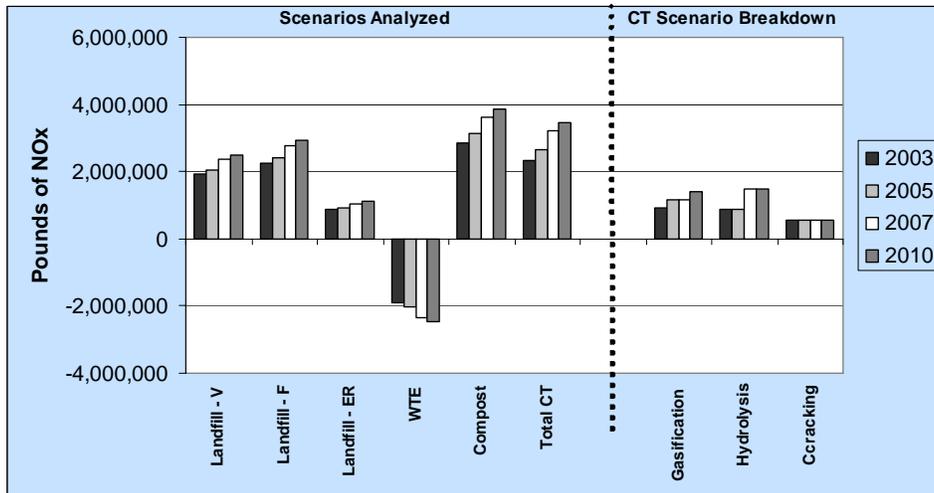
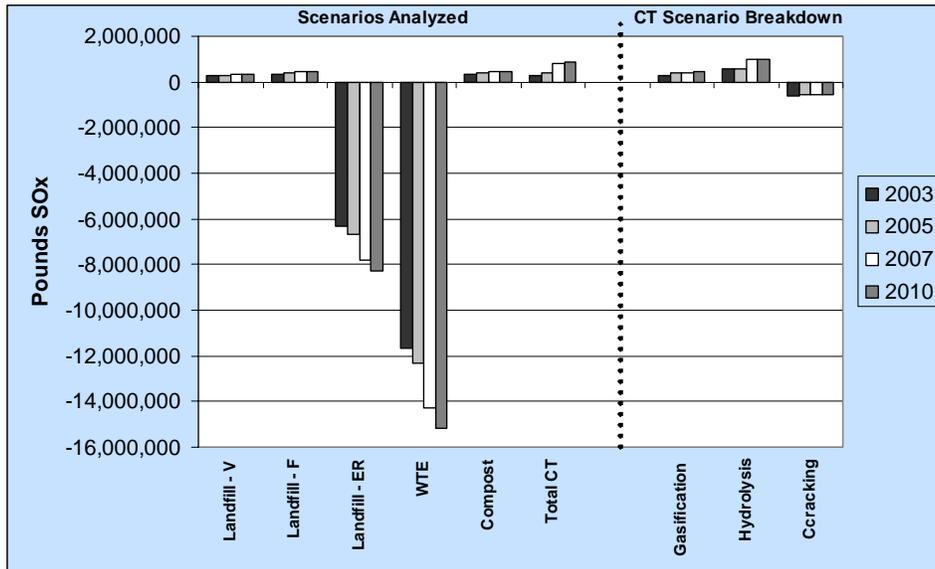


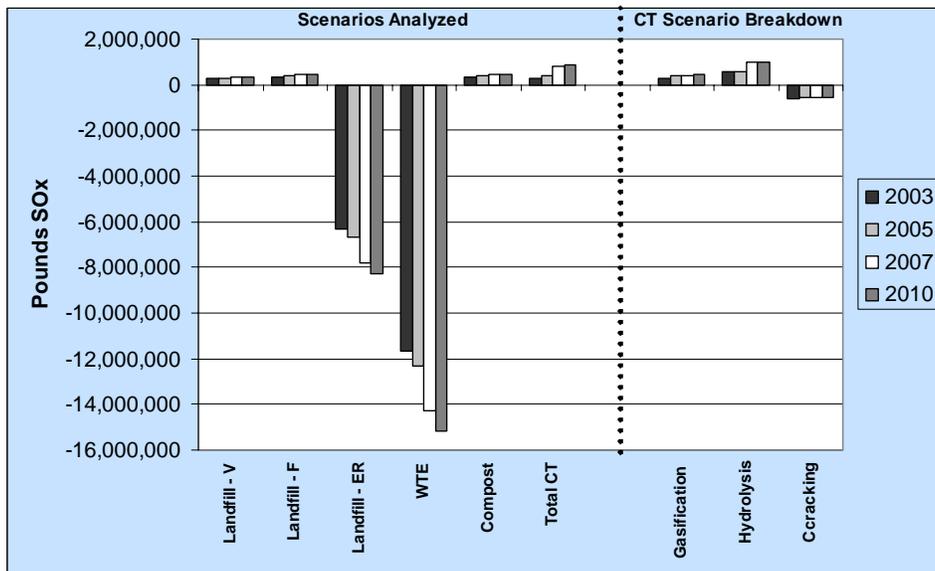
Figure G. San Francisco Region, Annual Net NO<sub>x</sub> Emissions

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SO<sub>x</sub> emissions are also largely a product of combustion processes, and SO<sub>x</sub> offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production, as well as the use of lower-sulfur-containing fuels. As shown in Figures H and I, the CT and landfill disposal scenarios without energy recovery from landfill gas have approximately the same level of net SO<sub>x</sub> emissions. The landfill with gas collection and energy recovery performs better than the CT scenario. As in the case of NO<sub>x</sub>, there are uncertainties about the specific air pollution control devices that would be used at CT facilities and the resulting level of SO<sub>x</sub> control that could be achieved. Catalytic cracking generates a significant SO<sub>x</sub> offset because of its production of low-sulfur diesel. It is likely that with additional air pollution controls at the acid hydrolysis and gasification facilities, the levels of SO<sub>x</sub> emissions could be reduced. The WTE scenario resulted in the lowest amount of net SO<sub>x</sub> emissions and, along with the landfill with energy recovery scenario, resulted in a net SO<sub>x</sub> savings.



