Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

Final Report

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June 21, 2009

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Executive Summary

The diversion of materials from landfill is one of the primary goals in California and elsewhere. Diversion efforts have increased substantially in California since the passage of the Integrated Waste Management Act in 1989, which established a target of 50 percent diversion from landfills by 2000. Despite substantial progress in material diversion, more than 43 million tons of material is still disposed of in landfills in the state. Of the materials landfilled, 79 percent is organic (biomass and plastic carbonaceous material), and could potentially be processed to provide chemical energy or be converted into other useful products. For example, the 31 million tons of organic waste currently landfilled annually contains the equivalent energy of more than 60 million barrels of crude oil, or could provide 2500 MW of electrical power.[1]

Potential options for reducing the current amount of waste disposed in landfills include reducing the generation of waste, re-use of materials, increasing the amount recycled, and/or diverting a portion of the stream through other conversion processes. The recycling market plays an important role in the waste infrastructure. Much of the readily recyclable material is already pulled from the waste stream due to market forces and local jurisdiction efforts to satisfy diversion required by the Integrated Waste Management Act. Programs to reduce waste at the source (i.e., producer responsibility laws) are also used elsewhere, such as Europe.

If a long-term reduction in disposal of solid waste is to be realized, additional steps are necessary. The state must continue to expand waste prevention efforts that include changing the way goods are produced and packaged. Another option to reduce the amount of material disposed of in landfills is to convert this valuable resource into energy, fuels, and other products. This can be accomplished by using modern combustion systems and non-combustion (biochemical, physicochemical, and thermochemical) methods.

A wide range of technologies is emerging for the conversion of biomass to biofuels and/or green power. The International Energy Agency is tracking more than 40 conversion technology projects now in development or construction in the United States. This report focuses on biomass (primarily municipal solid waste) as a feedstock for thermochemical conversion processes, provides emissions data from operational waste conversion plants in five countries, and compares this data with regulatory standards in California, the United States, the European Union, and Japan.

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[1] Hackett, C., Williams, R. B., Durbin, T. D., Welch, W., Pence, J., Aldas, R., Jenkins, B. M., and Salour, D. (2004). "Evaluation of Conversion Technology Processes and Products - Final Report." University of California

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An appendix to this report lists more than 100 facilities throughout the world that are treating (i.e., disposing and converting) biomass (principally municipal solid waste) in the process of producing energy and/or fuels.

As the environmental performance from thermochemical conversion of waste has been challenged by some stakeholders, efforts have been made to obtain and analyze third-party emissions data. Of particular interest are thermochemical processes using mixed waste feedstocks or MSW. Prior to 2005, very little information was available. University of California researchers conducted a limited study in 2005 of three prototype thermochemical conversion technologies.[2] Since then, significant efforts have been made to develop and analyze independent emissions data from thermochemical processes worldwide. These data are developed from independent source test reports, compliance reports from regulatory agencies, and peer-reviewed publications.

Results from the analysis indicate that pyrolysis and gasification facilities currently operating throughout the world with waste feedstocks meet each of their respective air quality emission limits. With few exceptions, most meet all of the current emission limits mandated in California, the United States, the European Union, and Japan. In the case of toxic air contaminants (dioxins/furans and mercury), every process evaluated met the most stringent emission standards worldwide. Facilities with advanced environmental controls are very likely to meet regulatory requirements in California. The actual impacts of specific facilities will need to be evaluated on a case-by-case basis as part of a local permitting process.

[2] *Durbin, T. D., Welch, W., (2005). "Evaluation of Environmental Impacts of Thermochemical Conversion Technologies Using Municipal Solid Waste Feedstocks – Final Summary Report." University of California, Riverside*

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Introduction

After significant efforts to reduce, re-use, and recycle waste materials, California still disposes over 43 million tons per year into landfills throughout the state. There is widespread agreement that the continued land disposal of waste is not a viable option in the state. Furthermore, the waste stream contains significant energy. While many landfills recover gas to produce electricity, only a small amount of the available energy is recovered. There are several approaches that are technically-viable alternatives to landfill disposal. These include incineration of wastes with electricity production, and non-incineration "conversion" of the waste stream into electricity, liquid/gaseous fuels and other marketable products.

The "non-incineration" conversion technologies include biochemical, physicochemical, and thermochemical processes. The following are summary descriptions of the various systems as described in a previous University of California study.[2]

Biochemical conversion proceeds at relatively low temperatures and lower reaction rates and can offer high selectivity for products. Higher moisture feedstocks are generally good candidates for biochemical processes. Non-biodegradable organic feedstocks, such as most plastics, are not convertible by biochemical processes. Examples of biochemical conversion include anaerobic digestion, aerobic conversion, and fermentation.

Anaerobic digestion is a bacterial fermentation process that is sometimes employed in wastewater treatment for sludge degradation and stabilization. This is also the principal process occurring in the decomposition of food wastes and other biomass in landfills. Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas, containing mostly CH_4 and CO_2. This biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, and the manufacturing of chemicals. Anaerobic digestion is also being explored as a route for direct conversion to hydrogen.

Aerobic conversion includes most commercial composting and activated sludge wastewater treatment processes. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Aerobic processes generally do not produce useful fuel gases. Aerobic decomposition can occur from as low as near freezing to about 160º F.

Fermentation is generally used industrially to convert substrates such as glucose to ethanol for use in beverage, fuel, and chemical applications and to other chemicals (e.g., lactic acid used in producing renewable plastics) and products (e.g., enzymes for detergents). Fermentation feedstocks require pretreatment by chemical, physical, or biological means to open up the structure of biomass and reduce the complex carbohydrates to simple sugars. This set of pretreatments is often referred to as hydrolysis. The resulting sugars can then be fermented by the yeast and bacteria employed in the process. Feedstocks high in starch and sugar are most easily hydrolyzed.

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Cellulosic feedstocks, including the major fraction of organics in municipal solid waste (MSW), are more difficult to hydrolyze, requiring more extensive pre-treatment. Ethanol and carbon dioxide are the primary products of glucose fermentation by yeast.

Physicochemical conversion involves the synthesis of products using physical and chemical processing at near-ambient temperatures and pressures. It is primarily associated with the transformation of fresh or used vegetable oils, animal fats, greases, tallow, and other suitable feedstocks into useful liquid fuels and chemicals such as biodiesel, frequently by transesterification, a reaction of an organic glyceride with alcohol in the presence of catalyst.

Thermochemical conversion is characterized by higher temperatures and conversion rates than most other processes. Thermochemical conversion includes a continuum of processes ranging from thermal decomposition in a primarily non-reactive environment (commonly called pyrolysis) to decomposition in a chemically reactive environment (usually called gasification if the products are primarily fuel gases). Pyrolysis can be considered an incomplete gasification process, in which a mixture of gaseous, liquid and solid products is produced, each of which may have some immediate use to sustain the process. The characteristics of each of these processes can also vary depending on the oxidizing or reducing media, process temperature and process pressure.

Environmental implications of conversion technologies are critically important to the overall feasibility of these processes. Current information suggests that thermochemical and biochemical waste conversion processes can be operated in a manner that presents no greater threat to human health or the environment than other common industrial or commercial processes.

While biochemical processes have gained widespread acceptance for treating various feedstocks, thermochemical processes have met with resistance from the environmental community and the public. Some of this resistance has stemmed from the misperception that pyrolysis and gasification processes are only minor variations of incineration or “mass burn.” An essential difference between combustion (incineration), pyrolysis, and gasification is that the latter two are intermediate processes for producing gaseous, liquid, and solid products that can be used in a wide variety of applications. For the broader category of coal and petroleum gasification, the production of chemicals, fuels, and synthetic gases is actually more prevalent than electricity production. Pyrolysis processes can be optimized for the production of oils.

Although chemical and fuel production from gasification and pyrolysis of MSW components is possible, the most prevalent process is the use of producer gases for on-site electricity production. These post-combustion processes associated with alternative thermochemical conversion processes still differ dramatically from incineration in several key respects:

• Pyrolysis and gasification processes use lower amounts of air/oxygen or none at all.

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• The volume of output gases from a pyrolysis reactor or gasifier is much smaller per ton of feedstock processed than that from an incineration process. While these output gases may be eventually combusted, the alternative processes provide an intermediate step where gas cleanup can occur. Mass burn incineration is limited in application of air pollution control equipment to the fully combusted exhaust only.

• Output gases from pyrolysis reactors or gasifiers are typically in a reducing environment, and can be treated with different technologies compared with a fully combusted (oxidative) exhaust. Reactant media can also be hydrogen or steam.

• Subsequent combustion of low molecular weight fuel gases from pyrolysis and gasification processes can be much cleaner than combustion of raw feedstocks .

These factors make control of air emissions less costly and less complex than that required for incineration. While exhaust gas cleanup of non-combustion thermochemical conversion processes may be easier than that associated with incineration, proper design of the process and emissions control systems is necessary to ensure that health and safety requirements are met. The output products of pyrolysis and gasification reactors can contain a variety of potential process and air pollutants that must be controlled prior to discharge into the ambient air. These include particulate matter (PM), aerosols or tars, oxides of nitrogen (NOx), oxides of sulfur (SOx), dioxins and furans, hydrocarbon (HC) gases, multiple metals, and carbon monoxide (CO). There are many strategies for controlling emissions from thermochemical conversion processes, and they are highly dependent on the process requirements of each individual facility.

Contaminant removal from the exhaust stream is typically accomplished with a variety of air pollution control technologies. These are often used in combination. As noted above, thermochemical conversion processes may employ air pollution control at the reactor outlet as well as the exhaust gas outlet.

Emissions of dioxins and furans are an important environmental consideration. Dioxins and furans are compounds consisting of benzene rings, oxygen, and chlorine that are considered or known to be toxic or hazardous. Dioxins and furans can form when waste streams containing chlorine are processed under conditions where the flue gas has a significant residence time in a temperature range between 480 and 1290° F, with a maximum formation rate at approximately 600° F. They are typically formed downstream of the combustion process and frequently within the air emission control equipment. In this temperature range, hydrogen chloride (HCl) in the flue gas reacts with oxygen to form chlorine (usually catalyzed by heavy metal vapor, such as copper) and the chlorine subsequently reacts with hydrocarbon radicals to form dioxins and furans. The low levels of oxygen present in pyrolysis and gasification processes inhibits the formation of dioxins and furans (however HCl in product gas must be managed if combustion for heat or power follows gasification).

