Solid Waste Conversion:

A review and database of current and emerging technologies

FINAL REPORT

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Abstract

A preliminary investigation was conducted of technologies and processes that are or can be utilized to convert post-recycled and/or post-consumer solid waste into useful products. A database of companies or organizations with recent activity or interest in MSW conversion has been developed. Of a total 400 entities identified, 28 companies with existing, near term commercial or commercial scale MSW conversion facilities have been identified and a brief synopsis of each of their systems is provided. Several jurisdictions in California and elsewhere that are investigating alternatives to land filling were identified and progress reviewed. A large body of literature was accessed and accumulated in the course of the work and is appended to the report. The database, available in electronic format, is also accessible through the internet. The database includes information on thermochemical, biochemical, and physicochemical technologies providing fuels, electricity, and products from solid waste, and is intended to aid in the implementation of solid waste landfill alternatives in California.

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Nomenclature

AD	anaerobic digestion
ADC	alternative daily cover
ASR	automobile shredder residue
BFB	bubbling fluidized bed
BGL	British Gas- Lurgi
BIGCC	Biomass integrated gasifier combined cycle
BTU	British Thermal Unit
CC	Combined Cycle
C&D	construction and demolition
C/N	carbon/nitrogen ratio
ca	capita
CADDET	Centre for Analysis and Dissemination of Demonstrated Energy Technologies
CEC	California Energy Commission
CFB	circulating fluidized bed
CIWMB	California Integrated Waste Management Board
d	day
DOE	Department of Energy
EC	European Community
EJ	10^{18} joules (exajoule)
FT	Fischer-Tropsch
GAIA	Global Anti-Incinerator Alliance
GWh	gigawatt-hour (10^{9} watt-hours)
h	hour
HHV	higher heating value
HRSG	heat recovery steam generator
HS	high solids
IEA	International Energy Agency
IGCC	Integrated Gasifier Combined Cycle
kg	kilogram
kW	kilowatt
kWh	kilowatt - hour
LS	low solids
MBT	mechanical biological treatment
MJ	10^{6} joules (megajoule)
MMBTU	million BTU
MRF	material recovery facility
MS	multi-stage
MSW	Municipal Solid Waste
Mt	million short tons
MW	Megawatt
MWe	Megawatt of electricity
MWh	Megawatt-hour
MW_{th}	Megawatt of heat
NETL	National Energy Technology Laboratory
NREL	National Renewable Energy Laboratory

Nomenclature (continued)

ofMSW	organic fraction of MSW
OS	one-stage
Quad	10^{15} BTU (Q)
RDD&D	research, development, demonstration and deployment
RDF	refuse derived fuel
REOI	Request for Expression of Interest
RFI	Request for Information
RFP	Request for Proposal
Short ton	US Customary ton (2000 lb)
ton	short ton (2000 lb)
tonne	metric ton (1000 kg = 1 Mg)
TWh	Terawatt-hour (10^{12} watt-hours)
wb	wet basis
y	year

Introduction

The California Integrated Waste Management Board (CIWMB) contracted with the University of California, Davis, Department of Biological and Agricultural Engineering to conduct a preliminary investigation of technologies and processes that are or can be utilized to convert post-recycled and/or post-consumer solid waste into useful products.

This Interagency Agreement is intended to develop information to aid CIWMB staff in making informed decisions and recommendations for implementing solid waste conversion technology in California. The work was originally divided into four tasks, including,

1. Literature search and review,
2. Development of evaluation criteria,
3. Conversion technology evaluation, and
4. Final report

The project was reorganized to focus on the literature review and identification of processes and suppliers relating to solid waste conversion. A database has been developed containing information on the entities identified over the course of the project. A certain number of existing, near term commercial or commercial scale MSW conversion facilities have been identified and some preliminary descriptions and evaluations of these facilities are included in this report (Tables 4 and 5 and Appendices 1 and 2).

Several waste management jurisdictions in the State and elsewhere that are actively pursuing alternatives to landfill technology were identified. This is not a comprehensive list (even for the state), but those listed embody a range of goals and limitations for the final selected alternative. Two jurisdictions with the most active or advanced searches are City and County of Santa Barbara and City of Toronto, Ontario. Santa Barbara has conducted a search for landfill alternative processes and companies, developed an evaluation methodology, issued two rounds of requests for information (RFI) and developed a 'short list' of seven companies. Toronto maintains a database of suppliers and has received responses to their request for expression of interest (REOI) which are currently being evaluated. The list and short descriptions appear in Appendix 3.

The most useful sources and references used in compiling the database are given in the database section. In addition, key references used in describing the commercial/near-term commercial facilities are within the respective technology appendix (Appendices 1 or 2). A large body of literature was accessed and accumulated in the course of the project. A bibliography of this literature is contained in Appendix 4, arranged by principal topical areas.

A more detailed follow-on project has been awarded by CIWMB to UCR in cooperation with UCD. The database developed in this preliminary project is being used as the working list for the purposes of conducting an industry survey.

Background

Though California diverts approximately 48% of its solid waste, the state still sent 37.5 million tons to landfill in 2002. Of this, about 80% is organic material (paper, wood, plastics, garden and food wastes). In the past 10 years, the amount of organic material annually diverted from landfill has grown from about 2 million tons to approximately 8 million tons and the number of facilities using or converting this waste fraction has grown from 10 composting facilities to 170 operations (includes composting, mulching, alternative daily cover [ADC], combustion facilities that burn or co-fire urban wood waste, and three dedicated mass burn facilities)[1].

The California Integrated Waste Management Board (CIWMB) recognizes that the existing market for organic material utilization is not sufficient to consume the state's production of organic waste. Furthermore, it has become evident that there are barriers to increased diversion of organic material that are not simply or wholly economic based. Among these barriers are certain statutory/regulatory restraints, and a lack of data on potential technologies and markets[2]. Recommendations for addressing the identified barriers include new legislation (i.e., recently enacted AB 2770), and the initiation of information gathering activities such as technology, life-cycle analysis, and market assessments, and possibly, grants for research, development, and demonstration (RDD) projects.

Continuing to landfill large amounts of organic material may not be in the best interest of California or society as a whole. Reasons why reducing organic material in landfills is desirable include:

- existing landfills have finite capacity and there is much expense and controversy associated with opening new capacity,
- reduces odors and animal pests such as rodents and birds,
- enables long term environmental benefits including reductions in greenhouse gas emissions,
- diverts the organic fraction of solid waste for other uses such as energy, fuels, chemicals, and industrial materials.

Estimate of energy available for solid waste currently disposed

The amount of material currently sent to landfill in California represents a substantial resource. Table 1 contains an analysis of the total energy and the electricity generation potential represented by the California MSW stream currently going to landfill. For each component of the waste stream, the table lists amount landfilled, typical moisture and ash contents and higher heating values (HHV) in both as-received and moisture-free basis. Of the 37.5 million tons landfilled, some 25.5 million tons are of biological origin, 4 million tons are plastics and textiles (assumed to be all synthetic textiles), and the

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[1] Conversion Technologies for Municipal Residuals, a Background Primer. 2001, CIWMB Staff and the CEC Power Plant Database at http://www.energy.ca.gov/database/index.html#powerplants

[2] See findings (Barriers and Recommendations) from May, 2001 'Conversion Technologies for Municipal Residuals' forum at: http://www.ciwmb.ca.gov/Organics/Conversion/Events/TechForum00/

Table 1 California disposed waste stream characterization and potential for generation of electrical power.

CA disposed MSW by type, equivalent primary energy represented and corresponding electricity generation potential.	Landfilled[a] (Mt)	% of Total	Ash[b] (% wb)	Ash (Mt y^{-1})	HHV[b] (MJ/kg, ar)	HHV contribution to composite stream (MJ kg^{-1} as received)	Moisture[b] (%wb)	Landfilled (Mt dry)	HHV (MJ/kg, dry)	Primary Energy by Component (EJ)[c]	Primary Energy by Component (%)	Electricity Potential[d] (MWe)	(GWh y^{-1})
Paper/Cardboard	11.3	30.2	5.3	0.6	16	4.83	10	10.2	17.8	0.164	44	1040	9,115
Food	5.9	15.7	5.0	0.3	4.2	0.66	70	1.8	14.0	0.022	6	200	1,752
Leaves and Grass	3.0	7.9	4.0	0.1	6	0.48	60	1.2	15.0	0.016	4	73	640
Other Organics	2.6	7.0	10.0	0.3	8.5	0.59	4	2.5	8.9	0.020	5	128	1,119
C&D Lumber	1.8	4.9	5.0	0.1	17	0.84	12	1.6	19.3	0.028	8	180	1,577
Prunings, trimmings, branches and stumps	0.9	2.4	3.6	0.03	11.4	0.27	40	0.5	19.0	0.009	2	58	509
Biomass Components of MSW Total	**25.5**	**68.1**		**1.4**		**7.7**		**17.8**		**0.26**	**70**	**1679**	**14,712**
All non-Film Plastic	1.9	5.0	2.0	0.04	22	1.11	0.2	1.9	22.0	0.038	10	238	2,085
Film Plastic	1.5	3.9	3.0	0.04	45	1.75	0.2	1.5	45.1	0.059	16	376	3,298
Textiles	0.8	2.1	7.0	0.06	17.4	0.37	10	0.7	19.3	0.012	3	79	693
Non-Biomass Carbon Compounds Total	**4.1**	**11.0**		**0.14**		**3.22**		**4.0**		**0.11**	**30**	**694**	**6,075**
Other C&D	2.5	6.6	100	2.5	0	0		2.5					
Metal	2.3	6.1	100	2.3	0	0		2.3					
Other Mixed and Mineralized	2.0	5.3	100	2.0	0	0		2.0					
Glass	1.1	2.9	100	1.1	0	0		1.1					
Mineral Total	**7.8**	**20.9**		**7.8**		**0.0**		**7.8**		**0**	**0**	**0**	**0**
Totals	**37.4**	**100**		**9.3**		**10.89**		**29.6**		**0.370**	**100**	**2373**	**20,787**

a) California waste stream composite data (http://www.ciwmb.ca.gov/WasteChar/Study1999/OverTabl.htm), Accessed 1 Sept., 2003

b) Adapted from Tchobanalglous, G., Theisen, H. and Vigil, S.(1993),"Integrated Solid Waste Management", Chapter 4, McGraw-Hill, New York & Themelis, N. J., Kim, Y. H., and Brady, M. H. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research, 20(3), 223-233.

c) EJ = 10^18 J (exajoule) and is approximately equal to 1 Quad (1 Q = 1.055 EJ)

d) Electricity calculations assume thermal conversion means for low moisture stream (paper/cardboard, other organics, C&D Lumber, all plastics and textiles) and biological means (anaerobic digestion) for high moisture components (food and green waste). Energy efficiency of conversion of matter to electricity by thermal means is assumed to be 20%. Biomethane potentials of 0.29 and 0.14 g CH4/g VS for food and leaves/grass mixture respectively are assumed for biogas production which is converted at 30% thermal efficiency in reciprocating engines. Capacity factor of 1 is used.

remaining 8 million tons are mineral and other inorganic material (glass, metal, non wood construction/demolition waste). Potential primary energy estimates were made by simply multiplying the appropriate material energy content on a per weight basis (HHV) by the amount of that material available. This is done for each component in the waste stream.

For estimating the amount of electrical generation capacity that could be developed from the current disposed waste stream, it was assumed that the stream would be divided based on moisture content. The high moisture components are perhaps most appropriately converted through biochemical systems (anaerobic digestion, for example). Though anaerobic digestion (AD) is suitable for high moisture feedstocks, a major disadvantage of AD is that conversion is incomplete; some 50% of the organic material is not converted. Lignin and other recalcitrant organics are not converted and remain as residue for composting[3] or landfill. The aerobic processing of digester sludge through composting can further reduce volume, but anaerobic conditions maintained in most landfills may not reduce volume except over very long periods of time. If only the produced biogas is converted to electricity (no energy production from the digestate), this process has an overall energy conversion efficiency (electrical energy out/waste stream energy in) of about 10% or less.