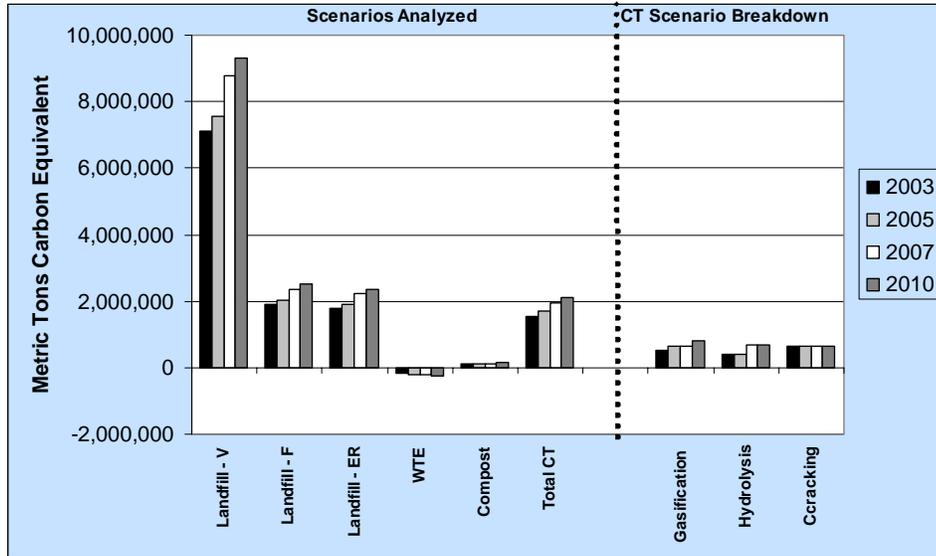
**Figure H. Los Angeles Region, Annual Net SO<sub>x</sub> Emissions**



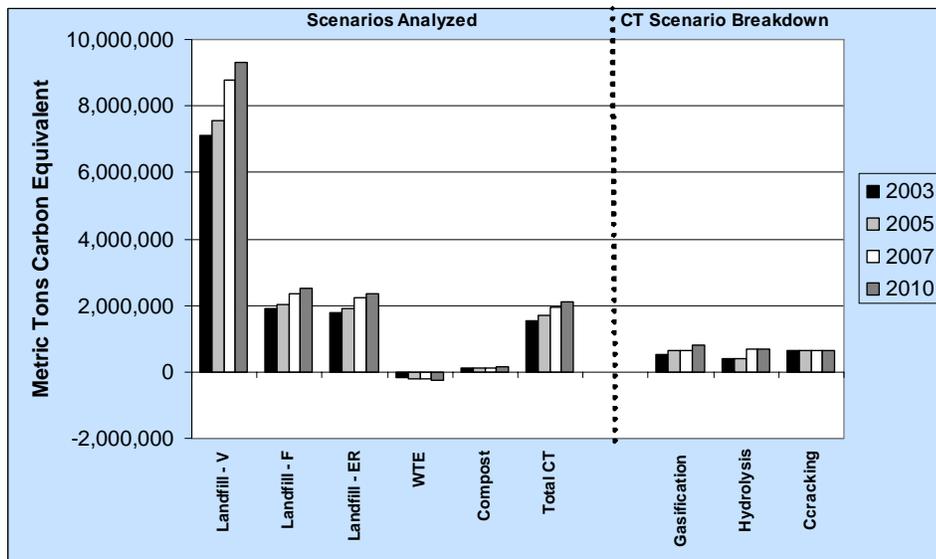
**Figure I. San Francisco Region, Annual Net SO<sub>x</sub> Emissions**

**Finding #3: From a climate change perspective, CTs are generally better than existing management options except for WTE.**

Carbon (i.e., greenhouse gas) emissions can result from the combustion of fossil fuels and the biodegradation of organic materials (e.g., methane gas from landfills). Offsets of carbon emissions can result from the displacement of fossil fuels, materials recycling, and the diversion of organic wastes from landfills. As shown in Figures J and K, the CT scenario performs at a level that is comparable to landfill disposal scenarios that collect and manage the landfill gas. The primary drivers for carbon emissions in the CT scenario are the residual waste that is disposed of in landfills, CO<sub>2</sub> emissions from the process steps, and carbon offsets associated with energy and



**Figure J. Los Angeles Region, Annual Net Carbon Emissions**



**Figure K. San Francisco Region, Annual Net Carbon Emissions**

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materials offsets. WTE is again the best performer in this category because of its large energy offset and some steel recovery for recycling.