From an environmental perspective, advanced alternative waste conversion technologies have several potential benefits over mass incineration or other current practices. Existing data and facilities indicate that conversion technologies can operate within existing regulatory constraints.

A summary of the current worldwide status of thermochemical conversion technologies is presented in this report. This is followed by a focused assessment of emissions from thermochemical conversion technologies processing waste streams. Independently-verified emissions from sixteen (16) such operations are presented in normalized terms compared with current emissions standards in the United States, the European Union, and Japan. Finally, a description and compliance status of several biomass processing plants in the United States is presented.

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Current Status of Thermochemical Conversion Technologies

The United States Department of Energy, in their most recent survey[3], found that world gasification capacity has grown to 56,000 megawatts thermal (MW_{th}) of syngas output (roughly equivalent to 29,000 MW_e) from 144 major operating plants that employ 427 gasifiers. An additional ten plants involving another 34 gasifiers were expected to become operational by 2010, involving another 17,000 MW_{th} of syngas capacity, an increase of 30%. The report, which only included commercial operating plants with a capacity in excess of 100 megawatts electric equivalent (MW_{th}), found that gasification plants are now operating in 27 countries, with 34% in Asia/Australia.

It reported that 50 gasification projects were in various stages of planning and preliminary engineering for future United States operation. As of 2007, South Africa's Sasol plants, which produce liquid fuels, represented 27% of the world's syngas-producing capacity. China had 44 operating gasification plants representing 24% of worldwide syngas production, with 16 new plants planned (seven of which were in start up).

Synthesis gas is the primary product of these plants, from which other marketable products are generated, including chemicals (45%), Fischer-Tropsch (F-T) liquids (28%), power (19%) and gaseous fuels (8%).

A second industry resource, the Zeus Global Gasification Database, follows more than 300 facilities. A key finding of Zeus' gasification research is that "the various roadblocks that have hindered gasification technology from realizing its potential are diminishing. More than ever, the industry is sustaining growth on the back of positive economics. Advanced gasification technology has demonstrated its benefits of lowering operating costs and reducing GHG emissions while utilizing a range of feedstocks."[4]

Gasification and pyrolysis technologies produce an intermediate product (e.g. synthesis gas, substitute natural gas, SNG, or syngas), which is used in a wide range of energy generation, liquid energy and chemical manufacturing processes. This distinguishes thermochemical conversion technologies from waste-to-energy, which directly combusts waste stream feedstocks. With no intermediate product, waste combustion technologies are limited to the production of steam and/or electricity.

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[3] *"Gasification World Database 2007, Current Industry Status," U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory.*

[4] *http://www.zeuslibrary.com/syngas/gasification/*

Emissions from Thermochemical Conversion Technologies

Emissions from Thermochemical Conversion Technologies Processing MSW and Hazardous Waste Streams

Independent emissions data for pyrolysis/gasification plants processing MSW or hazardous wastes throughout the world were obtained for this study. These data include compliance source test reports, confidential third-party company research reports, and peer-reviewed publications. An analysis format was developed to normalize the data for direct comparison with other processes as well as current emissions standards in the United States, Europe, and Japan. The emissions data were converted, where necessary, into terms of milligrams of pollutant per normal meter cubed at 7% oxygen (mg/Nm^3 @ 7% O_2). This is the standard commonly applied in the U.S. for MSW incinerators. The emissions evaluated in this report include criteria pollutants [particulate matter (PM), nitrogen oxides (NOx), and sulfur dioxide (SOx)], and hazardous air pollutants [hydrogen chloride (HCl), mercury (Hg) and dioxins/furans]

The following provides a summary of some companies that have developed or are operating the plants, information about the specific facilities evaluated, and Tables containing process and emissions data. Finally, charts are presented comparing emissions data for each pollutant with worldwide regulatory standards.

Ebara/TwinRec

Ebara is a Tokyo-based company, founded in 1912, specializing in fluid/machinery systems, precision machinery, and environmental engineering. As an engineering firm, they have successfully developed and implemented over 100 waste processing plants, including MSW incinerators and gasifiers. TwinRec is a process that combines fluidized bed gasification with an ash melting furnace. Heat generated from the process is used to produce steam for electricity production in steam turbines. Ebara reports installations for eleven TwinRec plants in Japan, which collectively process 1462 tons of MSW, 1063 tons of industrial waste and 16 tons of sewage sludge per day. Recent source test data was provided for an Ebara TwinRec facility located in Kawaguchi City, Japan[5].

The Kawaguchi-city Asahi Clean Centre uses the Ebara TWIN/Rec/TIFG gasification/ash melting system to convert 420 tons of MSW and 27 tons per day of fly ash into 12 MW of electric power. It has been in operation since 2003. The slag from the process is ground for use in pavement blocks and road construction. Process and Emissions results are shown in the following Table.

[5] "New York City's Focused Review of Advanced, Innovative Technologies – Supplemental Information Request," June, 2005 – Ebara TwinRec Technology, Compliance Testing Results from Feb-Mar, 2005.

Ebara TwinRec		
Asahi Clean Center, Kawaguchi, Japan		
Fluidized bed gasification/ash melting		
420 tpd Industial/MSW		
5.5 MW electricity		
Compliance source tests Feb-Mar 2005		
Emissions (mg/N-M^3 @ 7% O_2)	**measured**	**Japanese Standard**
PM	<1.4	15.4
HCL	<2.8	126
Nox	41	320
Sox	<4	225
Hg	<0.007	-
Dioxins/furans (ng/N-M^3)	0.000072	0.14

Entech Renewable Energy Technologies

Entech Renewable Energy Technologies produces Pyrolytic Gasification Systems for biomass and waste destruction and Renewable Energy Systems for utilization of biomass or waste as a fuel source. Entech gasification systems have been installed in more than 50 plants around the world since 1990, ten of which use MSW as their feedstocks in amounts ranging from 1.5 to 60 tons per day. These plants are located in Hong Kong, Taiwan, Australia, Indonesia, Malaysia, Korea and Poland. Independent source test data was obtained for an Entech plant operating in Kuznica, Poland.[6] The subject plant processes 25 tons per day of medical waste and was commissioned in 2004. Process and emissions results are shown in the following Table.

[6] *Glochanalski, A. "Analysis and Measurement of Pollution Concentration of Waste Gasification System – Kuznica, Poland," Laboratory for Trace Organic Analysis, Cracow University of Technology,2004*

Entech Renewable Energy Technologies		
Kuznica, Poland		
gasification		
3.5 tpd medical waste		
Demo Test 03/09/04		
Emissions		**EC 2000/76**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	0.98	14
HCL	7.9	14
Nox	254	281
Sox	51.9	70
Hg	0.008	14
Dioxins/furans (ng/N-M^3)	0.028	0.14

InEnTec

The proprietary Plasma Enhanced Melter ("PEM™") system of InEnTec (previously Integrated Environmental Technologies, LLC), transforms waste materials, including hazardous waste, into fuels for the generation of electricity, a glass-like substance that can be used to create items such as blasting grit or building materials, and recoverable metals.

In May, 2009 Waste Management, Inc. and InEnTec announced the formation of S4 Energy Solutions LLC, a joint venture to develop, operate and market plasma gasification facilities using the InEnTec Plasma Enhanced Melter technology. The joint venture is expected "to process commercial and industrial waste streams to produce a range of renewable energy and environmentally beneficial fuels and industrial products as well as to generate electricity."

In 2003 Kawasaki Heavy Industries in Japan purchased an InEnTec system that it has used to demonstrate the destruction of PCBs in asbestos. Global Plasma in Taiwan has been using the technology since 2005 to convert medical waste into syngas that is used to produce electric power. The company has formed a subsidiary company with Lakeside Energy LLC to build waste-to-gas facilities for the chemical industry in the United States. Its first project will be a facility at Dow Corning's Michigan plant to convert chemical wastes into reusable chlorine and synthetic natural gas.

Results of (2) two separate PEM system tests were submitted: a solid circuit board fabrication waste and bagged medical waste. These tests were observed as part of the US Environmental Protection Agency's Environmental Technology Evaluation Center (EvTEC). The testing was conducted to assess emissions from the PEM system as an alternative for treating hazardous wastes, with results furnished to UC researchers by IET.[7] The following Tables present the process and emissions results for the two sets of tests conducted.

InEnTec			
Richland, WA			
Plasma Arc Gasification			
10 tpd circuit boards			
EPA Environmental Technology Verification Testing (2000)			
Emissions		**US EPA**	
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**	
PM	3.3	20	
HCL	6.6	40.6	
Nox	74	308	
Sox	-	85.7	
Hg	0.0002	50	
Dioxins/furans (ng/N-M^3)	0.000013	13	

InEnTec			
Richland, WA			
Plasma Arc Gasification			
10 tpd medical waste			
EPA Environmental Technology Verification Testing (2000)			
Emissions		**US EPA**	
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**	
PM	<3.3	20	
HCL	2.7	40.6	
Nox	162	308	
Sox	-	85.7	
Hg	0.00067	50	
Dioxins/furans (ng/N-M^3)	0.0067	13	

[7] *Environmental Technology Evaluation Center (EvTec), CERF/IIEC Report #40633, "Environmental Technology Verification Report for the Plasma Enhanced Melter^{TM}," May 2002*

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INEOS Bio

In July 2008, INEOS, the world's third largest chemical company, acquired Bioengineering Resources, Inc. of Fayetteville, Arkansas and its thermochemical/biochemical conversion technology, which is capable of co-producing bioethanol and green power from a broad range of carbon-based feedstocks, including the biodegradable portion of municipal solid waste. It has established a new subsidiary, INEOS Bio, to oversee the worldwide implementation of the technology, which enables renewable fuels production to be sustainably de-coupled from food production.

Central to the INEOS Bio platform is a highly selective and efficient proprietary bacterial biocatalyst for the conversion of synthesis gas to ethanol. The technology can generate electricity as a by-product of the ethanol process without combustion. Waste heat from the cooling of the synthesis gases is used to create high temperature steam to drive a turbine.