The lower moisture components are assumed to be converted by thermal means (gasification, pyrolysis, or combustion). The energy and/or heat in the product gases can be used in a boiler to run a steam cycle[4] or the gases (from a gasifier or pyrolyzer) can run a gas engine or turbine for electricity production. These methods have overall energy efficiencies of electrical generation of 20-25%. The Table 1 estimate uses 20% for thermal conversion to electricity efficiency (Biomass integrated gasifier combined cycles[5], BIGCC, have projected electrical conversion efficiencies of 35% or above, but are not yet fully commercial. Natural gas fired combined cycles have electrical efficiencies above 55% by comparison, but utilize non-renewable fuel. The application of combined cycles to biogas produced by anaerobic digestion is a possibility but digesters tend to be small for the scales typically employed, and

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[3] Composting may or may not degrade these components further.

[4] The Rankine vapor power cycle is the most widely used thermal cycle for electrical power generation throughout the world. It is commonly called a 'steam cycle' when the working fluid is water. It consists of a boiler where heat is added to liquid phase pressurized working fluid (water) to create a high temperature and pressurized vapor (steam if the working fluid is water). The high pressure steam is expanded across a turbine which turns a generator creating electrical power. The low pressure steam coming out of the turbine is condensed to liquid by cooling after which the pressure of the relatively low temperature liquid is raised by a boiler feed pump or pumps to repeat the cycle. Rankine cycle efficiencies depend on plant size, fuel, and design and typically vary from about 10% for very small (< 1 MWe) solid-fueled systems to greater than 40% for large (>500 MWe) supercritical units. Typical solid-fueled biomass and waste fired power plants (~10-100 MWe) have net efficiencies of about 17-25%.

[5] Integrated gasifier combined cycles (IGCC), are combined cycle systems that incorporate a gasifier for the purposes of converting the solid fuel to a fuel gas for the gas turbine topping cycle. Combined cycle (CC) power systems can extract more useful energy from a given amount of input energy or fuel by utilizing two power cycles in combination: 1) a gas turbine topping cycle and 2) a steam bottoming cycle utilizing heat rejected in the gas turbine exhaust. In such systems, the steam boiler is conventionally referred to as a heat recovery steam generator (HRSG). Gas turbines require a very clean working fluid. Using gasified biomass or coal as a turbine fuel requires extensive cleanup before introduction to the turbine in direct fired systems similar to those employing natural gas fuel. Indirect gas turbines employ heat exchangers between the combustion products and the turbine working fluid to avoid turbine fouling from impurities, but are not yet commercial due to limitations in materials for high temperature heat exchangers. Gasification of solid fuels for IGCC is also not yet being done commercially. Gas cleaning is one of the primary technical hurdles for solid fuel gasification systems fueling internal combustion engines including reciprocating (piston) engines and gas turbines (though piston engines have less stringent gas cleanliness requirements). Gasifiers are currently fueling boilers and have been used with coal for liquid fuels production, for example, the SASOL plant in South Africa. Natural gas and distillate fueled CC systems are fully commercial.

digestion of MSW or MSW organics is still developmental for the most part in North America. Biogas co-fired with natural gas in large combined cycle power plants is a way to improve net efficiency of biogas to electricity production if the opportunity exists Fuel cells offer another high efficiency and clean option for biogas and fuel gases produced by thermochemical means, but these systems are also developmental and fuel purification is an issue.

In Table 1, the electrical generation estimates were simply calculated from the potential primary energy by applying the appropriate thermochemical or biochemical conversion efficiency and assuming an availability of 100% (meaning the conversion facilities operate only 100% of the time).

The resulting electrical energy potential from California MSW is substantial. About 1670 MWe of generation could be supported by the biogenic material (25.5 million tons) in the landfill disposal stream, and another 690 MWe from the plastics and textiles components. Figure 1 displays some of Table 1 information graphically; the waste stream component disposal amounts and their associated potential electric energy (annual basis).

The sum of 2370 MWe is about 5% of total electrical capacity available to the state, and the electrical energy potential is about 8% of state consumption.[6] Electrical potential from the renewable (biogenic) portion of the stream is equivalent to about 50% of the current amount of renewable electricity used in the State from all sources.[7] Full conversion to electricity is unlikely, but solid waste nonetheless represents a significant potential source of energy for the state[8].

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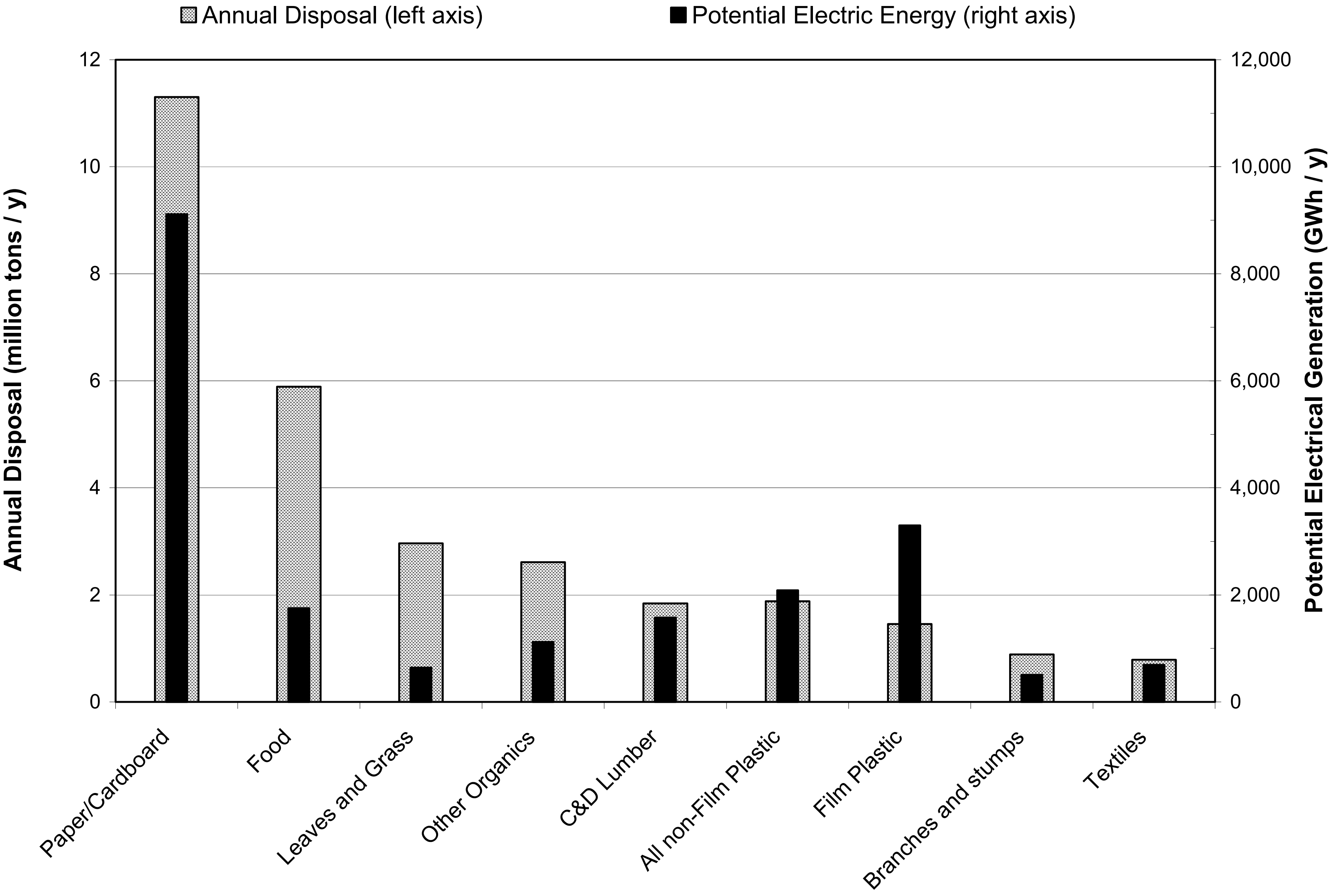
[6] Electricity consumption in California is ~ 275 TWh y^{-1}. Source: California Energy Commission.

[7] http://energy.ca.gov/electricity/gross_system_power.html To the extent that plastics made from petroleum or tires are used in conversion to energy, that portion of the energy produced would not be considered renewable.

[8] This analysis applies only to the current waste stream going to landfill. CIWMB estimates that approximately 8 million tons of MSW material go to compost, ADC, or solid fuel combustion facilities annually and only ~31% (4.8 million tons/y) of waste paper is diverted ((1997), http://www.ciwmb.ca.gov/Paper/ Accessed October, 2003) The amount of urban wood waste or C&D lumber estimated to be currently consumed in power production facilities is 1. 5 million t y^{-1}.



* See Table 1 for assumptions used in determining electric generation potential

Figure 1 Waste stream component disposal amounts and potential electric energy (annual basis).

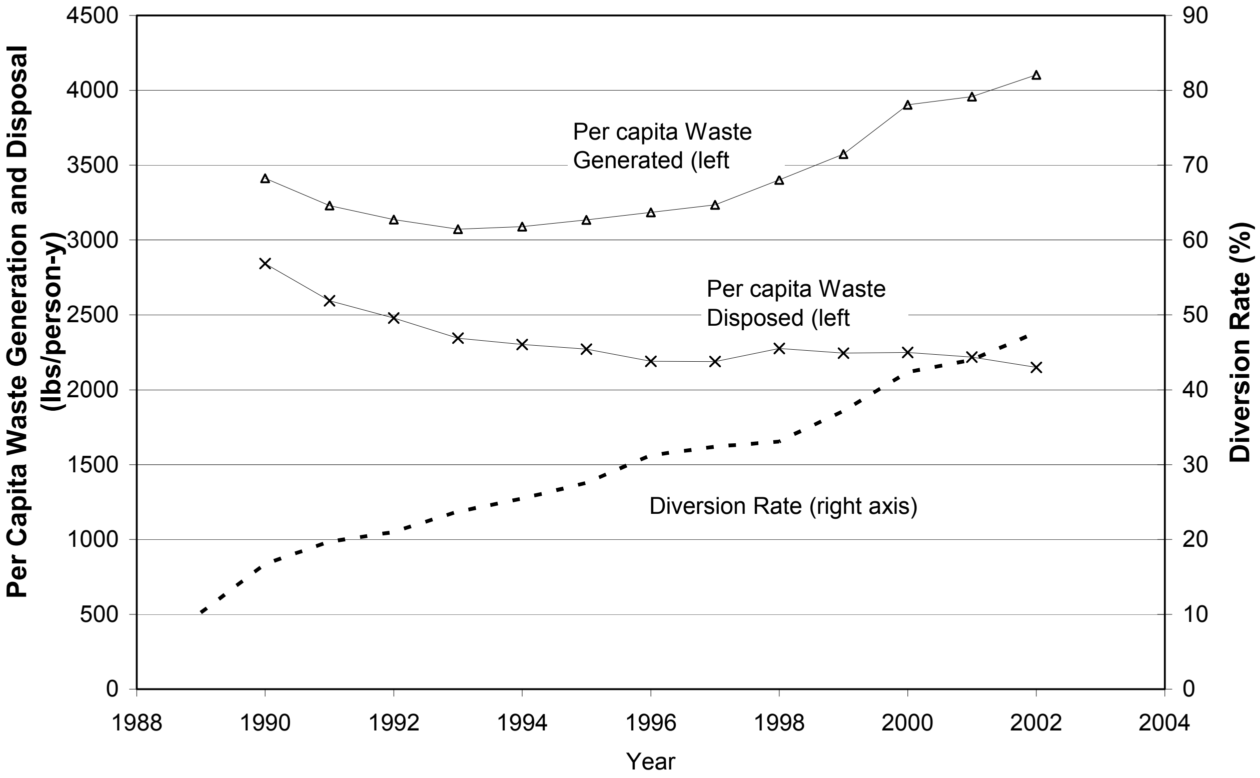


Figure 2 Historical per-capita waste generation and disposal in California (all waste generation sources) and associated waste diversion rate.