***Finding #4: There are not enough data to adequately assess the potential for CTs to produce emissions of dioxins and furans and other hazardous air pollutants (HAPs).***

With respect to other pollutants of concern, such as dioxins and furans, toxics, and heavy metals, data were not available for all of the processes in each scenario to develop comparable results. In addition, test data were not available from the technology vendors to associate levels of these pollutants to specific waste constituents. However, we compared available data on dioxins and furans and other HAPs from CT processes to existing activities that involve the combustion of wastes and coal, as well as landfill disposal. As shown in Table 6, CT-related data were only available for gasification and acid hydrolysis. Further, the gasification data are based on a single emission test as reported by Brightstar, and the hydrolysis data are based on permit limits for the Masada plant in Middletown, NY (so actual emissions would probably be lower). Table 6 does not show any clear differences between HAP emission factors for the CT processes, WTE, and coal utility boilers. The CT processes, WTE, and coal boilers all have higher emission factors for mercury than landfilling does. If landfill fires are included, the CT processes, WTE, and coal boilers all have lower emission factors for dioxins and furans than landfilling has; however, if landfill fires are excluded, they have higher emission factors.

**Table 6. Comparison of Dioxins and Furans and Other Hazardous Air Pollutants**

Pollutant	Coal Utility Boilers <sup>a</sup>	WTE <sup>b</sup>	Landfill <sup>c</sup>	Gasification <sup>d</sup>	Hydrolysis	Catalytic Cracking
Dioxins and furans <sup>f</sup>	1.47E-04	4.72E-04	4.78E-05 (6.87E-03)	1.42E-04	4.28E-04	No data
Lead	7.58E+01	1.70E+02	No data	No data	3.96E+02	No data
Cadmium	3.91E+00	1.19E+01	No data	1.42E+02	3.96E+01	No data
Mercury	6.23E+01	7.86E+01	6.20E-01	9.46E+01	1.58E+02	No data
Hydrochloric acid	1.64E+05	9.55E+04	No data	2.36E+04	No data	No data

<sup>a</sup> Emission factors for an average facility, in mg/Mg of coal fired, based on nationwide emissions data for 1994, from U.S. Environmental Protection Agency (EPA) Utility Air Toxics report.<sup>12</sup>

<sup>b</sup> Emission factors for a large combustor in 2000, in mg/Mg of waste fired, per Walter Stevenson of U.S. EPA.<sup>13</sup>

<sup>c</sup> Landfill values do not include potential emissions from vehicles and equipment operating at the landfills. Parenthetical value for dioxins and furans includes landfill fires.

<sup>d</sup> Emission factors for gasification based on concentration data reported by Brightstar.<sup>14</sup>

<sup>e</sup> Emission factors for hydrolysis based on concentration permit limits for Masada plant in Middletown, NY.

<sup>f</sup> Dioxins and furans values are in mg international toxic equivalents (ITEQ)/Mg of waste or coal.

***Finding #5: Like recycling, CTs will likely result in greater local environmental burdens and a potential reduction in regional or global burdens.***

One important point to consider when reviewing and interpreting the life cycle results is that the values are summarized over different locations and time frames. Thus, the local versus regional nature of the environmental burdens and offset benefits is not conveyed. Many of the environmental burdens associated with CTs will be local, while many of the offset benefits will be regional or global. For example, the considerable preprocessing of waste and other process steps of gasification result in the release of pollutants at the local level. Gasification also produces electrical energy, which may displace regional electrical energy production and thus regional

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environmental burdens. Similarly, the preprocessing requirements of gasification mean that glass and metals are recovered and can be recycled. Any benefits from recycling (i.e., offset of virgin materials extraction and processing) will likely occur at regional or global levels.

***Finding #6: It is important for CT facilities to achieve high performance in terms of conversion efficiencies and materials recycling.***

In terms of life cycle energy consumption, employing the CTs may result in a net energy savings as compared to landfill disposal options because the CTs produce energy (electrical energy and fuels), which offsets energy production from fossil sources. The magnitude of the energy-related offsets is significant and results from both the production of energy at the CTs and from additional materials recycling.

***Finding #7: CTs would decrease the amount of waste disposed of in landfills.***

We assumed that about half of the incoming material that is removed from the CT processes is recycled and the other half landfilled (except for metals, for which we assumed about 70 percent recycled and 25 percent landfilled). Because of the burdens associated with landfill disposal, the CT scenario would look worse if zero recycling were assumed and much better if high rates of recycling were assumed. In addition, the LCA does not capture issues about landfill space and the potential benefits of CTs in reducing the amount of needed landfill space as a result of materials recovery.

***Finding #8: CTs can result in increased materials recovery and recycling as a result of large associated benefits.***

For this study, we assumed that about half of the incoming material that is removed from the CT processes is recycled and the other half landfilled (except for metals, for which we assumed about 70 percent recycled and 25 percent landfilled). The offsets associated with recycling are very significant from a life cycle perspective. Therefore, the CT scenario would look much worse if zero recycling were assumed and much better if high rates of recycling were assumed.

***Finding #9: CTs are not equivalent in terms of life cycle environmental performance.***

Although all CTs recover energy and/or materials for recycling, it appears that acid hydrolysis and catalytic cracking may be better than gasification in terms of life cycle environmental burdens. The disadvantage of gasification is the lower conversion efficiency and the high level of control needed (ammonia input) for NO<sub>x</sub> air emissions control.

***Finding #10: No CT facilities exist in the United States for MSW, and therefore, there is a high level of uncertainty regarding their environmental performance.***

There is much uncertainty about the amount of unwanted metals, glass, and plastics that the CT facilities will be able to remove through the up-front separation and preprocessing steps. For this study, we assumed a 5 percent contaminant level entering the CT process. Higher levels of process contaminants would result in higher levels of local pollutants.