University of California researchers visited the INEOS Bio pilot plant facility August 23-24, 2005 to observe emissions source testing of the process using a post-recycled waste stream from California as a feedstock.[8] The testing was administered by a third-party engineering firm and conducted by an independent contractor. Process and emissions results are shown in the following Table.

INEOS Bio		
Fayetteville, AK		
gasification/biosynthesis		
1.5 tpd MSW		
150 gal/day ethanol		
UCR Observed testing, Parsons Engineering, 2005		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O$_2$)	**measured**	**Standard**
PM	2	20
HCL	-	40.6
Nox	10	308
Sox	-	85.7
Hg	0.0001	50
Dioxins/furans (ng/N-M^3)	0.003	13

[8] *Williams, R.B. and W.A. Welch, University of California Trip Report to CIWMB, BRI Energy, Fayetteville, AK, August 2005*

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International Environmental Solutions

International Environmental Solutions (IES) operates an Advanced Pyrolytic Treatment Thermal Conversion System that consists of a retort chamber followed by a thermal oxidizer and air pollution control equipment. Material is fed by a screw conveyor into the retort chamber, which maintains a temperature of 1400-1800 ^{o}F in a low oxygen environment. Air locks are utilized at each end of the chamber to minimize fugitive emissions. Ash and char exit the chamber through a lock hopper into a collection bin. The pyrolytic gases are ducted to a thermal oxidizer that is equipped with a 5 MM Btu/hr natural gas-fired burner. Exhaust gases from the thermal oxidizer are vented through waste heat boilers for energy recovery. The air pollution control system consists of selective non-catalytic reduction unit for NOx control, a baghouse for PM control, and a scrubber unit for control of acid gases and volatile metals.

After initial baseline testing to determine the appropriate NOx control devices for its Advanced Pyrolysis System demonstration plant in Romoland, California, International Environmental Solutions (IES) conducted numerous source tests on various waste streams, including municipal solid waste. The testing conducted with MSW was observed by UC researchers. During 2008, IES and its consultants compiled all of the information necessary to file for a full-term operating permit from the SCAQMD. The permit is currently awaiting approval. In January, 2009, the SCAQMD issued a moratorium on all new permits to operate due to litigation unrelated to the IES application. IES expects the permit to operate will be granted once the moratorium is lifted.

Emissions results were obtained from a compliance source test report. Performance and emissions results are shown in the following Table.[9]

[9] *South Coast Air Quality Management District Memo, "Evaluation of Source Test Report – International Environmental Solutions, Romoland," April 18, 2007*

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International Environmental Solutions		
Romoland, CA		
pyrolysis/syngas boiler		
30 tpd MSW		
SCAQMD Permit Tests 2006		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	5.75	20
HCL	-	40.6
Nox	129	308
Sox	0.44	85.7
Hg	-	50
Dioxins/furans (ng/N-M^3)	0.000581	13

JFE Environmental Services/Thermoselect

JFE Environmental Solutions Corp licensed this technology from Thermoselect S.A., a Swiss company, which has also licensed the technology to Interstate Waste Technologies for the development of projects in the United States and the Caribbean.

The process transforms organic waste components of the waste stream into syngas in a gasification step, which can be used for power generation or as a base material for chemical synthesis. The inorganic waste components are converted by means of process integrated melting into directly usable mineral substances and metals. The Thermoselect process does not produce any ash, slag or filter dust. There are seven JFE currently operating in Japan. Three process a mixed MSW stream; three process MSW and industrial waste, and the most recent plant, commissioned in 2007, processes wood chips in the Yamagata Prefecture.

UC researchers obtained independent compliance data for one of the MSW plants.[10] Process and emissions results from this plant are shown in the following Table.

[10] *Kenou-Kennan, Kankyou-Kumiai, "Emissions Data of JFE Nagasaki Plant," compliance source test report, April-June 2006*

JFE Environmental Services/Thermoselect			
Nagasaki, Japan			
pyrolysis + gasification/syngas engines and boiler			
300 tpd MSW			
8 MW electricity			
Compliance source test June 2006			

Emissions ($mg/N\text{-}M^3$ @ 7% O_2)	measured	Japanese Standard
PM	<4.7	15.4
HCL	11.6	126
Nox	-	320
Sox	-	225
Hg	-	-
Dioxins/furans ($ng/N\text{-}M^3$)	0.025	0.14

Mitsui Recycling 21 (R21)

Mitsui Recycling 21 (R21), developed by Mitsui Engineering and Shipbuilding Ltd. (MES), is a Pyrolysis Gasification and Melting process for the treatment of municipal waste, using its own heat energy for gasification and for ash melting into slag. Shredded waste undergoes drying and is gasified at 450ºC in a rotary drum reactor and converted into pyrolysis gas and carbon char, with other residue of metals, ash and debris. The pyrolysis reactor is heated indirectly by hot air, which passes through a number of heat transfer tubes, running along the length of the drum. The R21 process is designed for municipal household and commercial waste. It does not process construction or demolition waste.

The six R21 plants in commercial operation in Japan process from 60,000 tons to 150,000 tons of MSW per year. Compliance emissions data from one of these plants (Toyohashi 21) was obtained by UC researchers.[11] The process and emissions results are shown in the following Table.

[11] *Harada, "Mitsui Recycling 21 – Pyrolysis Gasification and Melting Process – Toyohashi R21 Plant," IEA presentation, 2003*

Mitsui Recycling 21 (R21)		
Toyohashi, Japan		
pyrolysis + gasification/steam turbine		
400 tpd MSW		
8.7 MW electricity		
Compliance Source Tests May-October 2002		
Emissions (mg/N-M^3 @ 7% O_2)	**measured**	**Japanese Standard**
PM	< 1.0	15.4
HCL	55.8	126
Nox	82.8	320
Sox	25.9	225
Hg	-	-
Dioxins/furans (ng/N-M^3)	0.0045	0.14

Nippon Steel DMS

Recognizing that landfill space was at a minimum In Japan and that developing new and productive methods of municipal waste disposal was becoming a national priority, Nippon Steel was one of a number of leading Japanese companies that undertook significant research and development programs during the period from 1970-1990 to develop technologies capable of recovering the energy resident in municipal solid waste. As a result, Nippon Steel now has 28 operating reference plants in Japan and one in Korea, which together process more than 1.9 million tons of municipal waste, sewage sludge and other residues per year. Another five plants are expected to come on line in these two countries by 2013, representing approximately 700,000 tons per year of additional waste processing capacity.

Nippon Steel employs a high temperature gasification system, or "Direct Melting System" (DMS). The process produces a syngas that is combusted in a steam boiler, driving a steam turbine to produce electricity. Process and emissions data for two Nippon Steel plants in Japan was obtained by UC researchers,[12] and are presented in the following Tables.

[12] *" Independent Waste Technology Report – Nippon Steel – Gasification – Full Process Review," Juniper Consultancy Services, Ltd., 2007*

Nippon Steel DMS		
Kazusa, Japan		
high temperature gasification		
200 tpd MSW		
2.3 MW electricity		
Compliance Source Tests 2005/2006		
Emissions		**Japanese**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	14.1	15.4
HCL	<12.5	126
Nox	31.2	320
Sox	<21.9	225
Hg	-	-
Dioxins/furans (ng/N-M^3)	0.045	0.14

Nippon Steel DMS		
Akita, Japan		
high temperature gasification		
400 tpd MSW/sewage sludge/industrial wastes		
7.7 MW electricity		
Compliance Source Tests 2005/2006		
Emissions		**Japanese**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	-	-
HCL	-	-
Nox	-	-
Sox	-	-
Hg	-	-
Dioxins/furans (ng/N-M^3)	0.0162	0.14

Plasco Energy Group

Plasco Energy Group Inc. is a private Canadian waste conversion and energy generation company based in Ottawa, Canada. Plasco's plasma arc-based gasification systems convert municipal household, commercial or industrial waste to green power and other valuable products.

Plasco owns and operates two facilities—a 110 ton-per-day commercial-scale evaluation and demonstration municipal solid waste conversion facility at Ottawa's Trail Road

Landfill, and a five ton-per-day research and development facility in Castellgali, Spain. The City of Ottawa, Canada has signed a letter of intent for a 450 ton-per-day Plasco facility and the Central Waste Management Commission in Red Deer, Canada has signed a contract for a 230 ton-per-day facility. UC Researchers obtained confidential third-party source test information for emissions tests[13], which is presented in the following Table.

Plasco Energy		
Ottowa, Canada		
plasma arc gasification		
110 tpd MSW		
Demonstration Source Tests 2008-2009		
Emissions		**EC 2000/76**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	12.8	14
HCL	3.1	14
Nox	150	281
Sox	26	70
Hg	0.0002	14
Dioxins/furans (ng/N-M^3)	0.009245	0.14

OE Gasification

For the past 15 years, South Korea has been actively pursuing a strategy of sustainable waste management, which includes the thermal treatment of non-recyclable waste. 40 plants treat a total of 18,000 tons of waste each day.

Municipalities in South Korea are not allowed to export waste outside their respective jurisdictions. This has led to the development and building of numerous small-scale plants. To serve this market, OE Gasification's patented SK 1000 technology is designed around a module capable of treating 25 metric tons of MSW per day. The technology consists of a feed module, a gasifier, a boiler, and an air pollution control module. The design parameter for the technology was based on achieving a constant energy output from a variable BTU value feedstock.

The South Korean Ministry of the Environment mandates continuous emissions monitoring and the data transferred is password protected to assure the delivery of actual data, with online reporting to the central authority for NOx, SOX, HCL, CO and dust. This continuous monitoring system begins on the day that the plant is commissioned and there is no allowance for exceeding the guidelines during start-up.

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[13] *"Plasco Trail Road Environmental Performance Update," confidential report, May 2009*

UC researchers obtained emissions data from five (5) SK 1000 plants operating in South Korea,[14] which are presented in the following Tables.