Future Waste Disposal Estimate

The amount of waste generated and disposed of in the state is not static. In 1990, the State disposed in landfills some 42 million tons[9], so diversion efforts certainly have been successful. The amount disposed reached a minimum (in recent history) in 1996 when 35 million tons were landfilled. Since then, the disposal amount has been increasing due to increased population and economic activity. While economic activity has probably tapered off (along with some commercial waste generation) due to the downturn in the economy since 2000, population continues to increase and is projected to expand at about 1.3-1.4% y^{-1} for the next several years[10]. From the historical landfill tonnage and population data, the per capita waste generated and disposed in the State can be estimated (Figure 2). The figure shows per capita waste generation and disposal as well as the amount of waste diverted from landfill (in % of the estimated generation). These data are for all generation sources; industrial, commercial and residential. The data reveal a somewhat surprising trend, in that the waste generated per capita has increased more than 35% since the low in 1993. The amount of material disposed per capita has decreased about 22% from the high in 1990, but has remained nearly constant since 1995 (2100-2200 lbs. ca^{-1} y^{-1}). The increase in diversion as shown in Figure 2 manages the increase in

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[9] http://www.ciwmb.ca.gov/lgcentral/Rates/Diversion/RateTable.htm Accessed June, 2003
[10] http://www.dof.ca.gov/html/demograp/druhpar.htm (Dept. of Finance Demographic Research Unit, State of California)

generated waste, not affecting the per capita disposal amount. Associated with these results are questions relating to the accuracy of the data and the effectiveness of the diversion regulations in encouraging reductions in overall waste generation.

If the per capita disposal remains constant as it has in recent years, total amount sent to landfill will simply rise with population. If waste generation per capita continues to rise, but diversion rate does not continue to increase to match, then waste going to landfill will again begin to increase. Major changes in recycling, compost markets, and conversion will be needed to enable continuing diversion from landfill. Three scenarios predicting the amount of waste going to landfill out to the year 2010 are shown in Figure 3. The assumptions and scenarios are described as follows,

> Each scenario uses a population growth rate of 500,000 y^{-1} (~ 1.4% of year 2003 population)[10] and year 2003 diversion is set at 50% (2002 reported diversion is 48%).
>
> Trend A assumes the current per-capita disposal (2100 lbs [950 kg] ca^{-1} y^{-1}) will remain constant (diversion keeps growing with total waste generated and population).
>
> Trend B has per-capita generation increasing at current rates of increase (~139 lbs [63 kg] ca^{-1} y^{-2}, with ~4100 lbs [1860 kg] ca^{-1} y^{-1} 2003 baseline) with diversion allowed to peak at 55% in 2006 and constant thereafter.
>
> Trend C uses constant per-capita generation (~4100 lbs [1860 kg] ca^{-1} y^{-1}) and diversion increasing to 55% by 2006, constant thereafter.

All three estimated trends predict increasing landfill amounts after 2006 (when diversion is capped at 55% by assumption, Trend C). Predictions A and B surpass current (2002) landfill tonnage around 2005 and B then climbs quite quickly at about 1.7 million tons y^{-2}.

The conclusion is that with the current trends of increasing population and invariant per-capita disposal, waste disposal in the State can be expected to increase substantially even with a state-wide diversion rate of 55%. Without major changes in consumption patterns, economic activity, packaging methods and material, and/or compost and recycle markets, there will be continued long term opportunity and need for utilization of components in the waste stream. Any single strategy for reduction of landfill materials is not likely to be sufficient. Increased recycling and composting, reduction in waste generation, and safe and reliable conversion technologies can each contribute to reducing or stabilizing the landfilled waste stream, but a combination of all potential reduction schemes will probably have the best chance for success.

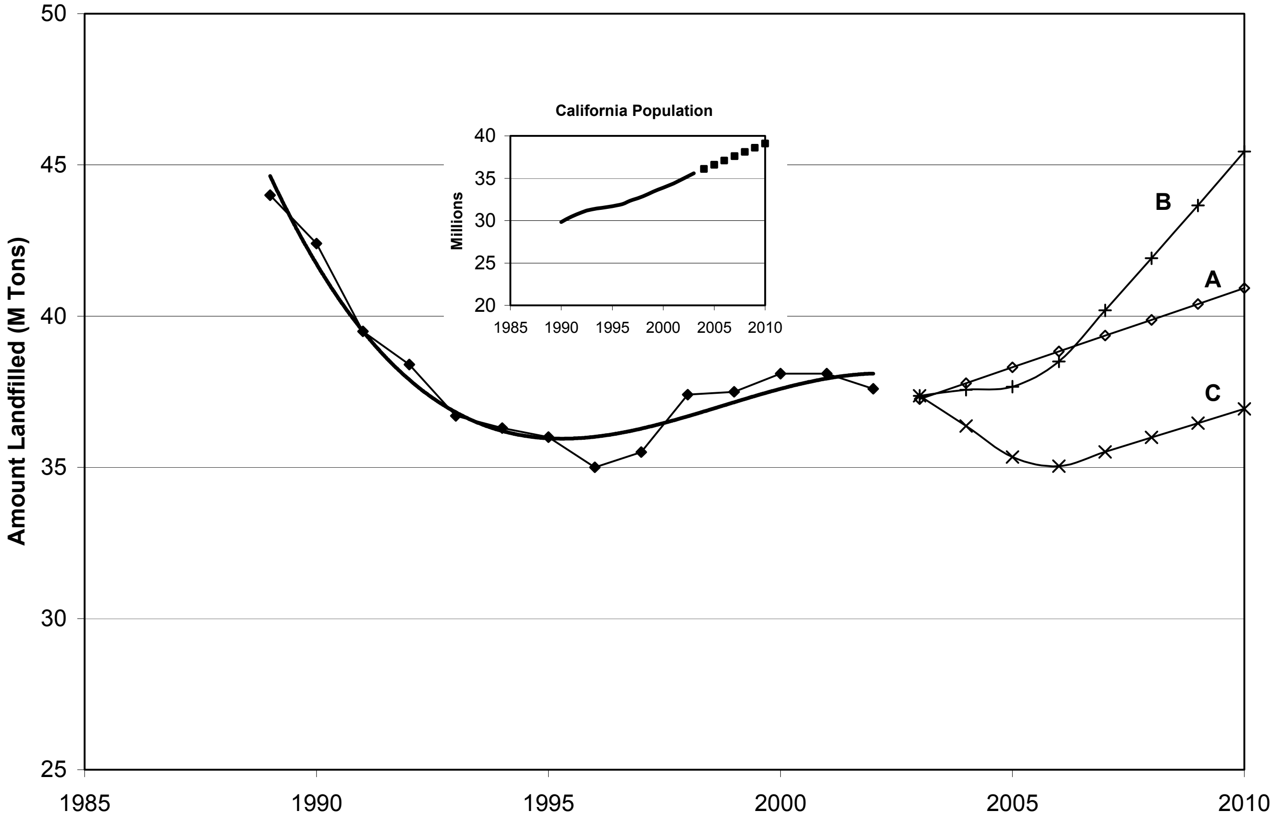

Figure 3 Historical landfill tonnage and estimates for future amounts with population (inset).

Conversion Pathways

Conversion of organic material can proceed along three main pathways—thermochemical, biochemical, and physicochemical. Currently, all three pathways are utilized to various extents.

Thermochemical conversion is characterized by higher temperature and conversion rates. It is best suited for lower moisture feedstocks and is generally less selective for products.

Thermochemical conversion processes include:

Combustion	oxidation of the fuel for the production of heat at elevated temperatures without generating commercially useful intermediate fuel gases, liquids, or solids. Flame temperatures range typically between 1500 and 3000 ºF depending on fuel, stoichiometry, furnace design, and system heat loss. Particle temperatures in heterogeneous combustion can differ from gas temperatures depending on radiative conditions. Combustion of solids involves the simultaneous processes of heat and mass transport, pyrolysis, gasification, ignition, and burning, with fluid flow. Normally employs excess oxidizer to ensure maximum fuel

	conversion, but also can occur under fuel rich conditions. Products of combustion processes include heat, oxidized species (e.g. CO_2, H_2O), products of incomplete combustion and other reaction products (most as pollutants), and ash. Other processes, such as supercritical water oxidation and electrochemical oxidation can produce similar end products at lower temperatures.
Gasification	typically refers to conversion via partial oxidation using substoichiometric air or oxygen or by indirect heating to produce fuel gases (synthesis gas, producer gas), principally CO, H_2, methane, and lighter hydrocarbons in association with CO_2 and N_2 depending on process used. Gasification processes also produce liquids (tars, oils, and other condensates) and solids (char, ash) from solid feedstocks. Gasification processes are designed to generate fuel or synthesis gases as the primary product. Fuel gases can be used in internal and external combustion engines, fuel cells, and other prime movers. Gasification products can be used to produce methanol, Fischer-Tropsch (FT) liquids[11], and other fuel liquids and chemicals. Gasification of solids and combustion of gasification-derived fuel gases generates the same categories of products as direct combustion of solids, but pollution control and conversion efficiencies may be improved.
Pyrolysis	a process similar to gasification except generally optimized for the production of fuel liquids (pyrolysis oils) that can be used straight (e.g. as boiler fuel) or refined for higher quality uses such as engine fuels, chemicals, adhesives, and other products. Pyrolysis also produces gases and solids from solid feedstocks. Usually, processes that thermally degrade material without the addition of any air or oxygen are considered pyrolysis. Pyrolysis and combustion of pyrolysis-derived fuel liquids and gases also produce the same categories of end products as direct combustion of solids, but like gasification, pollution control and conversion efficiencies may be improved. Direct pyrolysis liquids may be toxic, corrosive, oxidatively unstable, and difficult to handle. Generation of refined fuel liquids has advantages in fuel handling and distributed or mobile power generation.
	Plasma arc and radio frequency (or microwave) heating refer to specific devices providing heat for gasification, pyrolysis, or combustion depending on the amount of oxygen fed to the reactor. Catalytic cracking employs catalysts in the reaction to accelerate the breakdown of high molecular weight compounds into smaller products for the purposes of improving selectivity and imparting certain

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[11] Fischer-Tropsch synthesis is a process for producing mainly straight-chain hydrocarbons (C_xH_y) from a synthesis gas rich in CO and H_2. Catalysts are usually employed. Typical operating conditions for FT synthesis are temperatures of 390-660°F and pressures of 15-40 atmospheres depending on the desired products. The product range includes the light hydrocarbons methane (CH_4) and ethane (C_2), LPG (C_3-C_4), gasoline (C_5-C_{12}), diesel (C_{13}-C_{22}), and waxes (>C_{23}). The distribution of the products depends on the catalyst and the process conditions (temperature, pressure, and residence time). The synthesis gas must have very low tar and particulate matter content. Biomass derived synthesis gas for FT liquid production is still developmental due to gas cleaning issues. (See Boerrigter, H. and H. den Uil (2002). Green Diesel from Biomass via Fischer-Tropsch synthesis: New Insights in Gas Cleaning and Process Design. Pyrolysis and Gasification of Biomass and Waste, Expert Meeting, Strasbourg, France.)

desirable characteristics to the final product, such as volatility and flashpoint of liquid fuels.

Biochemical conversion proceeds at lower temperatures and lower reaction rates but tends to offer greater selectivity in products than thermochemical conversion. Higher moisture feedstocks are generally good candidates for biochemical processes.

Biochemical conversion processes include:

Anaerobic digestion

a fermentation technique typically employed in some waste water treatment facilities for sludge degradation and stabilization but also the principal process occurring in landfills. Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane and carbon dioxide but frequently carrying impurities such as moisture, H_2S, siloxane, and particulate matter. Anaerobic digestion requires attention to the nutritional demands of the facultative and methanogenic bacteria degrading the waste substrates. The carbon/nitrogen (C/N) ratio of the feedstock is especially important. Biogas can be used as fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, and the manufacturing of chemicals.

Aerobic conversion

including, for example, composting and activated sludge waste water treatment processes. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Nutritional considerations are also important to the proper functioning of aerobic processes. Aerobic processes operate at much higher rates than anaerobic processes, but generally do not produce useful fuel gases.

Fermentation generally used industrially to produce fuel liquids such as ethanol and other chemicals. Also operates without oxygen. Although fermentation and anaerobic digestion are commonly classified separately, both are fermentation methods designed to produce different products. Cellulosic feedstocks, including the majority of the organic fraction of MSW, need pretreatment (acid, enzymatic, or hydrothermal hydrolysis) to depolymerize cellulose and hemicellulose to monomers used by the yeast and bacteria employed in the process. Lignin in biomass is refractory to fermentation and as a byproduct is typically considered for use as boiler fuel or as a feedstock for thermochemical conversion to other fuels and products.

Physicochemical conversion

involves the physical and chemical synthesis of products from feedstocks and is primarily associated with the transformation of fresh or used vegetable oils, animal fats, greases, tallow, and other suitable feedstocks into liquid fuels or biodiesel, frequently by transesterification (reaction of glyceride with alcohol in the presence of catalyst).