## **MARKET IMPACT ASSESSMENT**

AB 2770 included the requirement that the CIWMB's report on CTs include a "description and evaluation of the impacts on the recycling and composting markets as a result of each CT."

The purpose of the market impact assessment (MIA) was to estimate the impacts that CTs might have on existing and future recycling and composting markets. The impacts were separated into two categories: (1) economic and financial impacts, and (2) institutional impacts on recycling and composting markets. More specifically, this MIA estimates and comments on whether the

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development of CTs in California will have negative, neutral, or positive impacts on the paper, plastic, and organic materials management industries’ ability to remain viable and/or expand. It also assesses possible current and future economic and financial impacts on these industries, including changes in

- Feedstock composition
- Price
- Employment
- Output
- Business elimination and creation
- Competitiveness
- Revenue
- Profit.

The objectives of the MIA are summarized in Table 7.

**Table 7. Summary of MIA Objectives**

<b>Economic and Financial</b>	<b>Institutional</b>
Effects on recycling and composting industries as a result of increases or decreases in feedstock supply If a tonnage effect, estimate economic gains or losses If a price effect, estimate economic gains or losses	Effects on hauler contractual relationships Effects on municipal contractual relationships Effects on regional recycling and composting infrastructure Effects of put-or-pay contracts on recycling and composting businesses

**Methodology**

Our general approach was to collect data regarding the current marketplace, including quantities and compositions of various waste and recycling streams; the entities that make decisions regarding disposition of these materials (generators, jurisdictions, MRF operators, and haulers); the reasons for those decisions (AB 939 regulatory mandates, political mandates, costs and transportation distances); and quality and quantity needs of paper and plastic recycling processors and exporters and the composting industry. We then modeled the relationships of material movement through the system, including prices paid at various points. We then overlaid the conversion technology system configurations, quality, composition, and price of material needs in order to estimate what might occur if such facilities were developed.

Our general methods included researching existing reports and articles and examining them for useable data; contacting industry associations for published reports and forecasts; collecting data from CIWMB in-house databases; compiling data from in-house databases, files and reports; and conducting surveys and interviews to collect primary data and “industry expert” forecasts and opinions.

In general, our work was organized into the following steps:

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- Develop CT configuration assumptions and other key modeling assumptions
- Develop baseline projections for recycling and composting
- Estimate impacts of CT on recycling and composting.

A financial model was developed to input and summarize data and to perform certain calculations.

**Key Findings of MIA**

**The key findings of the MIA are grouped into the following categories:**

- Feedstock Requirements and Recovery Rates for Selected CTs
- Current State of Commercial Development of CTs
- CT Pricing and Contractual Arrangements
- Relative Size of CT Configurations Versus Regional Landfill Markets
- Role and Relative Size of Material Recovery Facilities Versus Regional CT Configurations
- Control of Hauling Arrangements in Two Regions
- Projections of Future Increases in Recycling
- Impacts on Markets for Recycled Paper
- Impacts on Markets for Recycled Plastics
- Impacts on Organics and Landfill Markets.

**Feedstock Requirements and Recovery Rates for Selected CTs**

***Finding #1: Gasification can process 69–74 percent of the incoming waste stream, recycle 8 percent of the incoming waste stream, and must dispose of the remaining 18–23 percent of the waste stream.***

According to facility proponents, gasification can accept mixed solid waste for processing. In this context, “mixed waste” includes residuals from MRFs and waste normally sent to landfills. To prepare the waste for processing, certain materials must be removed for disposal or redirected to other facilities. Certain recyclables must be removed and can be recycled. The remaining materials are suitable for processing (see Table 8).

***Finding #2: Acid hydrolysis can process 61–64 percent of the incoming waste stream, recycle 12–13 percent of the incoming waste stream, and must dispose of the remaining 23–26 percent of the waste stream.***

According to facility proponents, acid hydrolysis can accept mixed waste for processing. In this context, “mixed waste” includes residuals from MRFs and waste normally sent to landfills. To prepare the waste for processing, certain materials must be removed for disposal or redirected to other facilities. Certain recyclables must be removed and can be recycled. The remaining materials are suitable for processing (see Table 9).

**Table 8. Gasification Materials Disposition**

<b>Material Types</b>	<b>Disposition</b>	<b>Percentage of Waste Stream in the Greater Los Angeles Area</b>	<b>Percentage of Waste Stream in the San Francisco Bay Area</b>
Paper, plastics, organics and mixed residue	Processed by gasification	74%	69.2%
Glass and metals, portion that can be recycled	Recycled	7.5%	8.1%
Construction and demolition debris, household hazardous waste, special waste, and the portion of the glass and metal waste streams that cannot be recycled	Disposed	18.5%	22.4%

**Table 9. Acid Hydrolysis Materials Disposition**

<b>Material Types</b>	<b>Disposition</b>	<b>Percentage of Waste Stream in the Greater Los Angeles Area</b>	<b>Percentage of Waste Stream in the San Francisco Bay Area</b>
Paper, organics and mixed residue	Processed by acid hydrolysis	65%	61%
Plastics, glass and metals, portion that can be recycled	Recycled	12%	13%
Construction and demolition debris, household hazardous waste, special waste, and the portion of the plastics, glass and metal waste streams that cannot be recycled	Disposed	23%	26%

***Finding #3: Catalytic cracking can process 3.7–4.5 percent of the incoming waste stream. The remainder would be processed as normal at MRFs.***

According to facility proponents, it is most practical for catalytic cracking to accept only specially prepared loads of plastic film for processing (see Table 10). This plastic film would come from MRFs and waste normally sent to landfills because there are no current markets for this material. Plastic bags must be pulled from the mixed waste stream at either clean or dirty MRFs, or can be segregated at businesses that generate a great deal of plastic film. It is technically feasible to use other types of plastics as feedstock as well, as long as PVC is excluded. Of materials that are currently disposed in landfills, approximately 10 to 11 percent are plastics. The total amount of plastics that may be suitable for catalytic cracking is likely 7 to 9 percent of all wastes currently being disposed.