OE Gasification		
Heanam, Korea		
gasification		
20 tpd MSW		
Average daily emissions, 2008		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	8.6	20
HCL	<27.4	40.6
Nox	105	308
Sox	37.5	85.7
Hg	<0.007	50
Dioxins/furans (ng/N-M^3)	0.0561	13

OE Gasification		
Gangjin, Korea		
gasification		
25 tpd MSW		
Average daily emissions, 2008		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	18.2	20
HCL	<27.4	40.6
Nox	115	308
Sox	30.3	85.7
Hg	<0.007	50
Dioxins/furans (ng/N-M^3)	0.0561	13

[14] *D'Ailly, J and S.C. Kim, "Gasification of MSW in South Korea," Proceedings of the 17th Annual North American Waste-to-Energy Conference, ASME, May 2009*

Emissions from Thermochemical Conversion Technologies

OE Gasification		
Bosung, Korea		
gasification		
45 tpd MSW		
Average daily emissions, 2008		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	7.5	20
HCL	25.3	40.6
Nox	59	308
Sox	18.7	85.7
Hg	<0.007	50
Dioxins/furans (ng/N-M^3)	0.0983	13

OE Gasification		
Pyungshan, Korea		
gasification		
25 tpd MSW		
Average daily emissions, 2008		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	11.3	20
HCL	21.1	40.6
Nox	77.2	308
Sox	41.1	85.7
Hg	<0.007	50
Dioxins/furans (ng/N-M^3)	0.0281	13

Emissions from Thermochemical Conversion Technologies

OE Gasification		
Hapchon, Korea		
gasification		
20 tpd MSW		
Average daily emissions, 2008		
Emissions		**US EPA**
(mg/N-M^3 @ 7% O_2)	**measured**	**Standard**
PM	8.45	20
HCL	23.2	40.6
Nox	84.2	308
Sox	29.9	85.7
Hg	<0.007	50
Dioxins/furans (ng/N-M^3)	0.0562	13

Overall Emissions Comparison

In order to obtain an overall perspective of emissions from these types of processes, individual pollutant emissions were compared for all of the processes described above, and compared with the regulatory standards currently in effect in the United States, the European Union, and Japan. These comparisons are presented in the following Figures.

Emissions from Thermochemical Conversion Technologies

Legend Key for Figures

	Company	Technology	Feedstock	Location
S1	US EPA Standard (new MSW incinerators)			
S2	European Commission 2000/76 Standard			
S3	Japanese Standard			
S4	SCAQMD MSW Incinerator Permit Limits			
A	Ebarra TwinRec	Fluidized bed gasification/ash melting	420 tpd Industial/MSW	Kawaguchi, Japan
B	Entech Renewable Energy Technologies	gasification	3.5 tpd medical waste	Kuznica, Poland
C	InEnTec	Plasma Arc Gasification	10 tpd circuit boards	Richland, WA
D	InEnTec	Plasma Arc Gasification	10 tpd medical waste	Richland, WA
E	INEOS Bio	gasification/biosynthesis	1.5 tpd MSW	Fayetteville, AK
F	International Environmental Solutions	pyrolysis/syngas boiler	30 tpd MSW	Romoland, CA
G	JFE Environmental Services/Thermoselect	pyrolysis + gasification/syngas engines and boiler	300 tpd MSW	Nagasaki, Japan
H	Mitsui Recycling 21 (R21)	pyrolysis + gasification/steam turbine	400 tpd MSW	Toyohashi, Japan
I	Nippon Steel DMS	high temperature gasification	200 tpd MSW	Kazusa, Japan
J	Nippon Steel DMS	high temperature gasification	400 tpd MSW	Akita, Japan
K	Plasco Energy	plasma arc gasification	110 tpd MSW	Ottowa, Canada
L	OE Gasification	gasification	20 tpd MSW	Heanam, Korea
M	OE Gasification	gasification	25 tpd MSW	Gangjin, Korea
N	OE Gasification	gasification	45 tpd MSW	Bosung, Korea
O	OE Gasification	gasification	25 tpd MSW	Pyungshan, Korea
P	OE Gasification	gasification	20 tpd MSW	Hapchon, Korea