Database

The main effort and primary product of this project has been the compilation of a current database of companies, institutions, and organizations with activity or interest in conversion technology suitable for MSW. Entities involved in any type of conversion with the exception of incineration and using either the whole or separated fractions of MSW were actively searched. Incineration (mass-burn) processes were specifically excluded in the contract due to existing legislative constraints. Some of the combustion technology suppliers as well as some firms not currently involved in MSW conversion (e.g., biomass conversion companies) are included because there is potential to apply their technologies to conversion of MSW by non-combustion means. Also, some ancillary technology companies or institutions, such as MRF, handling and separation, IEA bioenergy and MSW task forces, and industrial organizations are included because of relevance.

The database is available through the internet at

http://cbc1.engr.ucdavis.edu/conv/home.htm

and can be accessed and viewed interactively or downloaded as Microsoft Excel® or Microsoft Access® files. A printed version from the Access file is appended to this report as a separate volume (Appendix 6).

Database Sources

The initial database was drawn from a list of interested suppliers on the CIWMB Conversion Technology Vendors website[12]. Additional sources for the information resources include University of California Digital Library electronic catalog and searchable bibliographic databases (e.g., Melvyl, Current Contents, Science Citation Abstracts), US DOE information bridge[13], NREL data and documents[14], NETL gasification database[15], IEA Bioenergy Tasks[16], trade literature, general internet queries, and personal contacts and communications.

Other principal sources that were consulted include:

Heermann, C., F. J. Schwager, et al. (2001). Pyrolysis & Gasification of Waste: A worldwide technology and business review, Juniper Consultancy Services LTD.

Hendrix, J., K. Massey, et al. (1997). "Technologies for the identification, separation, and recycling of automotive plastics." Intl. J. of Environmentally Conscious Design and Manufacturing **6**(2): 37-50.

(1998). Advanced Thermal Conversion Technologies for Energy from Solid Waste, IEA/CADDET Center for Renewable Energy**:** 51.

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[12] http://www.ciwmb.ca.gov/organics/conversion/Vendors/

[13] http://www.osti.gov/bridge/

[14] http://www.nrel.gov/dd.html

[15] http://www.netl.doe.gov/coalpower/gasification/models/models.html

[16] http://www.ieabioenergy.com/

(1998). Review of Current Status of Anaerobic Digestion Technology for Treatment of Municipal Solid Waste, Regional Information Service Center for South East Asia on Appropriate Technology**:** 30.

Calaminus, B. and R. Stahlberg (1998). "Continuous in-line gasification/vitrification process for thermal waste treatment: process technology and current status of projects." Waste Management **18**(6-8): 547-556.

(1999). Business and the United Nations, Partners in Sustainable Development. New York, United Nations**:** 171.

(2001). "Biogas and More, Systems and markets overview of anaerobic digestion. IEA Bioenergy Task 24."

De Baere, L. (2000). "Anaerobic digestion of solid waste: State-of-the-art." Water Science and Technology **41**(3): 283-290.

Klein, A. (2002). Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes. Department of Earth and Environmental Engineering Fu Foundation School of Engineering and Applied Science. New York, Columbia University**:** 50.

(**Note**, A. Klein is currently employed by Juniper Consultancy)

Kwant, K. W. (2000). Status of Gasification in countries participating in the IEA Bioenergy gasification activity IEA Bioenergy Gasification.

Asa, A. and I. Faig (2002). System for treatment of waste. US Patent 6368500, Arrow Ecology & Engineering Overseas Ltd (Haifa, IL).

Calaminus, B. and R. Stahlberg (1998). "Continuous in-line gasification/vitrification process for thermal waste treatment: process technology and current status of projects." Waste Management **18**: 547-556.

Chieffalo, R. and G. R. Lightsey (1998). Municipal solid waste processing facility and commercial ethanol production process. US Patent 5,779,164, Controlled Environmental Systems Corporation.

Farneti, A., C. Cozzolino, et al. (1999). Semi-dry anaerobic digestion of OFMSW: the new full-scale plant of Verona (Italy). II Int. Symp. Anaerobic Dig. Solid Waste, Barcelona, June 15-17 (eds. J. Mata-Alvarez, A. Tilche and F. Cecchi), Int. Assoc. Wat. Qual.

Fruteau de Laclos, H., S. Desbois, et al. (1997). "Anaerobic disgestion of municipal solid organic waste: Valorga full-scale plant in Tilburg, the Netherlands." **36**: 457-462.

Granatstein, D. L. (2003). Case study- Waste fueled gasification project-Greve in Chianti, Italy, CANMET**:** 20.

Heermann, C., F. J. Schwager, et al. (2001). Pyrolysis & Gasification of Waste: A worldwide technology and business review, Juniper Consultancy Services LTD.

Jaeger, M. and M. Mayer (2000). "The Noell Conversion Process – a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials." Water Science & Technology **41**(8): 37-44.

Lorson, H. and M. Schingnitz (1994). "Conversion process for the thermic utilization of residual and waste materials." Bwk **46**(5): 214-217.

OPET (2002). Review of Finnish biomass gasification technologies. Espoo, VTT**:** 21.

Russo, J. and J. Lawrence (2002). Method for the separation of acid from sugars. US Patent 6391204, Controlled Environmental Systems Corporation.

RWBeck (2003). City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal, R.W.Beck,Inc**:** 32.

Sipila, K., Ed. (2002). Overview of Finnish waste to energy R&D program. Power production from waste and biomass IV -Advanced concepts and technologies. Espoo, Finland, VTT.

Sipila, K. and M. Rossi (2002). Power production from waste and biomass IV-Advanced concepts and technologies, VTT, EC DG TREN, IEA Bioenergy, Novem,Tekes,KTM**:** 354.

Verma, S. (2002). Anaerobic digestion of biodegradable organics in municipal solid wastes. Earth Resources Engineering. New York, Columbia University**:** 56.

http://nett21.gec.jp/JSIM_DATA/ Japan Advanced Environmental Equipment database

Database Structure

The database currently has over 400 listings. Some of the company names or institutions appear twice because they offer or are interested in more than one technology type. For each record in the database, a best effort was made to list all the most relevant information which includes,

- Name,
- Technology,
- Primary and Secondary feedstocks,
- Status of the technology,
- Company location and contact information,
- Internet address,
- Notes and comments.

Some of the fields remain empty as information was not available. As the database continues to develop, more information will be added.

Technology Classifications

The terms and definitions used for listing or classifying the technology of a supplier or institution involved in MSW activities are listed in Table 2.

Table 2. Technology classification definitions

Entry in Technology attribute (column) of database	Definition or description
Aerobic/Composting	Biochemical conversion by organisms requiring oxygen. Composting is an aerobic digestion process. See Aerobic conversion in the Conversion Pathways section above.
Anaerobic Digestion	Anaerobic digestion is a fermentation technique typically employed in some waste water treatment facilities for sludge degradation and stabilization but also the principal process occurring in landfills. Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane and carbon dioxide. See Anaerobic digestion in the Conversion Pathways section above.
Biocatalysts	Refers to processes which use biocatalysis (enzymes, proteins etc.) in conversion of a feedstock.
Carbon-Water Reforming	Refers to a process utilizing steam, carbon, and iron (or other reducing agents) to reform water and carbon for hydrogen production.
Combustion	Combustion means oxidation of the fuel without generating intermediate fuel gases, liquids, or solids intended for use. Combustion of solids involves the simultaneous processes of heat and mass transport, pyrolysis, gasification, ignition, and burning, with fluid flow. Provides useful heat at high temperature. See Combustion in the Conversion Pathways section above.
Consultancy	Consultants or consulting companies involved in MSW conversion activities.
Cryogenic shredding	A process that cools feedstock to a very low temperature at which material is brittle and can be shattered into small particles with low energy input. Can be used with tires and plastics, for instance.
Ecoparks	Entries in the database that are associated with eco-parks (which may or may not have a conversion component in the project) are listed in this category. An ecopark is a concept for a region's waste to be brought to a group of facilities that sort, re-use, recycle, or convert portions of the incoming stream such that very little (a few percent by mass) or none of the incoming material goes to landfill.
Energy Crops	Refers to companies or processes that are involved in dedicated energy crop production.
Engineering Company	A company that designs, builds, and/or operates a system with a MSW conversion component.
Environmental Group	Refers to organizations with interest in and usually advocates for environmental issues.
Gasification	Gasification is the thermal conversion of a solid or liquid to a fuel gas via partial oxidation (using substoichiometric air or oxygen) or indirect (external heating) methods. See Gasification in the Conversion Pathways section above.
Hydrogasification	A specific type of gasification process. Hydrogen is a component of the gasification medium.
Hydrolysis/Ferment/Liquid Fuels	Fermentation is generally used industrially to produce fuel liquids such as ethanol and other chemicals. Also operates without oxygen. Although fermentation and anaerobic digestion are commonly classified separately, both are fermentation methods designed to produce different product streams. Hydrolysis (acid, enzymatic, or hydrothermal hydrolysis) is a preprocessing step required for cellulosic feedstocks. See Fermentation in the Conversion Pathways section above.
Industry organization	Organizations composed of businesses and consultants with common interest in a particular industry. Here, the organizations have some relation to solid waste or energy production.

Table 2(Continued) Technology classification definition.

Entry in Technology attribute (column) of database (continued)	Definition or description
Liquid Biofuels	In this context, liquid biofuels generally refers to production of biodiesel from waste or dedicated vegetable oils, although some of the entries in this technology listing are related to ethanol production involving fermentation.
Microturbine	A class of relatively small gas turbines used to burn gaseous fuels and generate electricity. Power generation capacity of this class is considered to be typically less than 500 kW.
Organic Rankine	Refers to the Rankine power cycle with an organic working fluid such as iso-pentanes, ammonia, or Freon (CFCs). Most thermal combustion power plants use the Rankine power cycle with water (steam) as the working fluid.
Plasma Arc	Processes/technologies using electric arc generated plasma for heat source for pyrolysis, or in some cases gasification, conversion. This is actually a subset of pyrolysis or gasification but there are enough records related to this heating method to warrant its own technology listing.
Pyrolysis	Pyrolysis refers to a process similar to gasification except generally optimized for the production of fuel liquids (pyrolysis oils) that can be used straight (e.g. as boiler fuel) or refined for higher quality uses such as engine fuels, chemicals, adhesives, and other products. Gases, chars, and tars are usually produced as well. In this context, pyrolysis means thermal degradation of a feedstock without added oxidant and usually from externally applied heat. See Pyrolysis in the Conversion Pathways section above.
Sludge Drying	Refers to entries that are involved in drying of biosolids and sludge.
Socio-Economic Assessments	System and process analysis which considers societal impacts along with economic issues (similar to social-environmental-economic analyses that are part of sustainable development). Life cycle analysis (LCA) can be included in this definition. Records in this category can include organizations or companies involved in this activity.
Sorting/recycling/recovery	Entries involved in handling, sorting, recovering, and recycling solid waste streams. Material recovery facilities (MRFs) would be included in this category.
Stirling Engine	An energy conversion device (prime mover) nominally operating on the Stirling external combustion (or heat) cycle.
Supercritical Water	The reaction of organic (carbon containing material) in a supercritical water medium occurs at relatively low temperatures and can be extremely efficient for carbon conversion. It can be considered complete oxidation, partial oxidation, or even a pyrolysis process depending on amount of oxygen injected to reactor. These processes have been developed typically for hazardous waste conversion.
Techno-Economic Assessments	Assessments by organizations or companies of a system or process using technical and economic measurement parameters.
Thermal Sterilization	Refers to processes which use thermal means to sterilize the feedstock. Conversion is not necessarily a part of the process. Hospital wastes might be typical feedstocks that undergo thermal sterilization prior to further handling or disposal.
Waste Water Treatment	Refers to conventional municipal waste water treatment facilities. Could be anaerobic or aerobic conversion depending on the process employed.
University	Universities and affiliated institutes, or research groups with activity and interest in solid waste management and/or conversion.
Various or not determined	Entries in the database whose technology or interest has not yet been classified.

Database Contents

Fully one half of the entries are associated with the thermochemical conversion (gasification, pyrolysis, and supercritical water-hydrothermal). About 20% of the records are associated with biochemical conversion means, and less than 10% with physicochemical conversion. The remaining are either non-commercial processes generally involving biomass, MSW, or solid fuel conversion, or are yet undetermined (Table 3).