**Table 10. Catalytic Cracking Materials Disposition**

<b>Material Types</b>	<b>Disposition</b>	<b>Percentage of Waste Stream in the Greater Los Angeles Area</b>	<b>Percentage of Waste Stream in the San Francisco Bay Area</b>
Plastic film that can be processed by catalytic cracking	Processed by catalytic cracking	4.5%	3.7%

**Current State of Commercial Development of CTs**

***Finding #4:* For the technologies included in this study, no commercial-scale CT projects have been completed in the United States at this time, but one facility will break ground this year in California and another will break ground in New York. Several jurisdictions or groups of jurisdictions in California are researching CTs, and some have requested information or proposals from CT vendors.**

Several jurisdictions in California are researching CTs in California:

- The City of Los Angeles has begun a technical study of technology options
- A group of twelve jurisdictions in Santa Barbara County has issued a request for information and received responses from more than a dozen vendors
- Alameda Power and Telecom has requested proposals and is in the process of reviewing them
- The Coachella Valley Association of Governments has received proposals from interested vendors and has conducted interviews
- The County of Los Angeles has created a subcommittee of its Integrated Waste Management Task Force to review technology options.

Plastic Energy LLC has plans to break ground this year on a 50 tpd (expected to expand to 100 tpd) catalytic cracking facility in the City of Hanford, in Kings County. One acid hydrolysis plant is scheduled for construction in Middletown, New York, by Masada OxyNol,<sup>TM</sup> LLC.

**CT Pricing and Contractual Arrangements**

***Finding #5:* Since CT facilities require such large capital investments (ranging from \$40 million to \$70 million), the facilities will likely require contractual commitments from municipalities or haulers to secure the waste streams that will supply the facilities.**

The Masada plant that is to be built in Middletown, New York, has put-or-pay contracts with local jurisdictions that require a tight range of waste quantities to be delivered to the facility, from 100 percent to 108 percent of the amount committed to in the contract. There are monetary penalties for too little or too much waste delivered. The length of the contract is 20 years.

***Finding #6:* CT facilities may have tipping fees that range from \$25 to \$65 per ton of waste delivered, depending on location and other factors.**

Facility proponents have offered prices as low as \$25 per ton, as estimated in the Santa Barbara County request for information process, and as high as \$65 per ton, for the signed contract in Middletown, New York. In addition to the capital and annual operating costs of the facilities, local landfill prices affect costs. With the acid hydrolysis process, 10 percent of the waste emerges as residue and must be disposed of in a landfill at the local rate of \$75 per ton, which

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equates to \$7.50 of the \$65 per ton processing fee. Host fees (in lieu of business license fees for the host jurisdiction) are another significant component of the overall cost; host fees are nearly \$8 per ton for the facility at Middletown, New York.

### **Relative Size of CT Configurations Versus Regional Landfill Markets**

***Finding #7:*** Based on the assumed configuration of conversion facilities that were chosen for evaluation in this study, CT tonnage would represent about 8 percent of the landfill tonnage in the Greater Los Angeles area in 2003, increasing to 11 percent of the landfill tonnage in 2010. The exact same configuration of facilities would have a greater impact on the San Francisco Bay area landfill market; CT tonnage would represent about 20 percent of the landfill tonnage in 2003, rising to 29 percent in 2010.

The hypothetical configuration used for this study amounts to approximately 1.4 million tons of waste being sent to various CT facilities in each of two regions. Through growth in the number of facilities, the hypothetical annual tonnage requirement will rise to 2.2 million tons in 2010. In the San Francisco Bay area, approximately 6.5 million tons of waste were landfilled in 2002, and in the Greater Los Angeles area, approximately 19 million tons of waste were landfilled in 2002. After accounting for population growth and growth of diversion programs, estimated disposal for the San Francisco Bay area is approximately 6.7 million tons of waste for 2010, and 20 million tons in the Greater Los Angeles area in 2010.

### **Role and Relative Size of Material Recovery Facilities Versus Regional CT Configurations**

***Finding #8:*** MRF residuals are sufficient to supply the hypothetical configuration of CT facilities in the Greater Los Angeles area throughout the study period of 2003 to 2010. In the San Francisco Bay area, MRF residuals could comprise just over half of hypothetical CT demand. However, all of the facilities would need specialized or additional processing in order to create appropriate feedstock—typical MRF residuals are not suitable for any of the technologies studied without further preprocessing.

Residuals from “clean” MRFs, which receive and sort cleaner loads of recyclables, such as recyclables from residential curbside collection programs, amount to under 100,000 tpy in each of the two regions. Capacities of mixed waste processing facilities amount to over 600,000 tpy in the San Francisco Bay area and nearly 6 million tpy in the Greater Los Angeles area.