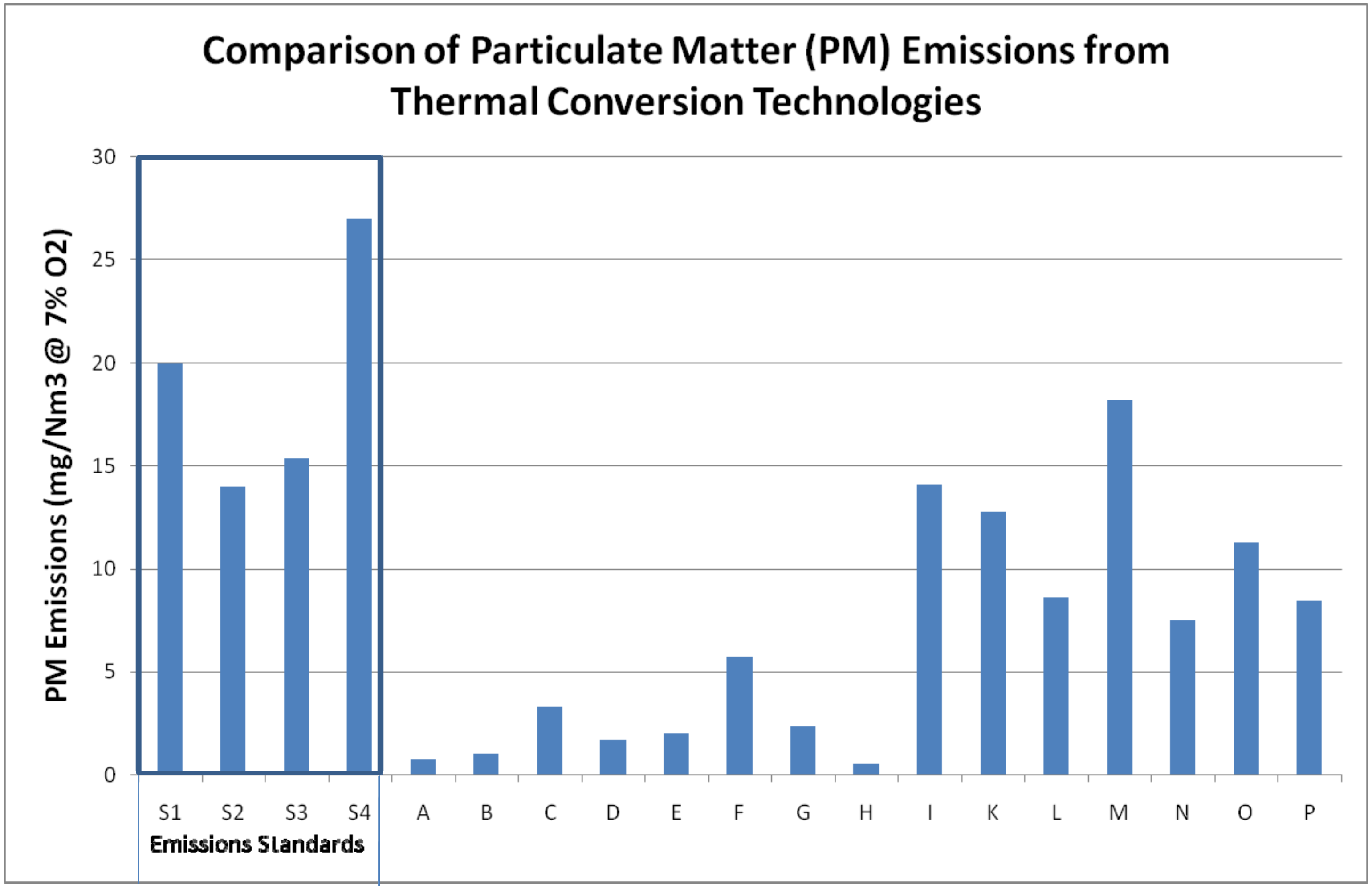

Figure 1 - Particulate Matter Emissions Comparison

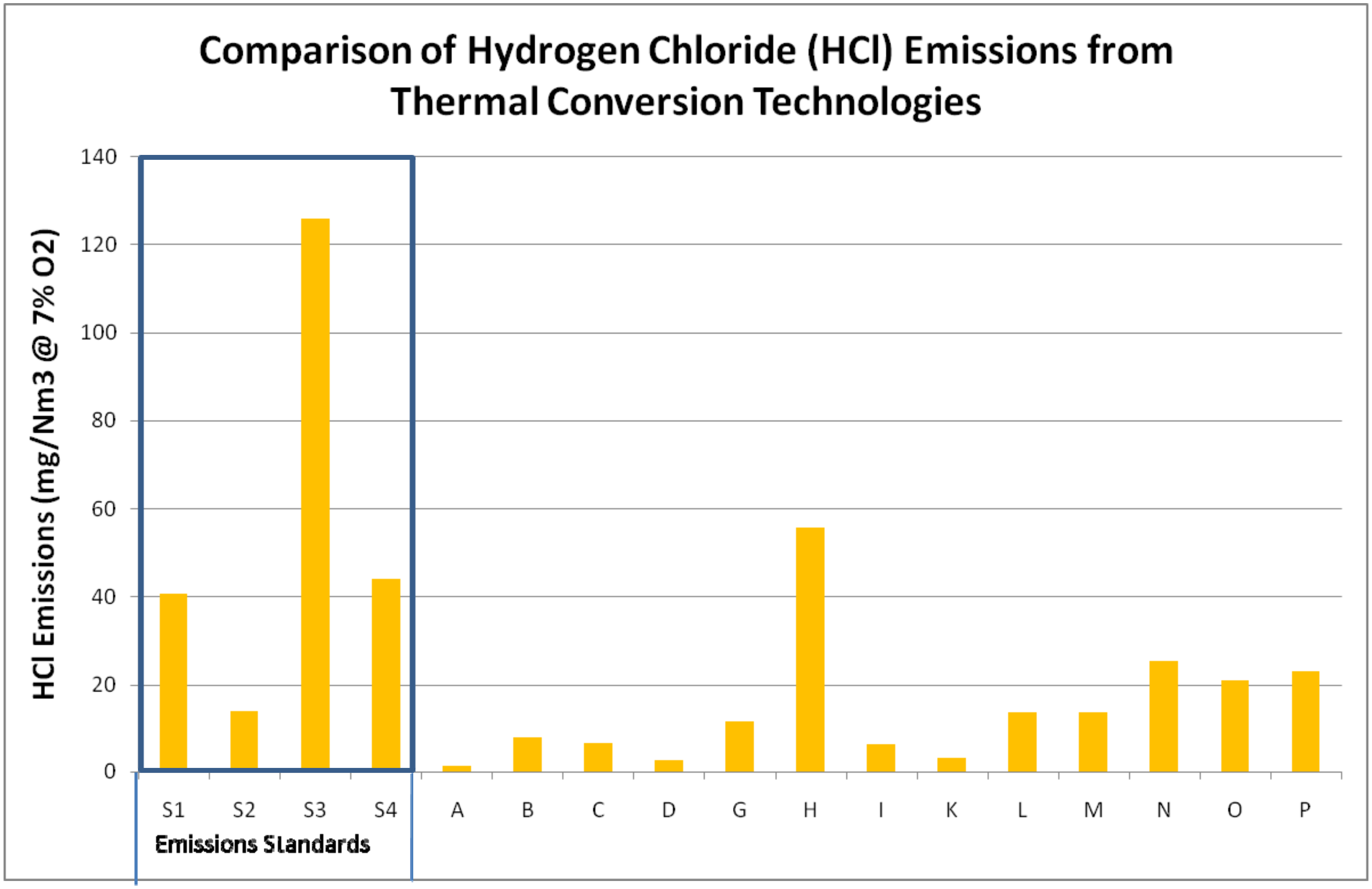

Figure 2 - Hydrogen Chloride Emissions Comparison

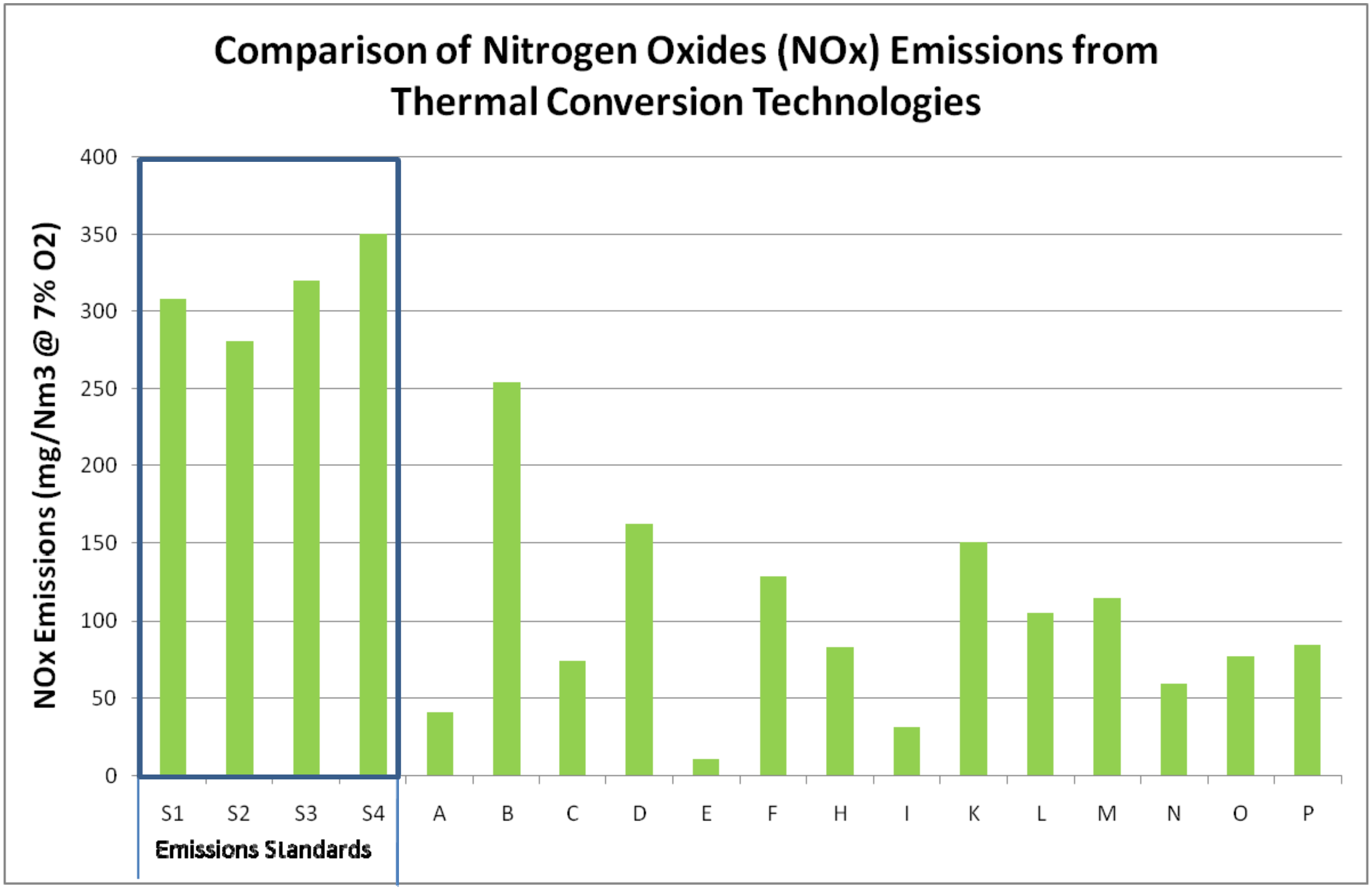

Figure 3 - Nitrogen Oxides Emissions Comparison

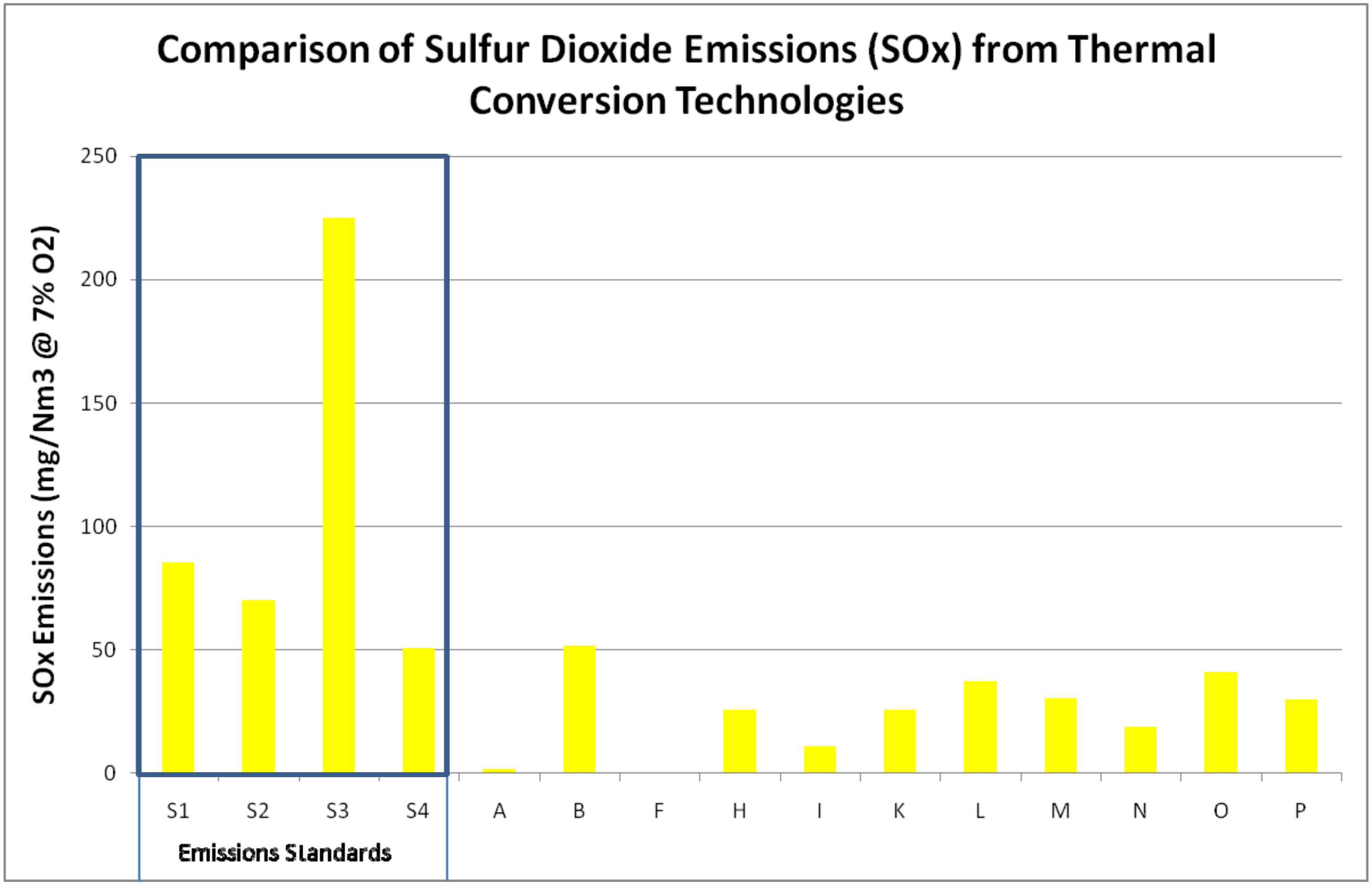

Figure 4 - Sulfur Dioxide Emissions Comparison

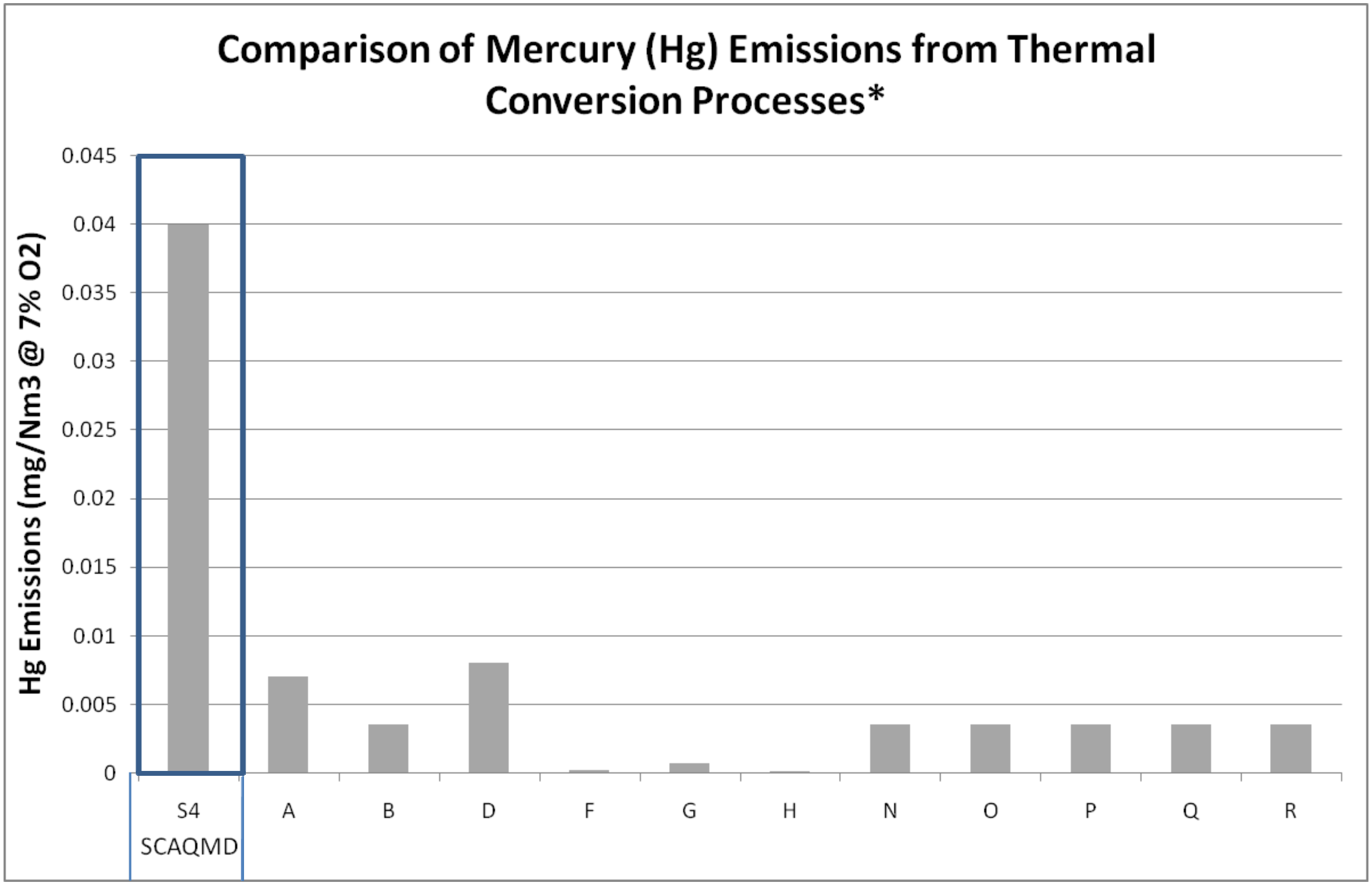

Figure 5 - Mercury Emissions Comparison

* US EPA limit (50 mg/Nm3) and EC 2000/76 limit (14 mg/Nm3) deleted for scale. There is no Japanese limit specific to Hg. Comparison to SCAQMD MSW Incinerator Permit Limit Only

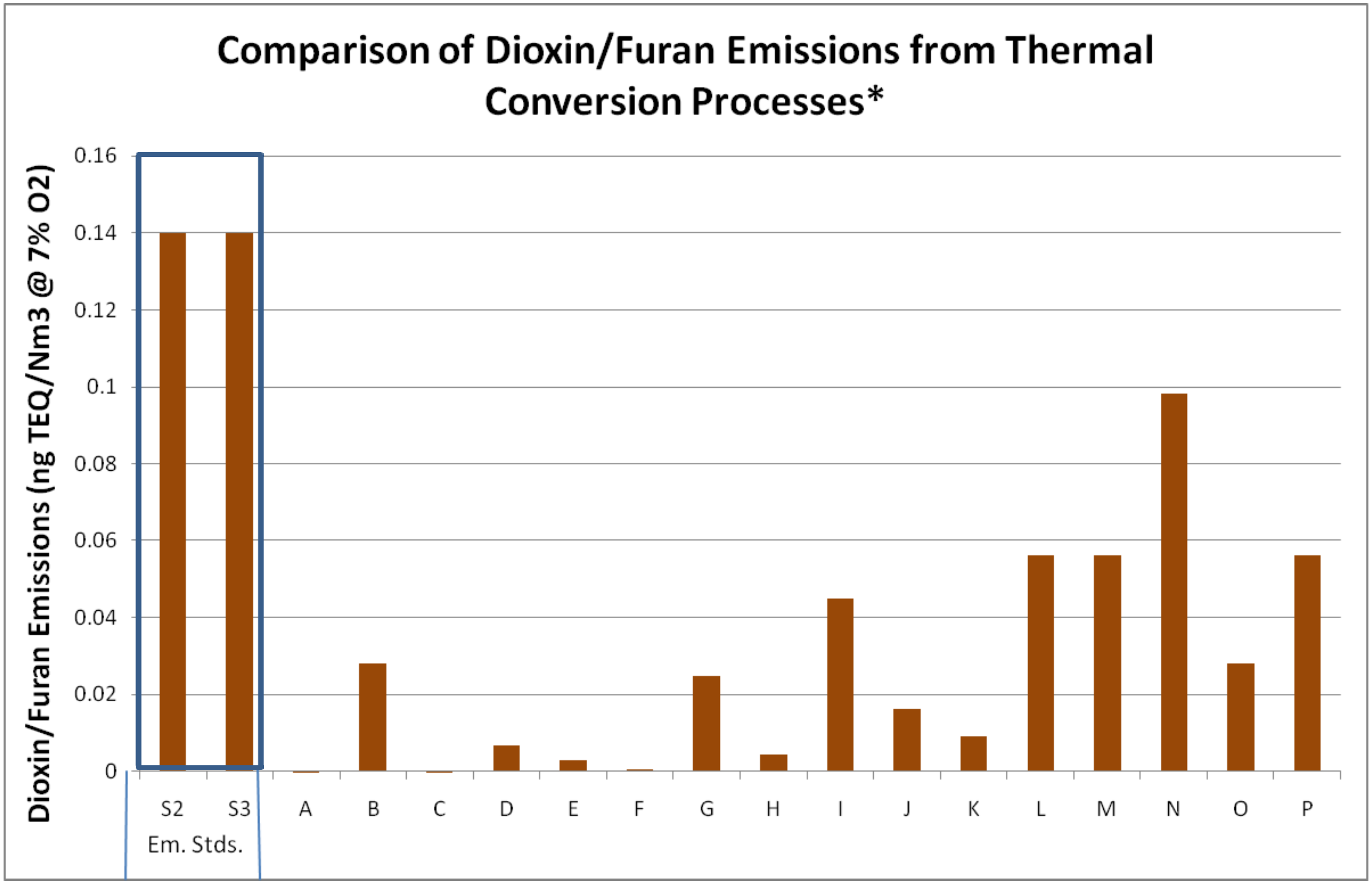

Figure 6 - Dioxins/Furans Emissions Comparison

* US EPA limit (13 ng/Nm^3) deleted for scale. There are no SCAQMD permit limits for dioxins/furans, as facilities are evaluated on an individual basis in a health risk assessment

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Emissions from Thermochemical Conversion Technologies

Emissions from Thermochemical Conversion Technologies in the U.S. Processing Non-Hazardous Waste Streams

In addition to the emissions results presented above, UC researchers were able to obtain independent, third-party emissions data from several gasification technology plants in the United States that process non-hazardous waste streams. The following provides summary descriptions, emissions results, and compliance limits for these plants.

Intrinergy

Founded in 2004, Intrinergy specializes in building, financing, owning, and operating renewable energy facilities. Intrinergy's plants in the United States and Europe convert biomass into renewable energy for industrial customers, reducing carbon emissions and their exposure to fossil fuel price volatility.

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For example, in late 2007, Intrinergy began simultaneously producing green electricity and thermal energy (steam) for a Mississippi paper mill facility. Its on-site energy unit provides up to 50,000 lbs/hour of process steam to fuel the mill's operations, saving the company an estimated 30% as compared to its previous fossil fuel operations. The Intrinergy facility reduces the mill's carbon dioxide emissions by 20,000 tons per year. The following Table presents compliance emissions results for this facility.[15]