Table 3 . Distribution of data entries by major technology category.

	Database components (~400 listings*)	Number in category
THERMO-CHEMICAL	Partial Oxidation (Gasification)	92
	Gasification using 'Plasma Arc'	33
	Pyrolysis - Indirect Heating	64
	Super Critical Water Methods	10
BIOCHEMICAL	Anaerobic Digestion	53
	Aerobic/Composting	15
	Fermentation Methods (to liquid fuels)	13
PHYSICO-CHEMICAL	Liquid Fuels - Biodiesel	7
OTHER	Including research institutes, universities, combustion, consultants, not determined, etc.)	117

* Approximately 15 listings appear twice due to multiple technology offerings

Discussion and Conclusions

Tables 4 and 5 list companies in the database that were identified as having MSW conversion facilities that are 1) currently operating commercially, 2) commercial scale demonstrations, 3) reportedly in commissioning, or 4) under construction. Table 4 lists sixteen thermochemical conversion processors while Table 5 lists twelve biochemical process companies. Appendices 1 and 2 give brief descriptions of the entries from Tables 4 and 5 (respectively), including descriptions of the process and some information on facility locations, history, and scale.

Europe and Japan by far outrank North America in terms of numbers of installations using non-combustion thermal or biological MSW conversion. Europe’s efforts are motivated by a combination of upcoming restrictive landfill diversion requirements, in combination with Kyoto Protocol greenhouse gas reduction goals. In Germany for example, carbon and energy limits have been set on disposed material. Material going to landfill is restricted to total organic carbon (TOC) of ≤ 18%, and energy content ≤ 6000 kJ/kg[17] (California average disposed MSW stream has HHV ≈ 10,800 kJ/kg [Table 1]). In order to reduce green house gas emissions in attempts to comply with the Kyoto Protocol, the European Union is implementing strategies which include increased use of energy produced from renewable sources. The European Community Directive 2001/77/EC (27 September 2001) contains definitions for renewable electrical energy sources. Biomass is, of course, a renewable source. The EC Directive includes in the definition of biomass- "the biodegradable fraction of industrial and municipal waste"[18] (although this definition appears overly restrictive depending in turn on the definition of "biodegradable" that may discount some fraction of biomass). The Directive also advises that of the electricity produced by facilities that consume both renewable and non-renewable feedstocks, only that portion attributable to the renewable energy source is considered renewable electricity[19]. Electricity and heat from the organic portion of MSW is considered renewable in the Netherlands[20] and Switzerland. Currently, that fraction in Switzerland is 50%, based on a recent feedstock characterization for MSW combustion facilities.[21]

In Japan there are additional motives for improving upon alternatives to landfill. Japan's lack of significant domestic (traditional fossil) energy resources in combination with very limited space for landfills has led to the development of a large solid waste combustion for energy industry. Environmental issues related to emissions from the waste combustion facilities and leaching problems from the generated ash caused the Japanese government to investigate and invest in better air pollution control technologies and methods to stabilize the ash. A range of processes have been developed through this effort in Japan including high temperature gasification (oxygen blown or plasma arc) with ash melting and specific plasma arc systems for melting ash from MSW combustion facilities. Europe is beginning to employ a range of thermochemical conversion methods (Table 4 and Appendix 1), and has made great progress with large biochemical conversion facilities (Table 5 and Appendix 2).

The database contains a comprehensive list of companies, institutions, and related organizations with recent interest and activity in MSW conversion. The records that form the database contain varying amounts of information, from perhaps just a name of a company or person to fully developed notes and process descriptions, contact information, and some assessment of status.

Verification of status and detailed process descriptions and/or explanatory notes are missing for many of the records due to insufficient or unqualified information from suppliers. Validation will require substantial additional effort. The current ongoing phase II effort includes an industry survey using the records from the database. The survey results and a portion of the evaluation component will support further database development.

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[17] Ludwig, C., et al., Eds. (2003). Municipal Solid Waste Management-Strategies and Technologies for Sustainable Solutions. Berlin, Springer-Verlag.

[18] Directive 2001/77/EC (27 September 2001). Article 2(b). http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_283/l_28320011027en00330040.pdf

[19] Ibid. Article 2(c).

[20] Junginger, M., S. Agterbosch, et al. "Renewable electricity in the Netherlands." Energy Policy **In Press, Corrected Proof**.

[21] Ludwig, C. personal communication. 9 October 2003

Table 4 Companies using thermochemical conversion methods to process MSW.

Company Name	Corp. Headquarters	Process Name	Process Type
Hitachi Metals Environmental Systems	Yoshii, Japan		Gasification (plasma arc)
Ebara/Alstom	France-Switzld-Japan	TwinRec & EUP	Gasification
Brightstar Environmental	Queensland, Australia	SWERF	Pyrolysis w/ Char gasification
Eco-Waste Solutions	Burlington Ontario	EWOX	Gasification
Enerkem	Sherbrooke, Quebec	BIOSYN	Gasification
Environmental Waste International	Ajax, Ontario		Pyrolysis (microwave heat)
Foster Wheeler Energia Oy	Finland		Gasification
Nippon Steel	Tokyo, Japan	Waste Melting	Gasification
PKA	Aalen, Germany		Pyrolysis w/ char gasification
SVZ	Schwarze Pumpe, Germany		Gasification
Thermoselect	Locarno, Switzerland	HTR	Gasification/pyrolysis
Thide Environmental	Bretonneux, France	Arthelyze	Pyrolysis
TPS	Nyköping, Sweden		Gasification
WasteGen UK	UK		Pyrolysis
IES	Romoland, CA		Pyrolysis
SMUDA Technologies	Roseville, CA		Pyrolysis w/catalytic cracking

Table 5 Companies using biochemical conversion methods to process MSW.

Company Name	Corp. Headquarters	Process Name	Process Type
Valorga	Montpellier, France	Valorga	Anaerobic Digestion (OS – HS)
Wehrle Werk AG	Emmendingen, Germany	Biopercolat	Anaerobic Digestion (MS-HS)
Wright Environmental Management	Ontario, Canada		In vessel Composting
CiTec	Finland/Sweden	Waasa	Anaerobic Digestion (OS – LS)
Linde-KCA-Dresden	Dresden, Germany		Anaerobic Digestion & composting (MBT)
Kompogas	Glattbrugg, Switzerland	Kompogas	Anaerobic Digestion (OS – HS)
U-plus Umweltservice	Ettlingen, Germany	ISKA	MBT followed by Anaerobic Digestion
Eco Tec	Finland	WABIO	Anaerobic Digestion (OS – LS)
Organic Waste Systems	Gent, Belgium	Dranco	Anaerobic Digestion (OS – HS)
BTA (Canada Composting in North America)	Munich, Germany (Ontario, Canada)	BTA	Anaerobic Digestion (OS or MS – LS)
Arrow Ecology	Haifa, Israel	Arrow Bio	Anaerobic Digestion (MS – ?S)
Masada Resource Group	Birmingham, Alabama	CES Oxynol	Acid Hydrolysis for ethanol production

OS= One Stage
MS = Multi Stage
HS = High Solids
LS= Low Solids

MBT= Mechanical-Biological Treatment

Appendix 1

Description of Thermal Conversion Facilities and Companies

Hitachi Metals Environmental Systems Company (Yoshii, Japan)

Plasma Arc Gasification/melting of MSW (commercial/commercial scale demonstration)

After demonstration of the gasification technology for MSW at the pilot plant in Yoshii, Japan during 1999-2000, the Japanese government certified the technology for construction of a commercial size plant. A consortium called Eco Valley Utashinai, was formed by Hitachi. Ltd., Hitachi Metals Ltd., Hokaido Prefecture, and the Utashinai City. The plant was completed in July 2002. This new plant uses primarily automobile shredder residue (ASR) as fuel with approximately 165 ton d^{-1} capacity but has been designed to run with a 50% mixture of MSW. It can also process approximately 300 ton d^{-1} of 100% MSW. After commissioning, the plant was released to the customer for commercial operation in April 2003. In December 2002, the twin cities of Mihama and Mikata, Japan commissioned a MSW and sewage sludge treatment plant. Hitachi Metals Ltd. designed and installed this plant. It processes 24 ton d^{-1} of MSW and 4 ton d^{-1} of sewage sludge.

The RW Beck report for Honolulu (RWBeck 2003) indicates Hitachi and Westinghouse Plasma were co-developers of a MSW conversion plant in Yoshii, Japan. This ran at a scale of 166 ton d^{-1} so it can be considered commercial scale demonstration.

Electricity Potential From Plasma Arc Gasification of MSW

Plasma gasification facilities require a large amount electricity to operate the plasma torch. The RCL Plasma website[22] (Resorption Canada Ltd. is a company marketing plasma MSW gasification facilities) discusses material and energy flows for the plasma gasification process. RCL indicates that 704 kWh (~2500 MJ) of electrical energy is required to process 1 metric ton (wet basis) of MSW. The RCL process analysis assumes the energy content of waste material used in their process is 10,900 MJ/tonne.

The 2500 MJ required to gasify or pyrolyze MSW in a plasma system is for the most part energy that would be required to gasify/pyrolyze the material by other technologies (up- or downdraft or CFB gasifiers, or indirectly heated pyrolyzers or example). While these processes use part of the product gas to provide thermal energy by burning (internally for gasifiers, externally for pyrolyzers), the plasma arc system uses 'high quality' electrical energy to create the heat for the reaction. Efficiency of electrical generation is about 30% for fuel burned in a gas engine (or large steam cycle, or California grid average electricity). This electrical energy used by the plasma torch requires about three times that amount in primary energy.

From energy flow data from the RCL Plasma website, net electrical production (or efficiency) from a plasma gasification facility (consuming MSW), is only about 7-10% based on the energy in the incoming feed and assuming Rankine steam cycle or reciprocating gas engine for power production (with producer gas to electricity conversion efficiencies of ~30%). See table A1-1 below.

A report on new waste disposal systems for the City and County of Honolulu (Towill-Corporation 2000) that reviewed plasma gasification of solid waste states that 900 kWh electricity (3240 MJ) can

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[22] http://www.rcl-plasma.com/overview.htm

be produced per ton of refuse processed, but only 300 kWh (1080 MJ) would be available for export to the grid. These figures correspond with those from RCL as displayed in table A1-1.

In comparison, the H-Power MSW combustion facility on Oahu, HI reportedly produces 534 kWh (1900 MJ) per ton of waste consumed (RWBeck 2003). RWBeck does not indicate if this is gross or net electrical energy production. Another MSW combustion facility discussed in (Themelis, Kim et al. 2002) exports to grid 610 kWh (2200 MJ) electricity per ton MSW consumed (overall efficiency of 18% based on 12 MJ/kg HHV of MSW used in facility).

Table A1-1. Process energy and net electrical energy production per ton of MSW (wet basis) from a plasma arc gasification facility.[23]

		Energy per ton MSW (MJ)	
Input	MSW	10900	
	Electricity to torch	2204	
Out puts	Torch loss	362	
	Slag losses	89	
	Vessel losses	60	
	Other losses	1278	
	Non Recoverable losses Total	**(1789)**	
	Gas Sensible Energy	1291	
Producer Gas	Chemical Energy (based on HHV)	10020	
	Electricity Conversion Efficiency	0.3	Recover sensible energy to Electricity (@ 20% eff.)
	Recover Gas Sensible Energy	0	258.2
	Electrical Energy Generated	3006	3264.2
	Less Electricity to Torch	2204	2204
	Net Electricity (MJ)	802	1060.2
	Net Conversion Efficiency (%) [Net Elect./MSW energy in]	**7.4**	**9.7**

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[23] Adapted from RCL website (http://www.rcl-plasma.com). Accessed 2 Sept., 2003

Alstom/Ebara (France, Switzerland and Japan)

"TwinRec" and "EUP" processes.

Alstom Power (Meudon-la-Foret, France) acquired ABB Enertech in 1999 which had exclusive license of Ebara's (Japan) fluidized bed technology that has several commercial facilities in Japan (Heermann, Schwager et al. 2001). Ebara builds and operates full MSW combustion facilities in Japan and some other Asian countries. Ebara also has developed the TwinRec and EUP gasification processes through the Japanese initiative to develop more sustainable waste disposal technologies.