However, residuals from any type of MRF (“dirty” or “clean”) may not be attractive CT facilities. While some contaminants are removed during processing of mixed waste, so are desirable materials, such as paper, organics, and plastics. Residuals from either source-separated or mixed-waste loads will still need to be sorted again prior to entering the CT vessel. Contaminants to the CT processes would still remain in the feedstock even after mixed waste processing. Whether residuals from mixed waste processing or other waste goes to a landfill versus a CT facility may depend primarily on transportation economics, which are determined by location, travel time, and distance.

### **Control of Hauling Arrangements in Two Regions**

***Finding #9:*** According to the survey data collected for this study, in the Greater Los Angeles area, approximately 42 percent of residential waste is hauled by municipally owned and operated collection vehicles, 54 percent is hauled by private companies under contract with the City, and the remaining 4 percent is hauled by a variety of private companies who contract directly with residents. In the San Francisco Bay area, approximately 3 percent of residential waste is hauled by municipally owned and operated collection vehicles ,

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**81 percent is hauled by private companies under contract with the City, and the remaining 17 percent is hauled by a variety of private companies who contract directly with residents.**

In the San Francisco Bay area, some jurisdictions have separate agreement for hauling and landfill disposal, but very few jurisdictions in either area exercise direct control over specific recycling or composting facility arrangements. In general, the contracts for hauling usually specify that recycling and composting must be accomplished, but do not specify facilities or prices. In addition, some of the cities that exercise the most municipal control over recycling and composting contracts are also the least likely politically to change their recycling and composting policies.

***Finding #10:* The commercial sector waste is less regulated than the residential sector in the Greater Los Angeles area, with 4 percent of the waste being collected municipally, 48 percent through contracts with waste haulers, and the remaining 48 percent open to competition from multiple haulers. In the San Francisco Bay area, nearly all of the commercial waste is hauled by contract haulers.**

**Projections of Future Increases in Recycling**

***Finding #11:* Based on the data gathered for this study, recycling growth rates (in the absence of CT facilities) are estimated at an average of approximately 2 percent per year for paper, plastics, and organics.**

Recycling tonnage growth (or decline) occurs as a result of several factors, including population growth, changes in material types used to manufacture products, and implementation of new or expanded diversion programs. Nationwide, plastics and paper recycling rates have not increased much in the last few years. Nationwide recycling rates for newspaper and corrugated cardboard are above 70 percent, suggesting there is little room for growth. In California, many jurisdictions have achieved the 50 percent recycling goal, while other jurisdictions continue to strive toward achieving 50 percent diversion. A few jurisdictions have goals above 50 percent, including the cities of Los Angeles and San Francisco. The statewide average diversion rate was 47 percent in 2003.

Projected future growth of recycling (assuming CT facilities are not developed) was computed using population growth rates, rates of growth or decline of specific material types, and documented plans for increased recycling program implementation from jurisdictions. Growth rates are different for each material type in the study (paper, plastics, and organics.) Additional growth in recycling programs is possible as a result of technology advances and implementation of new programs, but these possibilities could not be quantified for this study. Current and projected quantities of the recyclables targeted in this study are shown in Table 11.

**Table 11. Current and Projected Quantities of Paper, Plastics, and Organics Recycling**

Component	Los Angeles		San Francisco	
	2003 (tons)	2010 (tons)	2003 (tons)	2010 (tons)
Paper	4,900,000	5,900,000	2,000,000	2,400,000
Plastic	180,000	340,000	100,000	180,000
Organics, including ADC	3,100,000	3,300,000	1,700,000	1,900,000

### **Impacts on Markets for Recycled Paper**

***Finding #12: Implementation of any of the three selected technologies is not likely to increase or decrease the recycling of paper.***

Feedstock must be sorted prior to use at acid hydrolysis or gasification facilities. Unacceptable materials, such as metal and glass, must be removed from the mixed waste stream prior to entering the conversion process, which would slightly increase recovery of these materials. However, paper is a desirable feedstock for these two technologies and it would not be recovered from the mixed waste stream for recycling. Catalytic cracking uses only plastic that is positively sorted from the waste stream and therefore would have little or no effect on paper markets.

While paper is an acceptable feedstock for acid hydrolysis and gasification, the recent values of baled paper make it unlikely that paper will be directed to a CT facility. Paper markets have historically been very volatile, with high prices for a given year being twice that of low prices for that year. However, average annual paper prices have been above zero for a 10-year period for all paper grades and have gone over \$100 per ton for some grades of paper. Acid hydrolysis and gasification projects will require a payment (a tip fee) to accept materials, and that tip fee will likely be in the range of prices charged at local landfills (\$25 to \$60 per ton).

***Finding #13: Exports of paper, particularly to China, have increased dramatically over the past five years. These exports are exerting upward pressure on prices in the paper markets and are providing an outlet for all of the paper that is collected.***

Paper exported from this country has grown significantly in recent years: by 77 percent from 1993 to 2002, or an average of 5.9 percent per year. The increases averaged 6.8 percent per year for the more recent period of 1998 to 2002. Nationwide, 24 percent of the paper recovered in the United States is exported for recycling.

Locally, exports from the Greater Los Angeles area increased 9.6 percent per year on average from 1998 to 2002, and exports from the San Francisco Bay area increased an average of 10.9 percent per year from 1998 to 2002. China has been the dominant driver of these increases in paper exports. During the five-year period from 1998 to 2002, exports to China from these two California port areas have increased by 209 percent, and represent 48 percent of the total exports for this period.