Pollutant	Allowable	Measured
PM	0.03 lb/MMBtu	0.0184 lb/MMBtu
CO	0.22 lb/MMBtu	0.162 lb/MMBtu
NOx	0.22 lb/MMBtu	0.210 lb/MMBtu

Nexterra Energy

In late 2007, Nexterra Energy completed the installation of a gasification system that converts wood residues (known in the building materials industry as hog fuel) to provide 60,000 lbs/hour of high pressure steam for district heating and power for the University of South Carolina. The greenhouse gas reductions achieved by the plant are estimated to be more than 22,000 tons per year. The new system replaced two of three utility boilers fired on fossil-fuels.

Among other present and future projects:

- Nexterra Energy has been selected by the University of Northern British Columbia to supply and install a turnkey biomass gasification system to heat UNBC's Prince George campus and anchor its new Northern Bioenergy Innovation Centre.

[15] *Environmental Monitoring Laboratories, "Report of Air Emissions Test for Intrinergy, LLC – Nos.1 and 2 Wood-fired boilers*

- A Nexterra gasification system at Tolko Industries' plywood mill in Heffley Creek, British Columbia converts 27,500-tons per year of green bark wood residue into low-cost thermal energy. Tolko received the Canadian Industry Program for Energy Conservation (CIPEC) Leadership Award for switching from natural gas to the synthesis gas produced by Nexterra's biomass gasification system.

- Its biomass gasification system at Dockside Green in Victoria, British Columbia is now operational and providing heat and hot water to residents of this award-winning $600 million green development.

- Johnson Controls has ordered a Nexterra biomass gasification system to provide heat for the Oak Ridge National Laboratory campus, the US Department of Energy's largest science and energy research laboratory.

Nexterra provided compliance source test data[16] for a new plant operating at the University of South Carolina that gasifies wood waste to provide process heat and electricity. The following Table presents compliance emissions results for this facility.