TwinRec Process

Ebara has long experience with fluidized bed combustion systems for waste materials. They adapted their bubbling fluidized bed reactor to operate as a gasifier and coupled it with a secondary combustion chamber where the producer gas is burned with the addition of secondary air. This is an atmospheric pressure, air blown process. The larger ash particles along with metal and glass pieces leave the gasifier bed as bottom ash from which the metals can be separated. Smaller ash and char particles are carried over with the producer gas and enter the combustion chamber which operates at high enough temperature to melt the inorganic material carried over. This slag is water quenched which yields vitrified granules. It is possible to grind the bottom ash from the gasifier portion and inject it into the melting combustor (at higher processing and energy expense) to slag essentially all of the inorganic material present in the original feedstock This is the ash melting process used to meet the low leachability requirements for ash from conversion processes in Japan. The table below shows existing facilities using the TwinRec process.

The following is excerpted from Ebara web site engineering abstracts (Review No.197, 2002)[24]

> *Japan's first municipal waste, fluidized-bed, gasification-melting furnace system, equipped with a power recovery steam turbine, has started operation at Sakata City, Japan. The dioxin concentration in the exhaust gas of this system is being controlled to be below the allowable standard and the produced slag is effectively encapsulated and used as pavement material (inter-locking blocks). The exhaust gas from the furnace is used for driving a power recovery turbine (max. output 1 990 kW) and excess electricity produced is being sold to the local electricity company.*

UEP Process

Ebara and the Ube Industries Ltd. (a plastics and chemical company) developed this process for recycling the chemicals in waste plastic. Based on the TwinRec process, the UEP system uses two pressurized gasifiers in series. The process operates up to 10 atmospheres and is oxygen blown. The first gasifier is essentially the same bubbling fluidized bed as used in TwinRec and runs at a relatively low temperature. The produced gas flows to the second chamber which, as in the TwinRec second reactor, receives secondary oxygen allowing higher temperatures to be reached and slagging inert material. There is still insufficient oxygen for complete conversion of the producer gas. The complete material flow through the second high temperature gasifier (gas and slag) is forced through a water

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[24] http://www.ebara.co.jp/en/

trap which solidifies and captures the inert material. The remaining gas can be used for energy production, liquid fuels production or chemical feedstocks. The table below shows existing facilities using the UEP process.

Alstom reportedly (Heermann, Schwager et al. 2001) markets the Ebara reactor modified to operate as a gasifier and is targeted for higher energy containing fuels (automobile shredder residue, plastics, electronic scrap, tires), but can process other domestic and urban residues. But Ebara (Environmental Engineering Group) also has a Zurich, Switzerland office plainly stating it is the representative for the Ebara TwinRec and UEP processes in Europe.

No Alstom/Ebara European installations were identified, but there are several of the Ebara TwinRec and UEP facilities operating in Japan (See tables A1-1,2).

Table A1-2 Ebara TwinRec gasification facilities[25]

Location	Commissioning Date	Feedstock	Mass (%)	Scale (t/y)	LHV (MJ/kg)	Thermal Capacity (MW)	Output Elect. (MWe)
Kurobe	Dec, 2000	Automotive Shredder Waste Waste Plastics copper slag + sorbents	41 13 46	22,000	10.2	7.4	
Minami-Shinshu	Mar, 2003	MSW	100	34,000	8.4	2x4.5	
Joetsu City	Mar, 2000	Dry Sludge Waste Plastic	68 32	57,000	12.3	2.2	
Chuno Union	Mar, 2003	MSW	100	61,000	11.3	3x7.3	
Sakata Area	Mar, 2002	MSW	100	72,000	10.9	2x12.3	2
Ube City	Nov, 2002	MSW	100	72,000	12.5	3x9.5	
Nagareyama City	Feb, 2004	MSW	100	75,000	11.7	3x9.3	
Kawaguchi	Nov, 2002	MSW	100	153,000	13	3x21.0	12
Aomori	Feb, 2000	Automotive Shredder Waste Sewage Sludge	70 30	160,000	14.3	2x40	17
Kuala Lumpur Malaysia	May, 2006	MSW	100	548,000	9.6	5x33.3	

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[25] Adapted from Ebara Reference List (http://www.ebara.ch/downloads/ebara_Referencelist_TwinRec_100203.pdf)

Table A1-3 Ebara UEP pressurized gasification for chemical recycling facilities[26]

Location	Commissioning Date	Feedstock	Scale (t/y)	Product
Ube City	1999	Waste Plastic	11,000	Fuel gas or feedstock for ammonia production
Ube City	2002	Waste Plastic	24,000	Feedstock for ammonia production
Kawasaki	Expected 2003	Waste Plastic	107,000	Feedstock for ammonia production

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[26] Adapted from Ebara Reference List (http://www.ebara.ch/downloads/ebara_Referencelist_EUP_0103.pdf)

Brightstar Environmental (Queensland, Australia)

SWERF (Solid Waste and Energy Recycling Facility) Process

Energy Developments Limited (Australia) is the majority owner company of Brightstar Environmental. Brightstar Synfuels (Texas) is a minority holder.

The SWERF process accepts unsorted MSW. The material is first treated in an autoclave (steam and pressure) to create a manageable pulp and reduce odors and pathogens, after which standard material handling/separation equipment removes metals and rigid plastics for recycling or disposal. The remaining pulp is washed to remove sand and glass followed by pulp drying and storage. Energy for drying is provided by exhaust heat.

The core conversion technology consists of two steps, pyrolysis followed by char steam gasification. The synthesis gas is run through reciprocating internal combustion engines for process heat and power for export.

There is a commercial scale (50,000 tons/y) demonstration in Wollongong, NSW, Australia which has been undergoing commissioning since early 2001. Apparently, there are problems with the char gasification component of the process causing the parent company Energy Developments Ltd. to announce that it is ceasing to fund further development and is looking for a buyer of its portion of the Brightstar Environmental stock (~88%). It is not known how this will affect the Wollongong facility and current proposals in the UK and the USA for SWERF installations.

Eco Waste Solutions (Burlington Ontario)

Eco Waste Oxidizer (EWOX)

These are relatively small scale systems, sized for 1 to 25 ton/d. The process is a gasifier followed by burning the producer gas in a controlled combustion chamber. Typically operates on a 24 hr batch cycle. The material is enclosed in the gasification chamber and then heated (presumably with natural gas or propane) until enough energy is released by the gasification reactions to sustain itself.

Marketed to small scale and/or remote waste producers. Units are installed in Canada, Alaska, Belize, Hawaii.

Canada's Environmental Technology Verification (ETV) program has verified Eco Waste Solutions' performance claims for both municipal and biomedical waste.

Enerkem, Université de Sherbrooke, and KEMESTRIE INC. (Sherbrooke, Quebec)
BIOSYN process

ENERKEM TECHNOLOGIES INC. is a subsidiary of the Kemestrie Inc. Group, a spin-off company of the Université de Sherbrooke, founded in 1992. It is the sole owner of a technology portfolio resulting from investments begun in 1981 by the Canadian Federal Government as part of its "National Energy Plan", and continued in partnership with the Ministère des Resources Naturelles du Québec, the Centre Québécois de Valorisation de la Biomasse (CQVB), the Université de Sherbrooke and KEMESTRIE INC. A principle member of the company is Dr. Esteben Chornet, a member of the staff at NREL[27] and a professor Chemical Engineering at Université de Sherbrooke[28]

Known as the BIOSYN process, it utilizes a bubbling fluidized bed (BFB) gasifier, with air or oxygen operating at pressures up to ~ 16 atmospheres. The process includes proprietary catalysts for cracking tar and other components in the producer gas. Capable of operating on biomass, sorted MSW, and plastics. Enerkem will provide performance guarantees of minimum energy conversion efficiency (solids to conditioned synthesis gas) of 70%[29] as well as composition of the synthesis gas based on the composition of the feedstock

The Poligás plant in Ribesalbes (Castellón), owned by Poligás Ambiente, S.L., and built by Environmental International Engineering, S.L. (EIE) has recently gone into operation. Spain's Institute of Energy Diversification and Efficiency (IDAE), and the waste management company Revima participated in the project. Financing was provided by regional government (Valencia) and EU funds. The plant is fuelled with discarded plastics wrappings from the ceramics industry. This plant reportedly (Enerkem website[30]) is generating 7 MWe (80 MMBTU/h of synthesis gas) from approximately 25,000 metric tons y^{-1} waste plastic.

In 2002, Enerkem began working with the City of Sherbrooke to convert waste into synthetic gas (BioSyngaz-Estrie project). Federal, provincial, and corporate monies financed the project. The pilot unit was designed and constructed with the capacity to convert 2.5 tonnes of sorted municipal waste residue per day.

MSW Pilot Plant in Sherbrooke (BioSyngasEstrie Project)

Enerkem, City of Sherbrooke, provincial and federal agencies have partnered to build and operate a pilot plant based on the BIOSYN process for sorted MSW. Apparently, the system ran at capacity of 2.5 metric ton d^{-1} for much of 2002 with technical reports and feasibility studies that should be complete at this time.

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[27] http://www.nrel.gov/chemistry_bioenergy/staff_alpha.html#c
[28] http://www.usherbrooke.ca/gchimique/personnel/profs/chornet/
[29] Note: energy conversion efficiency for overall process (through to electrical generation) would be about 20% (steam turbine) up to about 30% (large reciprocating internal combustion).
[30] http://www.enerkem.com/2002/pages_en/main_en1_ns.html

Environmental Waste International (Ajax, Ontario)

EWI manufactures and markets systems that use microwave heating to pyrolyze the feedstock in an inert or low oxygen atmosphere. The basic process is pyrolysis with standard volatile gases, tars, and char as the products (relative amounts and compositions are feedstock dependant). Existing installations are used in destruction of medical wastes.

The company does not foresee a market for this technology in non-separated MSW conversion. They are investigating the process with feedstocks such as sludge, non-recyclable plastics, automobile shredder residue, diseased animal carcasses, and used tires. In fact, the company believes the destruction of used tires is where its' future is due to the potentially valuable products that result from pyrolytic conversion of used tires (carbon black, steel, liquid and gaseous hydrocarbons). The company claims that 100% of the material in a used tire can be reclaimed by thermal pyrolysis.

Company press release indicates it has an agreement with a private firm in the UK to design and build its first facility to pyrolyze waste tires with the microwave heating process. It would be capable of converting 3000 tires per day.

Material and energy flow diagram on company website claim that a tire conversion facility that consumes 6000 tires/day can provide sufficient energy to drive a 6 MWe steam turbine (if all pyrolysis oils and gases are burned in a boiler). The magnetrons and balance of plant will consume 3 MW of electrical power leaving 3 MW available for export.

Foster Wheeler Energia Oy (Finland)

Lahti, Finland

Foster Wheeler, in cooperation with Kymijärvi Power Station at Lahti, Finland has installed an atmospheric (air blown) circulating fluidized bed (ACFB) gasifier next to the coal/fossil fuel fired utility boiler. Thermal capacity of the gasifier is 40-70 MWth depending on the moisture content of the fuel (which can be up to 60%)(OPET 2002) The producer gas from the gasifier is co-fired in the boiler. . The ACFB is sized to provide up to 15% of the energy input to the boiler (replacing up to 30% of the coal feed). The lack of gas cleaning limits the fuels to woody biomass and low/no chlorine containing waste-derived fuels (some amount of separation of residential or municipal wastes to remove chlorinated plastics). See table below for composition of the refuse derived fuel. The project demonstrates commercial scale feasibility of close coupled gasification of low quality 'opportunity' fuels which otherwise could not be utilized in the combustion boiler.

A municipally owned, waste management company (Päijät-Hämeen Jätehuolto Oy) started the processing of refuse derived fuel in 1997. In the first year of operation, (1998), more than 8000 tons of residential refuse fuel was gasified accounting for 22% of the energy through the gasifier (the bulk of the gasifier energy came from wood residues-71%).

Table A1-4

Composition of refused derived fuel at Lahti[31]

Component	% by weight
Plastic	5-15
Paper	20-40
Cardboard	10-30
Wood	30-60

Varkaus Finland

Foster Wheeler installed a bubbling fluidized bed gasifier (BFB) as part of an integrated recycling process at the Corenso United Oy, a large paper and cardboard/packaging material manufacturer. Used multilayer packaging material (which includes plastic film and aluminum foil layers, for example, Tetrapak aseptic drink containers) is recycled by separating as much of the cellulose material from the plastic and aluminum as possible and then gasifying the remaining plastic and aluminum containing portion in the Foster Wheeler BFB. From the process diagram found in (OPET 2002), apparently vaporized aluminum is recovered from the hot gas. The aluminum is solidified into ingots and reused. The energy from the gas replaces some of the fossil fuel used to raise process steam. The gasifier is 40 MWth in capacity and recovers about 3000 t y^{-1} of aluminum and gasifies 27,000 t y^{-1} polyethylene.