### **Impacts on Markets for Recycled Plastics**

***Finding # 14: Plastics recycling will increase if acid hydrolysis facilities are built, because plastics must be removed prior to processing.***

Metals and glass recycling will increase as a result of both acid hydrolysis and gasification, because those materials must be removed prior to processing. However, of the materials targeted in this study (paper, plastics, and organics), only plastics recycling will increase, and only by acid hydrolysis preprocessing. Currently, only those plastics with positive economic values are typically recycled. In contrast, feedstock preparation for acid hydrolysis would seek to remove ALL plastics.

If catalytic cracking facilities are developed, and if those facilities target plastic bags, then jurisdictions might be encouraged to add plastic bags to their curbside recycling programs for subsequent separation at a MRF. Residents might stop returning plastic bags to grocery stores for recycling as a result of the convenience of placing materials in their curbside recycling bins.

### **Impacts on Organics and Landfill Markets**

***Finding #15: Assuming no diversion credit is allowed for CTs, it is unlikely that significant quantities of green waste that are currently delivered to composters or to landfills as ADC will be redirected to CT facilities for the following reasons:***

1. Currently, jurisdictions that contract for source-separated collection of green waste will continue to require their contractors to deliver green waste to facilities that qualify for diversion credit. Approximately 80 percent of the green waste delivered to diversion facilities is delivered by either public agencies or haulers under contract to public agencies.
2. Green waste delivered to diversion facilities at posted rates probably is delivered by self-haulers that are not regulated by contractual arrangements with public agencies. Approximately 20 percent of the green waste delivered to diversion facilities pay the posted rates. These self-haulers will deliver their green waste loads to the most economical facility. Currently, these self-haulers pay posted rates at green waste facilities of \$11 to \$31 per ton in the Greater Los Angeles area and \$15 to \$40 in the San Francisco Bay area. It is unlikely that CT prices will be competitive for most of this tonnage. Furthermore, CT facilities will be most interested in steady waste flows from contract haulers rather than the uneven flow delivered in loads from self-haulers.
3. There is sufficient refuse tonnage available to fully utilize the capacity of the proposed CT configurations that is currently paying higher disposal tipping fees than the fees charged by green waste facilities. As a result, CT facilities, in order to maximize profit, are likely to charge tipping fees that are competitive with landfill costs. A CT tipping fee of \$30 to \$40 per ton in the Greater Los Angeles area and \$40 to \$50 per ton in the San Francisco Bay area should be able to attract sufficient refuse to be used as feedstock, and there would be no need to lower CT prices to attract green waste.

The above assessment is contingent on a policy of not providing diversion credit for CT facilities. If diversion credit was provided without regulatory measures to protect current feedstock, public agencies would have an economic incentive to discontinue separate green waste collection and instead deliver mixed loads of refuse and green waste to CT facilities, because it would likely be less costly as a result of savings in waste hauling costs.

### **Changes in Job Creation as a Result of Conversion Technology Facilities**

***Finding #16: Preparing feedstock for use in CT facilities generates additional recycling-related jobs in two ways, as listed below. For the purpose of determining the number of jobs potentially generated, we assumed that facilities were operating at the capacities listed in Table 3.***

#### **1. Additional MRF Sorting Positions**

Feedstock must be sorted in a specific manner prior to use in any of the three types of CT facilities reviewed in this study. For acid hydrolysis and gasification, the most likely feedstock has been determined to be material destined for a landfill. Whether or not this material includes residuals from MRFs, this material must be sorted in a specialized way and will require additional sorters to remove recyclables and contaminants.

Feedstock for catalytic cracking facilities would not need to be sorted on a separate facility line. Catalytic cracking facilities would accept only film plastic, which could be sorted from an existing material recovery facility line that is already sorting clean recyclables or mixed waste. It would also require additional workers on existing sorting lines.

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R.W. Beck, Inc., determined in the *U.S. Recycling Economic Information Study* (July 2001) that based on the MRFs they studied, a cumulative annual throughput of 3,625,000 tons at an MRF resulted in 2,606 jobs, or a ratio of 0.7 jobs per 1,000 tons of annual throughput. Assuming a 15 percent contamination rate, that equates to 0.82 jobs per 1,000 tons recovered.

Whether the new positions are at an existing facility or on a line set up specifically for CT sorting, increased sorting will translate to increased workers needed. Using R.W. Beck's ratio, acid hydrolysis sorting requirements could add from 74 to 138 sorting jobs in each region over the term of this study. Gasification sorting needs could add from 52 to almost 94 positions. Sorting out the additional film plastic for catalytic cracking could add 13 positions.

2. Additional Recovered Material

This additional sorting of acid hydrolysis and gasification feedstock will result in the recovery of additional recyclable materials. When these materials are recycled back into the market for remanufacturing, additional jobs could be created relating to the use of this recovered material, as shown in Table 12.

3. CT Facility Jobs

Additional workers would be employed to operate CT facilities. Using a rough estimate from the projected number of jobs at the Masada plant under construction, CT facilities will generate 0.76 jobs per 1,000 tons of throughput. It is not clear how many of these jobs are sorting jobs.

4. Landfill Job Losses

CT facilities would decrease the amount of waste disposed in landfills, which would result in a net loss in revenues to landfills. Decreases in tonnage and revenues to landfill may result in job losses at landfills in proportion to the loss in tonnage. CT tonnage would decrease tons sent to landfills by about 8 percent in the Greater Los Angeles area in 2003, increasing to 11 percent of the landfill tonnage in 2010. The exact same configuration of facilities would decrease tons sent to landfills in the San Francisco Bay area landfill market by about 20 percent in 2003, rising to 29 percent in 2010.