Pollutant	Allowable	Measured
PM	0.03 lb/MMBtu	0.00221 lb/MMBtu
CO	NA	0.00430 lb/MMBtu
NOx	NA	0.176 lb/MMBtu
SO_2	3.5 lb/MMBtu	0.0534 lb/MMBtu

NA- Not Applicable

PrimeEnergy

PrimeEnergy has successfully developed a number of state-of-the art biomass gasification facilities at several locations in the United States. Three such plants are described below:

1) Lifeline Foods in Saint Joseph, Missouri is one of the most advanced biofuels plants in the nation, and its production method is the most efficient. By employing dry fractionation, the plant counters the food vs. fuel debate by first producing corn flour, corn meal, masa flour and extruded cereal & snack products. The softer endosperm of the corn kernel is then converted into 40 million gallons of fuel-grade ethanol per year through fermentation. The kernels that remain after the ethanol process are sold as animal feedstock.

168 tons per day of Corn Fiber are gasified using a Primenergy system to provide 60,000 lbs/h of steam to the plant, about 70% of the plant's requirement, thereby reducing the

[16] *GEL Engineering, LLC, "Results of the February 2009 Emissions Testing of the Biomass Gasification System – University of South Carolina," March 2009*

amount of natural gas consumed. Beyond simply producing ethanol from the starch, optimizing use of the whole kernel permits the production of food and animal feed from the proteins and oil and cellulosic ethanol from the bran, using approximately 60% less energy, 10-20% less water and less corn--and returning greater value to Lifeline.

2) Riceland Foods, Inc. owns and operates a large agricultural products storage and manufacturing complex in Stuttgart, Arkansas that consists of soybean oil and rice bran oil manufacturing plants, an edible oil refinery, grain receiving, storage and drying facilities. The facility also includes a rice hull thermal energy conversion system (TECS), which is comprised of three Primenergy Model R-318 gasifiers operating in parallel. The system gasifies 600 tons-per-day of rice hulls to produce a substitute natural gas, which in turn, fuels the production of 150,000 pph of steam and 12.8 MW of electricity. A permit to increase Stuttgart's gasification capacity to 800 tons-per-day was issued in 2008.

The company has a second plant in Jonesboro, Arkansas, which utilizes a Primenergy gasification system to process 175 tons-per-day of Rice Hulls, which provide process heat for rice boiling and 600º F heated air for drying.

The processing of rice for the consumer market is energy intensive. The rice must first be boiled and then dried prior to the removal of the outer hull or husk. Although the hull has an energy value of about one-half that of coal, silica contained in the hull melts into an agglomerating glass when burned by conventional industrial methods. Consequently, prior to the installation of the gasification systems, the hulls were disposed in landfill, ground into filler for animal feed, hauled away as animal bedding or stockpiled. The controlled, oxygen-starved atmosphere within the gasifier prohibits the formation of molten silica from the hull. It enables continuous operation, converting the expense of disposing of rice hulls into an energy asset.

3) Shaw Industries, the world's largest carpet manufacturer, produces and sells carpet, rugs, ceramic, hardwood and laminate flooring for residential and commercial applications throughout the world. At Shaw Carpet's Plant 81 in Dalton, Georgia, 80 tons per day of waste carpet and wood flour from laminate operations are converted to 50,000 lbs/hr of steam energy through gasification.

The Primenergy gasification unit replaced traditional coal-fired boilers that were used to create steam for carpet dyeing operations at Shaw's plants in Dalton. Carpet waste has the same pound-for-pound BTU range as coal. A partnership of Shaw and Siemens Building Automation & Technology, the facility is currently diverting from landfills approximately 16,000 tons of carpet waste and 6,000 tons of wood flour per year, while also reducing fuel oil consumption at this one manufacturing facility by 90%--more than 2.5 million gallons of fuel oil per year—at an annual savings for Shaw Carpet of as much as $2.5 million. The fiscal year compliance report for 2009 was obtained by UC researchers with the following emissions results.[17]

Pollutant	Allowable	Measured
PM_{10}	19.0 tons/year	1.57 tons/year
HAP/TAP	1.95 tons/year	1.96 tons/year
NOx	54 tons/year	29.46 tons/year

HAP/TAP – Hazardous Air Pollutants/Toxic Air Pollutants
NA- Not Applicable

[17] *Georgia Department of Natural Resources, "Fiscal Year Compliance Report – Shaw Industries, Inc., Plant 81," January 2009*

Conclusions

Thermochemical conversion technologies are technically viable options for the conversion of waste streams, including post-recycled municipal solid waste (MSW). This conclusion is based on the peer-reviewed information from the *Evaluation of Conversion Technology Processes and Product* report prepared by UC Riverside and UC Davis, the *Life Cycle and Market Impact Assessment of Noncombustion Waste Conversion Technologies* prepared by RTI International, and the independent evaluation of emissions from dozens of facilities worldwide. Thermochemical conversion technologies possess unique characteristics that have potential to substantially reduce the amount of material that is ultimately landfilled.

While no one technology is suitable for all waste streams, no single waste management practice, be it landfilling, recycling, composting, or conversion, can handle the full array of waste sources. Each can form part of an integrated waste management system, which is based on the idea of an overall approach for the management of waste streams, recyclable streams, treatment technologies, and markets.

Biological technologies and thermal technologies may each have advantages and disadvantages when compared to each other. However, the studies contain no scientific basis to classify one technology class as less favorable based solely on temperature ranges or the resulting product, which is subsequently combusted. If these were the sole criteria, then secondary smelting of aluminum and glass recycling would be looked at less favorably because of their high temperatures, which lead to dioxin formation. In addition, electricity production from biogas derived from anaerobic digestion or methane from landfills would also be looked at less favorably because the gas is combusted.

Independently-verified emissions test results show that thermochemical conversion technologies are able to meet existing local, state, federal, and international emissions limits. Today, there are advanced air pollution control strategies and equipment that were not available even ten years ago. It is obvious from the results that emissions control of thermochemical conversion processes is no longer a technical barrier. That said, it is recommended that facilities and agencies provide both continuous and periodic monitoring to keep the public informed and ensure ongoing compliance.

Thermochemical technologies can process a wider variety of feedstocks than biological processes, and can have a greater effect on landfill reduction. Thermochemical technologies can also produce a larger variety of products than incineration, which can displace the need for non-renewable traditional sources of energy and fuels. Other indirect effects include eliminating diesel truck trips and reducing landfill gas emissions.

APPENDIX – WORLDWIDE GASIFICATION LIST

Selected Worldwide Biomass Waste Conversion Facilities
(Employng Gasification and/or Pyrolysis Technologies)
(Partial List)

Location	Company (Technology)	Began Operation	Feedstock	Gasification/ Pyrolysis	Capacity	Syngas / Waste Heat Utilization
Kita-kyushu City (Shin-Moji), Jap	Nippon Steel	2007	MSW, Sludge	G	720 t/d	23.5 MW Power
Stuttgart, Arkansas, USA	Primenergy/Riceland	1996	Rice Hulls	G	600 t/d	Steam. Power
Kurashiki, Okayama Pref., Japan	Thermoselect/JFE	2005	MSW+Industrial	G	550 t/d	Fuel, Mizushima Works
Tokyo Rinki Recycle Power, Japan	Ebara	2006	Industrial Waste	G	550 t/d	23 MW Power
Narumi Clean System, Nagoya, Ja	Nippon Steel	2009	MSW	G	530 t/d	9 MW Power
Ibaraki City #1, Osaka Pref., Japa	Nippon Steel	1980	MSW/CFC Gas	G	450 t/d	5 MW Power
RER Aomori RE Recycling, Japan	Ebara	2001	Industrial Waste, ASR	G	450 t/d	17.8 MW Power
Yorii, Saltama Prefecture, Japan	Thermoselect/JFE	2006	MSW+Industrial	G	450 t/d	SNG for Steam Turbine
Kawaguchi City, Japan	Ebara	2002	MSW	G	420 t/d	12 MW Power
Toyohashi City, Japan	Mitsui R-21	2002	MSW	P	400 t/d	8.7 MW Power
Akita City, Akita Prefecture, Japa	Nippon Steel	2002	MSW, Sludge	G	400 t/d	8.5 MW Power
Oita City, Oita Pref., Japan	Nippon Steel	2003	MSW, Sludge	G	387 t/d	9.5 MW Power
Hamm, Germany	Techtrade	2002	MSW, Sewage Sludge	P	353 t/d	power generation
Chiba, Chiba Prefecture, Japan	Thermoselect/JFE	1999	Industrial Waste	G	330 t/d	Power for Steel Works
Kita-kyushu Eco Energy, Japan	Nippon Steel	2005	Industrial Waste, ASR	G	320 t/d	14 MW Power
Ibaraki #2, Osaka Pref., Japan	Nippon Steel	1996	MSW	G	300 t/d	3.3 MW Power
Ishhaya, Nagasaki Pref., Japan	Thermoselect/JFE	2005	MSW	G	300 t/d	SNG for Steam Turbine
Goyang City, Republic of Korea	Nippon Steel/Posco E&	2009	MSW	G	300 t/d	6 MW Power
Kagawa, Japan	Hitachi-Zosen	2004	MSW	G	300 t/d	Power Generation
Eco Valley, Utashinai City, Japan	Hitachi Metals	2004	MSW or ASW	Plasma	274 t/d	7.9 MW Steam Turbine
Koga Seibu, Japan	Mitsui R-21	2003	MSW	P	260 t/d	4.5 MW Power
Kazusa Clean System #2, Japan	Nippon Steel	2006	MSW, Sludge	G	250 t/d	5 MW Power
Ansbach, Germany	Thermoselect	2004	MSW	G	240 t/d	Power Generation
Yame Seibu, Japan	Mitsui R-21	2000	MSW	P	220 t/d	2.0 MW Power
Nishiiburi, Japan	Mitsui R-21	2003	MSW	P	210 t/d	2.0 MW Power
Nagareyama, Japan	Ebara	2004	MSW	G	207 t/d	3 MW Power
Izumo, Japan	Thide Environment	2003	MSW, Industiral & Sludge	P	70,000 t/y	Power Generation
Narashino City, Chiba Pref., Japan	Nippon Steel	2002	MSW, Sludge	G	201 t/d	2.4 MW Power