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[31] http://www.fosterwheeler.com/publications/tech_papers/powgen/bagasse3.cfm

Nippon Steel (Tokyo, Japan)

The Japanese motivation

Japan generates over 100 million tons y-1 of MSW but has limited available land for disposal. Consequently, much of the waste (75%) (Heermann, Schwager et al. 2001)is burned in combustion facilities. Concern over high levels of dioxin emissions led the Japanese government to institute programs to address the issue. These programs included tighter emissions limits, investment in more efficient facilities with better emissions control technologies and RDD of alternatives to MSW combustion.

Results so far appear successful. The Japanese Environment Agency estimates that dioxin emissions in 1998 were reduced by 70% compared to those of 1997. Legislation was in place to require 2002 emissions to be only 10% of the 1997 levels (Heermann, Schwager et al. 2001).

One of the RDD initiatives launched by the Japanese government was the 'Technologies for the 21st century' which focused on developing gasification/pyrolysis systems and direct melting of waste. The non-combustion thermal technology thrust is to address the dioxin issue while waste melting programs address ash recycling and disposal problems.

A further motivator for Japan is its lack of significant domestic energy resources. Any energy that can be recovered from conversion of MSW and other solid wastes directly displaces imported coal or petroleum fuels.

Waste Melting Process

The Nippon Steel 'Waste Melting Process' evolved from metallurgical processing technology. The process accepts unsorted MSW that has been processed to required particle size. From Juniper (Heermann, Schwager et al. 2001), the Nippon Steel process uses a fixed bed gasifier (not clear if pressurized), with enriched oxygen air injection in the melting section. Coke is added to the MSW (~50kg/tonne MSW or 5% by weight) input feed which reacts with the oxygen and pyrolytic gases at the air injection and melting region. This is apparently done to help provide energy for full ash melting. Limestone is also added (~5% by weight of input) to provide some pH buffering of the melt. The producer gas is burned in conventional steam boilers from which heat and power can be generated. Output materials include granulated slag (90 kg/ tonne input), recyclable iron (10 kg/ tonne input) and fly ash (~30kg/ tonne input) which is sent to landfill. Mercury and heavy metals present in the waste are found in the fly ash and producer gas requiring that these streams be managed appropriately before discharge.

There are perhaps a dozen plants (operational or being commissioned) in Japan utilizing the Nippon Steel waste melting process. The capacities range from 100 to 450 tonne d^{-1}.

Nippon Steel is a market leader in large scale MSW conversion applications.

PKA Umwelttecnik (Aalen, Germany)

This is a pyrolysis process followed by gas converter (cracker). Char from the pyrolysis step is gasified, or an additional oxygen based melter for char and ash residues is available. MSW feedstock is processed to remove glass, metals, and other marketable recyclables. The remaining material then goes through a size reduction process. Drying to below 15% moisture is recommended, but not mandatory.

The pre-processed material is conveyed into a rotary pyrolysis drum which is externally heated by hot combustion gas (from burning natural gas during start-up, of from a portion of the synthesis gas if available in sufficient quantity and quality. The material takes up to 1 hr to progress through the drum. Pyrolytic gases are drawn off to undergo cracking and cleaning according to final use. The pyrolytic char may have high value uses (if not contaminated with ash impurities/heavy metals), but typically is gasified/combusted for additional energetic gases or heat.

There is a PKA facility in Aalen operating on a blend of MSW, commercial waste, and sewage sludge. Juniper(Heermann, Schwager et al. 2001) indicates there is a char/ash melter with the facility. char and ash

PKA has a unit installed in Freiberg/Saxonia where high aluminum content industrial waste is pyrolyzed for recovery of the aluminum which is sent next door to an aluminum melting plant. Pyrolysis gas is sent to the aluminum plant as well.

SVZ (Sekundärrohstoff-Verwertungszentrum) Schwarze Pumpe, Germany

Waste/Biomass

This facility, built to gasify petroleum residues and coal in the mid 1960's now processes MSW and household waste with lesser amounts of petroleum refinery residues and coal. The capacity of the facility is 495,000 ton y^{-1} and 55,000 ton y^{-1} of solid waste and liquid water/oil residues respectively[32]. A recent survey[33] of gasifiers utilized primarily in the fossil energy sector indicates annual feedstock flows at SVZ are 1.3 Mton y^{-1} and 190,000 t y-1 for solid and liquid wastes respectively. The reason for this discrepancy has not been pursued, but material flow rates through this facility are substantial.

The products of the process are electricity (75 MW) and 300 t d^{-1} methanol (from all gasifiers and feedstocks)

SVZ claims to process plastics, waste wood, sewage sludge, domestic garbage (combined or source-separated), and other solid wastes. Liquid and slurry waste oils, solvents, paint sludges, etc. are processed as well.

There are 10 separate gasifiers in the facility. Seven are 'Lurgi Dry Ash' gasifiers, and one each of Lurgi multi-purpose (MPG), British Gas-Lurgi, and Noell KRC gasifiers.

The Lurgi (Lurgi Energie, Germany)[34] dry ash gasifier is a pressurized oxygen and steam blown 'moving bed' gasifier. Dry ash refers to the condition that ash material does not reach it's melting temperature which would produce a liquid slag. Solid feedstock enters the reactor through a lock hopper at the top and moves down through the bed, while oxygen and steam are injected in the bottom and move up counter currently to the solid fuel. The Lurgi multipurpose is pressurized, oxygen blown gasifier and configured for liquid feedstocks.

British Gas-Lurgi (BGL) fixed bed gasifier is pressurized and oxygen/steam blown similar to the Lurgi dry ash. The difference is the fuel is present as a substantial piled mass in the reactor and slowly moves down as the material in the bottom of the pile reacts and gasifies. Oxygen and steam are injected into the fuel mass with lances and reaction temperatures are allowed to be high enough to melt (or slag) the ash, which drains and is removed from the bottom. Synthesis gas leaves near the top of the reactor.

The Noell –KRC gasifier is an entrained flow gasifier (also pressurized and oxygen blown). The liquid or small particle fuel is injected at the top of the reactor with oxygen. The falling fuel particles react with the oxygen and heat. Ash slags and runs down reactor wall. Synthesis gas and slag exit reaction chamber together through a drain like orifice and are quenched with water condensing some of the tars and creating vitrified ash granules which eventually exit the pressurized vessel through lock hoppers. Jaeger describes the Noell process in waste water treatment (sewage sludge)(Jaeger and Mayer 2000). Also in German,(Lorson and Schingnitz 1994)

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[32] http://www.svz-gmbh.de/GB/Seiten/rahmen.html

[33] SFA Pacific for USDOE National Energy Technologies Laboratory (NETL) http://www.netl.doe.gov/coalpower/gasification/models/models.html

[34] See Conversion Technology data base for Lurgi Energie

Thermoselect (Locarno, Switzerland)

The Thermoselect High Temperature Recycling (HTR) is a novel process which began with a commercial scale demonstration in Fondotoce, Italy in 1989.

There is one client owned facility in Europe (Karlsruhe, Germany) and two in Japan. The Karlsruhe facility has been plagued by commissioning problems causing delays in licensing and designing other facilities in Germany. This led to cancellation of some of the European orders. The Japanese facilities seemed to proceed through commissioning more easily, perhaps due to different or better air pollution control systems.

The process uses slow pyrolysis followed by fixed bed oxygen blown (atmospheric pressure) gasification and ash melting (Calaminus and Stahlberg 1998). Some information indicates natural gas is added along with a portion of the synthesis gas to the gasifier for supplemental energy for gasification. This may be due to variability of feedstock character (moisture, energetic value for example).

The process accepts unsorted MSW. Waste is loaded into a chamber which is pushed and compacted by hydraulic press and moved (in plug flow fashion) through a cylindrical heating chamber where drying and some pyrolysis occurs. At the end of this horizontal heating/pyrolysis tube, the solid material falls into a high temperature oxygen blown gasifier. Organic material is gasified, and ash is melted and allowed to separate by density before being cooled. Producer gas is cleaned and utilized appropriately. Recyclable metals and vitrified minerals are useable outputs. Gas cleaning creates a sludge containing heavy metals. The Juniper Report indicates that 23 kg/ton MSW of natural gas is an input. This represents about 12% of the energy contained in 1 metric ton of MSW[35]. The synthesis gas can be used for energy production or possible chemicals or liquid fuels.

The process is attractive because of minimal or zero feedstock preparation/processing. The reasons for the commission problems in Karlsruhe need be learned.

A US Company, Interstate Waste Technologies, is marketing the Thermoselect process in North America and the Caribbean. The website indicates potential projects in Costa Rica, US Virgin Islands, and Puerto Rico (letters of intent, artist conceptual drawings of facilities, etc.)

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[35] Assumes natural gas HHV of 55 MJ/kg and MSW HHV of 10 MJ/kg.

Thide Environmental (Voisins Le Bretonneux, France)

The Thide 'Arthelyse' process is a rotating drum pyrolysis scheme (similar to WasteGen UK, and PKA). Following materials sorting and drying, the material is conveyed into the rotating pyrolysis drum. Residence time is approximately 30 minutes. The synthesis gas is burned to provide the heat for the pyrolyzer and process steam for drying.

Thide seems to be trying to market the solid residue char as a solid fuel for use off sight. Claim the char can washed and separated from the metals, other inerts, and soluble salts. Even if washing the char is effective, it seems that it would be costly and energy intensive possibly making unattractive as an off sight solid fuel.

Thide reports that the solids output (in % of input material mass), 4% is recyclable metal, 10% are ash, and 23% is the washed char.

Hitachi has the license for the process in Japan and there is a small plant located in Nakaminato operating since 1999 (capacity ~ 10,000 ton y^{-1}).

A larger facility (50,000 ton y^{-1}) is under construction in the town of Arras scheduled to debut in 2004.

TPS Termiska Processer AB (Nyköping, Sweden)

TPS is an employee owned company in Sweden with a fairly long history in gasification and combustion technologies for heat and power fueled by biomass and coal. A large amount of R&D is undertaken by the company from funds provided by the Swedish National Energy Administration, the European Community (various energy agencies), as well as private companies. TPS specializes in fluidized bed, both circulating (CFB) and bubbling (BFB) types operating in combustion or gasification modes. Gasifier attributes include atmospheric or pressurized, using air, oxygen, or steam injection.

Their CFB designs are licensed (under the name of Studsvik) to several large boiler manufactures throughout the world including Babcock and Wilcox (USA), Kvaerner (Sweden), Austrian Energy (Austria), and SER Consortium (Brazil).

TPS is also involved in integrated gasification combined cycle (IGCC) systems fuelled by biomass. A demonstration plant of this type has been built in the UK (ARBRE project) and has been operated. It is wood fueled with a design capacity of 8MWe. Recent discussion in bioenergy email discussion groups claim the project has stopped because of lack of risk funds and is searching for a buyer. TPS is investigating and designing two projects in Brazil for IGCC plants. One would be fueled by bagasse and sugar cane trash, and the other from eucalyptus trees.

Greve, Italy

In the late 1980s, TPS licensed the CFB process to Ansaldo of Italy and provided the design of two gasifiers to be fueled by pelletized refuse derived fuel (RDF). The plant was built by Ansaldo and began operation in 1991.

The two 15MWth CFB gasifiers consume 100t/d (each) of pelletized RDF from nearby Florence. The gasifiers are air blown and operate slightly above atmospheric pressure near 850 ºC (below ash melting point). Raw gas leaving cyclone particle separator is combusted in a boiler. The boiler raises steam which is expanded through a condensing turbine. System design is for 6.7 MWe. System can feed gas to a nearby cement plant if electricity economics are unfavorable.

A recent case study of the Greve facility (Granatstein 2003) was published by the IEA Task 36[36](Energy from Solid Waste Management Systems). Operational problems with the plant have been experienced. The gasifiers themselves reportedly operate flawlessly but the boiler fouls with fly ash and condensed tar. Steam production has been low. A two phase remediation program was undertaken late in 1997 with planned completion in 2000. The modifications to the system include a new RDF plant with better quality control and better particulate removal from the gas before it enters the boiler. It was unknown at the time of Granatstein's publication whether the operational problems were fixed as the plant owners have not returned requests for information. The case study includes mass and energy diagrams and emissions information as well as economic data.