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**Table 12. Additional Material Diverted Through Conversion Technology Sorting**

<b>Material</b>	<b>Jobs per 1,000 Tons<sup>a</sup></b>	<b>Tons – 2003<sup>b</sup></b>	<b>Additional Jobs - 2003</b>	<b>Tons – 2010<sup>b</sup></b>	<b>Additional Jobs - 2010</b>
<b>Greater Los Angeles Area - Acid Hydrolysis</b>					
Plastic	77.1	36,109	2,784	61,353	4,730
Glass	5.0	17,960	90	28,946	145
Metal	8.3	35,778	297	57,656	479
MRF	0.82	89,847	74	147,955	121
Total			3,245		5,475
<b>San Francisco Bay Area - Acid Hydrolysis</b>					
Plastic	77.1	34,784	2,682	59,419	4,581
Glass	5.0	18,628	93	31,050	155
Metal	8.3	46,208	384	77,223	641
MRF	0.82	99,620	82	167,692	138
Total			3,241		5,515
<b>Greater Los Angeles Area – Gasification</b>					
Glass	5.0	21,024	105	30,423	152
Metal	8.3	41,882	348	60,599	503
MRF	0.82	62,906	52	91,022	75
Total			505		730
<b>San Francisco Bay Area – Gasification</b>					
Glass	5.0	21,904	110	32,763	164
Metal	8.3	54,334	451	81,483	676
MRF	0.82	76,238	63	114,246	94
Total					934
<b>Greater Los Angeles Area - Catalytic Cracking</b>					
MRF - sorting of film plastics	0.82	16,450	13	16,450	13
<b>San Francisco Bay Area - Catalytic Cracking</b>					
MRF - sorting of film plastics	0.82	16,450	13	16,450	13

<sup>a</sup> Calculated using jobs per ton factors in the report "U.S. Recycling Economic Information Study" by R. W. Beck, Inc., July 2001.

<sup>b</sup> Assumes CT facilities are operating at full capacity under proposed configurations. See Table 3 for tonnage.

# **Abbreviations and Acronyms**

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AB – assembly bill  
ADC – alternative daily cover  
BIGCC – biomass integrated gasifier combined cycle  
CO – carbon monoxide  
CO<sub>2</sub> – carbon dioxide  
CT – conversion technology  
CWIMB – California Integrated Waste Management Board  
EPA – U.S. Environmental Protection Agency  
H<sub>2</sub> – hydrogen  
HAP – hazardous air pollutant  
ITEQ – international toxic equivalent  
kW – kilowatt  
LCA – life cycle assessment  
LCI – life cycle inventory analysis  
MIA – market impact assessment  
MW – megawatt  
MRF – materials recovery facility  
MSW – municipal solid waste  
MSW-DST – RTI’s Municipal Solid Waste Decision Support Tool  
NO<sub>x</sub> – nitrogen oxides  
POTW – publically owned treatment works  
PVC – polyvinyl chloride  
RDF – refuse derived fuel  
SCR – selective catalytic reduction  
SWERF – Solid Waste Energy Recycling Facility  
SO<sub>x</sub> – sulfur oxides  
TCLP – toxicity characteristics and leaching procedure  
tpd – tons per day  
tpy – tons per year  
VOC – volatile organic compound

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WTE – waste-to-energy

WWT – wastewater treatment

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## Source Reference Notes

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<sup>1</sup> NYSDEC. Air Title V Facility, Permit ID 3-3309-00101/00003, Mod 1, Issued to Pencor Masada Oxynol LLC, October 1, 2001.

<sup>2</sup> Ibid.

<sup>3</sup> Ibid.

<sup>4</sup> *Ozmotech's municipal recycling facility setup now complete*, Mapslink, <<http://www.ozmotech.com.au/news4.html>> (October 11, 2003).

<sup>5</sup> R. Menville, *SWERF ME*, Technical Presentation, Emissions Table. 2004.

<sup>6</sup> Niessen, Walter, Charles Markes, and Robert Sommerland, *Evaluation of Gasification and Novel Thermal Processes for the Treatment of Municipal Solid Waste*, NREL/TP-430-21612, August 1996, pg. 3-12.

<sup>7</sup> Ibid., pg. 6-11.

<sup>8</sup> *SWERF®*, *Wollongong NSW, Australia*, <<http://www.brightstarensvironmental.com/html/projects/aus.htm#stage#stage>> (October 8, 2003).

<sup>9</sup> P. Wootton. 2004. "FW: Final questions for Ron Menville of Brightstar," January 5, 2004, pg. 6. E-mail to J. Simpson and R. Menville.

<sup>10</sup> *H.SMART Presents an Advanced Catalytic Cracking Technology*, 2002 LEA/CIWMB Partnership Conference, <<http://www.ciwmb.ca.gov/part2000/Events/02Conf/ConvTec/Plastic.htm>> (October 8, 2003).

<sup>11</sup> Larry Buckle, H.SMARTech Inc., personal communication with V. Putsche, October 7, 2003.

<sup>12</sup> U.S. EPA, *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units – Final Report to Congress*, EPA-453/R-98-004, February 1998. Executive Summary.

<sup>13</sup> Walter Stevenson, U.S. EPA, personal communication with Mark Bahner, April 1, 2004.

<sup>14</sup> *SWERF®*, *Wollongong NSW, Australia*, <<http://www.brightstarensvironmental.com/html/projects/aus.htm#stage#stage>> (October 8, 2003).