Emissions from Thermochemical Conversion Technologies

Location	Company (Technology)	Began Operation	Feedstock	Gasification/ Pyrolysis	Capacity	Syngas / Waste Heat Utilization
Itoshima Area, Fukuoka Pref., Jap	Nippon Steel	2000	MSW, Sludge, CFC gas	G	200 t/d	3 MW Power
Kazusa Clean System #1, Japan	Nippon Steel	2002	MSW, Sludge	G	200 t/d	3 MW Power
Yangsan City, Republic of Korea	Nippon Steel	2007	MSW	G	200 t/d	Hot Water Recovery
Ube City, Japan	Ebara	2002	MSW	G	198 t/d	4.1 MW Power
Sakata Area Clean Union, Japan	Ebara	2002	MSW	G	196 t/d	2 MW Power
Shiga Area Clean Union, Japan	Ebara	2007	MSW	G	180 t/d	3 MW Power
Lizuka City, Fukuoka Pref., Japan	Nippon Steel	1998	MSW, Sludge	G	180 t/d	1.2 MW Power
Tajimi City, Gifu Pref., Japan	Nippon Steel	2003	MSW, Sludge	G	170 t/d	2.0 MW Power
St. Joseph, Missouri, USA	Primenergy, Lifeline Fo	2006	Corn Fiber	G	168 t/d	Steam
Jonesboro, Arkansas, USA	Primenergy, Riceland	1997	Rice Hulls	G	168 t/d	Steam, Process Heat
Chuno Union, Japan	Ebara	2003	MSW	G	168 t/d	2 MW Power
Ishikawa, Japan	Hitachi-Zosen	2003	MSW	G	160 t/d	Power Generation
Genkai Environmental Union, Japa	Nippon Steel	2003	MSW, Sludge		160 t/d	2.4 MW Power
Kyoboku Regional, Japan	Mitsui R-21	2003	MSW	P	160 t/d	1.5 MW Power
Burgau, Germany	Technip/Waste Gen	1988	MSW, Sewage Sludge	P	154 t/d	power generation
Ibaraki #3, Osaka Pref., Japan	Nippon Steel	1999	MSW	G	150 t/d	1.7 MW Power
Nara, Japan	Hitachi-Zosen	2001	MSW	G	150 t/d	Power Generation
Shimada City, Shizuoka Pref., Jap	Nippon Steel	2006	MSW, Sludge	G	148 t/d	2.0 MW Power
Mutsu, Aomori Prefecture, Japan	Thermoselect/Mitsubisl Materials/JFE Sub-License	2003	MSW	G	140 t/d	SNG for Steam Turbine
Hata Regional Municipalities, Japa	Nippon Steel	2002	MSW, Sludge	G	140 t/d	1.8 MW Power
Ebetsu City, Japan	Mitsui R-21	2002	MSW	P	140 t/d	2.0 MW Power
Fukuroi City, Shizuoka Pref., Japa	Nippon Steel	2008	MSW	G	132 t/d	1.7 MW Power
Toyokawa Hoi Health Union, Japa	Nippon Steel	2003	MSW, Sludge	G	130 t/d	1.85 MW Power
Kagawa Prefecture #1, Japan	Nippon Steel	1997	MSW	G	130 t/d	1.6 MW Power
Trenton, Ontario, Canada	TRI/Norampac	2006	Black Liquor Solids	G	127 t/d	Steam
Arras, France	Thide Environment	2004	Household Wastes	P	40,000 t/y	Industrial Steam

Emissions from Thermochemical Conversion Technologies

Location	Company (Technology)	Began Operation	Feedstock	Gasification/ Pyrolysis	Capacity	Syngas / Waste Heat Utilization
Iryu Health Facilities Adm., Japan	Nippon Steel	1997	MSW	G	120 t/d	1.1 MW Power
Niigata City, Niigata Pref., Japan	Nippon Steel	2002	SW, Sludge, Landfill Wast	G	120 t/d	1.5 MW Power
Tokushima, Tokushia Pref., Japan	Thermoselect/JFE	2005	MSW	G	120 t/d	SNG for Steam Turbine
Nippon Steel, Nogoya Works, Japa	Nippon Steel	2006	Industrial Waste, ASR	G	120 t/d	Internal Steam Supply
Kamaishi City, Iwate Pref., Japan	Nippon Steel	1979	MSW/CFC Gas	G	100 t/d	Hot Water Recovery
Takizawa Village, Iwate Pref., Jap	Nippon Steel	2002	MSW	G	100 t/d	1.2 MW Power
Ottawa, Ontario, Canada	Plasco Energy	2008	MSW	Plasma	100 t/d	Power Generation
Izumi, Osaka Pref., Japan	Thermoselect/Kyokoto	2005	Industrial Waste	G	95 t/d	SNG for Steam Turbine
Minami-Shinshu, Japan	Ebara	2003	MSW	G	93 t/d	.8 MW Power
Seino Environmental, Japan	Nippon Steel	2004	MSW	G	90 t/d	Hot Water Recovery
Kameyama City, Mie Pref., Japan	Nippon Steel	2000	MSW, Landfill Waste	G	80 t/d	1.25 MW Power
Dalton, Georgia, USA	Primenergy, Shaw Carp	2006	Carpet Residues	G	80 t/d	Steam
Singapore	Entech Renewable Ene	1997	Food Processing Wastes	P	72 t/d	4.0 MWt (as Steam)
Kagawa Prefecture #2, Japan	Nippon Steel	2002	MSW	G	65 t/d	1.1 MW Power
Honshu, Yamagata Pref., Japan	Thermoselect/JFE	2007	wood chips	G	65 t/d	Power Generation
Korea	Entech Renewable Ene	2006	MSW	P	60 t/d	Power Generation
Hong Kong	Entech Renewable Ene	1990	MSW	P	58 t/d	Power Generation
Nagasaki, Japan	Hitachi-Zosen	2003	MSW	G	58 t/d	Power Generation
Heffley Creek, British Columbia	Nexterra	2006	Hog Fuel (Wood Residues)	G	27,600 t/y	Synthetic Natural Gas
Aalen, Germany	PKA	2001	MSW	P/G	27,000 t/y	SNG as energy source
Genting/Sri Layang, Malaysia	Entech Renewable Ene	1998	MSW (WDF)	P	60 t/d	6.9 MWt
Westbury, Canada	Enerkem	2008	creosoted urban wood	G	40 t/d	Ethanol
P.N.G.	Entech Renewable Ene	2003	MSW	P	40 t/d	Power Generation
Romoland, California, USA	IES	2007	MSW	P	40 t/d	SNG as energy source
Gifu, Japan	Hitachi-Zosen	1998	MSW	G	33 t/d	Power Generation
Geochang, South Korea	OE Gasification	2007	Curbside MSW	G	30 t/d	Steam or Hot Water
Chung Gung Municipality, Taiwan	Entech Renewable Ene	1991	MSW	P	30 t/d	2.3 MWt (Steam)

Emissions from Thermochemical Conversion Technologies

Location	Company (Technology)	Began Operation	Feedstock	Gasification/ Pyrolysis	Capacity	Syngas / Waste Heat Utilization
Korea	Entech Renewable Ene	2003	MSW	P	30 t/d	Power Generation
Bristol, United Kingdom	Compact Power	2002	Clinical & Special Waste	P/G	9,000 t/y	Heat for Autoclave
Richland, Washington, USA	InEnTech, LLC	2005	MSW	Plasma	25 t/d	SNG for biofuels, etc.
Bosung II, South Korea	OE Gasification	2006	Curbside MSW	G	25 t/d	Steam or Hot Water
Heanam, South Korea	OE Gasification	2003	Curbside MSW	G	25 t/d	Steam or Hot Water
Gangjin, South Korea	OE Gasification	2006	Curbside MSW	G	25 t/d	Steam or Hot Water
Mihama-Mikata, Japan	Hitachi Metals	2002	MSW and sewage sludge	Plasma	25 t/d	Hot Water for Heating
Global Plasma, Inc., Taiwan	InEnTech, LLC	2005	1edical & Industrial Waste	Plasma	25 t/d	Power Generation
Bosung I, South Korea	OE Gasification	2001	Curbside MSW	G	20 t/d	Steam or Hot Water
Pyungshan, South Korea	OE Gasification	2007	Curbside MSW	G	20 t/d	Steam or Hot Water
Hapchon, South Korea	OE Gasification	2007	Curbside MSW	G	20 t/d	Steam or Hot Water
Wiggins, Mississippi, USA	Intrinergy	2007	Chipped Wood Residues	G		Steam
Vancouver, British Columbia	Nexterra	2009	Urban Wood Residues	G	3,000 t/y	Heat & Hot Water
Australia	Entech Renewable Ene	1996	MSW (WDF)	P	15 t/d	Power Generation
Indonesia	Entech Renewable Ene	1998	MSW (WDF)	P	15 t/d	Power Generation
Chung Gung Municipality, Taiwan	Entech Renewable Ene	1992	MSW (WDF)	P	15 t/d	2.3 MWt (Steam)
Broomfield, Colorado	Range Fuels	2006	Timber & Forest Residues	G	5 t/d	Ethanol
Sherbrooke, Quebec, Canada	Enerkem	2003	MSW pellets	G	5 t/d	Ethanol
Scinopharm Corporation, Taiwan	Entech Renewable Ene	2002	harmaceutical Prod. Wast	P	15 t/d	3.5 MWt
Fayetteville, Arkansas, USA	INEOS Bio Pilot Plant	2003	MSW, wood waste, etc.	G	1.5 t/d	Ethanol
Poland	Entech Renewable Ene	2004	iohazardous Waste (WDF	P	3.5 t/d	5.6 MWt
Broomfield, Colorado	Range Fuels	2006	Timber & Forest Residues	G	5 t/d	Ethanol
Sherbrooke, Quebec, Canada	Enerkem	2003	MSW pellets	G	5 t/d	Ethanol
Scinopharm Corporation, Taiwan	Entech Renewable Ene	2002	harmaceutical Prod. Wast	P	15 t/d	3.5 MWt
Fayetteville, Arkansas, USA	INEOS Bio Pilot Plant	2003	MSW, wood waste, etc.	G	1.5 t/d	Ethanol
Poland	Entech Renewable Ene	2004	iohazardous Waste (WDF	P	3.5 t/d	5.6 MWt