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[36] http://www.ieabioenergy.com/ourwork.php?t=36#36

WasteGen UK[37]

Marketing "Materials and Energy Recovery Plants" (MERPS). This company seems to be the inheritor of the technology developed by PLEQ, a defunct East German company that developed a rotary kiln pyrolyzer to convert municipal solid waste. Franz-Eicke von Christen is the technical director for the company. He was a founder and director of the original PLEQ company.

A full scale unit has been operating in Burgau, Germany since 1987. Reportedly, the plant is owned by the municipality. It consists of two rotary kilns, 20 m long by 2.2 m diameter. Each processing line is capable of 3 ton h-1. The Burgau plant is reviewed in the Juniper Report (Heermann, Schwager et al. 2001).Some 36,000 t y-1 of waste material is pyrolyzed at the facility. A mixture of MSW, commercial waste, bulky wastes and sewage sludge are mixed together from separate storage pits. Particle size is reduced to < 4 inch and then conveyed to the rotary kilns. The kilns are heated by combustion of a portion of the pyrolytic gas. The remaining energy in the pyrolysis gas is recovered from combusting in boiler producing steam for a 2.2 MWe turbine/generator. It appears there is no sorting of the waste required. Ferrous metals are recovered after pyrolysis. The char product is not used and is sent to landfill. Dust and fly ash recovered in a baghouse gas cleaning system is considered hazardous because of heavy metals contamination and must be disposed of properly.

Energy recovery is claimed to be 470 kWh t^{-1} of input material which corresponds to 4.7 t hr^{-1} of input feed. This feed rate on an annual basis (90 % capacity factor) would be 37,000 t y^{-1} which is essentially equivalent to the reported annual input. On a mass basis, 12% is recovered as recyclable metal and 21% (pyrolysis char and fly ash) is sent to landfill.

The Juniper report (Heermann, Schwager et al. 2001) gives a very favorable review of the process with high marks for reliability, minimal preprocessing (no sorting), and decent energy recovery. The report concludes that the process should be regarded as a leader for medium to large scale pyrolysis mixed waste processing.

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[37] http://www.wastegen.com/template.htm

References (App, 1)

Calaminus, B. and R. Stahlberg (1998). "Continuous in-line gasification/vitrification process for thermal waste treatment: process technology and current status of projects." Waste Management **18**: 547-556.

Granatstein, D. L. (2003). Case study- Waste fueled gasification project-Greve in Chianti, Italy, CANMET**:** 20.

Heermann, C., F. J. Schwager, et al. (2001). Pyrolysis & Gasification of Waste: A worldwide technology and business review, Juniper Consultancy Services LTD. **2001**.

Jaeger, M. and M. Mayer (2000). "The Noell Conversion Process – a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials." Water Science & Technology **41**(8): 37-44.

Lorson, H. and M. Schingnitz (1994). "Conversion process for the thermic utilization of residual and waste materials." Bwk **46**(5): 214-217.

OPET (2002). Review of Finnish biomass gasification technologies. Espoo, VTT**:** 21.

RWBeck (2003). City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal, R.W.Beck,Inc**:** 32.

Themelis, N. J., Y. H. Kim, et al. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research **20**(3): 223-233.

Towill-Corporation, R. M. (2000). New Systems Research for Refuse Disposal- Oahu Municipal Refuse Disposal Alternatives Study. Honolulu, City&County of Honolulu.

Appendix 2

Description of Biochemical conversion Facilities and Companies

Valorga (Montpellier, France)

The Valorga process was designed to treat organic solid waste. It is an anaerobic digestion process and accepts MSW after appropriate separation of recalcitrant fraction.

The process dilutes and pulps the organic fraction to about 30% solids content. This is considered a high solids process. Steam is used for heating/maintaining temperature in the reactors as necessary. Mesophilic or thermophilic systems are used depending on feedstock and economics.

The reactor is a continuous one-step plug-flow process. The reactor consists of a vertical outer cylinder with an inner wall on about the 2/3 diameter of the outer one. Material enters at the bottom on one side of inner wall and must flow up onside and down the other side before it can exit (Fruteau de Laclos, Desbois et al. 1997). The retention time is on the order of 3 weeks. Biogas is injected in the base of the reactor and the bubbles serve as a means for mixing and keeping solids suspended (gas-mixed). The digestate is dewatered and can be composted. Table A2-1 lists existing facilities.

Table A2-1 Valorga Process Installations[38]

Location		Material	Capacity (ktonnes/y)	Start-up Date
Bottrop	Germany	Kitchen waste	6.5	1995
Geneva	Switzerland	Kitchen/Green waste	10	2000
Engelskirchen	Germany	Kitchen/Green waste	35	1998
Freiburg	Germany	Kitchen/Green waste	36	1999
Tilberg	The Netherlands	Kitchen waste	52	1994
Bassono	Italy	Sorted MSW/sludge	55	2003
Mons	Belgium	Sorted MSW	59	2002
Amiens	France	Sorted MSW	85	1988
Varennes-Jarcy	France	Sorted MSW	100	2002
Cadiz	Spain	Sorted MSW	115	2002
Barcelona	Spain	Sorted MSW	120	2004
Hanover	Germany	Sorted MSW/sludge	125	2002
La Coruna	Spain	Sorted MSW	142	2001

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[38] Adapted from corporate webpage (http://www.steinmuller-valorga.fr/index_en.php) and Verma, S. (2002). Anaerobic digestion of biodegradable organics in municipal solid wastes. Earth Resources Engineering. New York, Columbia University**:** 56.

Wehrle Werk AG (Emmendingen,Germany)

Biopercolat Process

A large company active in thermal conversion of biomass and MSW with several combustion facilities. Also active in waste water treatment and has led to solid waste digestion facility at Kahlenberg (2000 t/y) using the 'Biopercolat' process which is mechanical aerobic-anaerobic treatment A multi-stage high-solids process.

The Biopercolat process is a multi-stage high solids process(Verma 2002). The first hydrolysis stage is carried out under partial aerobic conditions. Process water is continually percolated through the mechanically agitated (and slightly aerated) hydrolysis chamber (a horizontal tunnel much like the Wright MBT system). The leachate hydrolysis water is fed to an anaerobic plug flow filter filled with support material operating as an upflow anaerobic blanket sludge (UASB) reactor. The process has a retention time of only seven days.

Wright Environmental Management (Ontario, Canada)

Company supplies ‘in-vessel’ composting systems. These are managed and accelerated aerobic conversion processes. The material is loaded into a tunnel like enclosure and moves slowly in plug flow fashion. Any leachate is recirculated and air is actively pumped through the material through out the length of the enclosure. In situ mixing and moisture management results in a 10-14 day retention time for material. Excess air and gaseous products can be fed through a biofilter for odor control before release to the environment. The system is modular and capacities can be scaled from 600 lbs. to 30 tons per day through one enclosure tube.

MSW can be processed after appropriate separation of non compostable material.

The company lists several reference plants which include,

Aberdeenshire, Scotland	32,000 t/y MSW
Isle of Wright, UK	22,000 t/y mixed food/green waste
Dept. of Corrections, Powhatan,VA	730 t/y food waste
Dept. of Corrections, Ogendburg, NY	730 t/y food waste
Allegheny College, PA	365 t/y food waste
Albany, NY	18250 t/y organic fraction MSW

CiTec (Finland/Sweden)

CiTec is a group of Finnish and Swedish companies with the majority of operations originating from the Vaasa, Finland office. The Waasa process was developed by CiTec.

The Waasa process.

This is a single stage "wet" (total solids < 15%) anaerobic digestion system. For the organic fraction of MSW to be used in this system, it must undergo pretreatment in a pulper which shreds, homogenizes, and dilutes the material to the desired concentration of total solids (10-15% TS). Recycled process water and some fresh make-up water is used in the dilution. The slurry is then digested in large 'complete mix' (completely stirred) reactors. The pretreatment required to obtain adequate slurry quality while removing coarse or heavy contaminants is complex and inevitably incur a 15-25 % loss of volatile solids (Farneti, Cozzolino et al. 1999). Mechanical impellers and injection of a portion of the biogas into the bottom of the reactor tank are used to keep the material continuously stirred and homogenous as possible. To reduce short-circuiting of the feed (i.e., passage of a portion of the feed through the reactor with a shorter retention time than that for the average bulk material), a pre-chamber (within the main reactor tank) is used. Fresh material from the pulper enters the pre-chamber along with some of the biomass from the main tank for inoculation. The pre-chamber operates in plug flow taking a day or two before the material makes it's way into the main reactor, thus ensuring all material entering the process has a guaranteed few days retention time. Even with the pre-chamber arrangement, enough short-circuiting occurs that all pathogens are not eliminated requiring a pasteurization step in the pre-treatment. Steam is injected in the pulper to maintain feed at 70 ºC for one hour.

The process can be operated at both thermophilic and mesophilic temperatures and the plant at Vaasa has both types running in parallel (the thermophilic process has a retention time of 10 days while 20 days is required in the mesophilic design). The operational performance (manufacturer's summary data) indicates that gas production is in the range 100-150 m^3/tonne of bio-waste added, volume reduction of 60%, weight reduction 50-60% and a 20-30% internal consumption (heat) of biogas. The digestate can be further treated by aerobic composting, but this depends on the waste quality.

There are several plants operational in Europe and Japan based on the Waasa process. Capacities range from 3000 - 90,000 tonnes per annum (see table A2-2).

Table A2-2 List of Waasa Process AD sites[39].

Waasa (CiTec) System Locations		Feedstock	Scale (t/yr)	Temp. (ºC)	Year began Operation	Status	Output Elect. (kWe)	Output heat (kWth)
Kil	Sweeden	Biowaste	3000	55	1998	Operational	0	228
Vaasa	Finland	MSW	15000	55	1994	Operational	300	620
Pinerolo	Italy	MSW /Sludge	30000*	55	2003	Completion	1200	1880
Groningen	The Netherlands	MSW	85000*	55	1999	Operational	1920	3000
Friesland	The Netherlands	MSW	90000*	55	2002	Start-up	2000	3140
Tokyo	Japan (Ebara)	Biowaste/Sludge	500	55	1997	unknown		
Ikoma	Japan (Ebara)	Biowaste/Sludge	3000	55	2001	unknown		
Shimoina	Japan (Ebara)	Biowaste/Sludge	5000	37	2001	unknown		
Jouetsu	Japan (Ebara)	Biowaste/Sludge	12000	55	2001	In operation		

* From pretreatment

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[39] Adapted from CiTec Waasa Reference List (http://www.citec.fi/lang/eng/enviroment/Waasa_process/Ref_biogas.pdf)

Linde-KCA-Dresden GmbH (Dresden, Germany)

A Large engineering design/build firm active in pharmaceuticals, chemical and waste water and solid waste treatment.

Active in both low and high solids (wet and dry) digestion systems, and mechanical-biological treatment systems (MBT)for separated MSW. MBT systems include aerobic composting systems with mechanical manipulation of the feedstock and intensive aeration. Some systems include intensive aerobic digestion as a pre-process for a feedstock that is later anaerobically digested. Company reports it was the designer-builder of the world's largest compost facility in Bangkok, Thailand with an **output** of 1200 ton d^{-1}.

Recent orders for company projects include a mechanical-biological integrated waste treatment plant to be located at the landfill in Leipzig-Crobern. The facility will include material separation and recovery. The capacity will be 300,000 t/y. One third of the material will be recycled, one third thermally converted, and one third treated biologically. Residues from the thermal and biological treatments will be landfilled.

Another mechanical-biological waste treatment plant has been ordered for Fridhaff, Luxemburg.

Projects currently under construction include,

Municipal Solid Waste Treatment Plant ECOPARC I in Barcelona, Spain

-Wet pretreatment, anaerobic digestion and composting of MSW

Municipal Solid Waste Treatment Plant PINTO in Pinto/Madrid, Spain

-Wet pretreatment, anaerobic digestion and composting for MSW

Biowaste Treatment Plant Lisbon, Portugal

-Organic fraction of MSW

Kompogas (Glattbrugg, Switzerland)

Swiss company with several operating or planned units throughout Europe. Plants are also in Japan and a facility in Martinique is under construction (approximately 25 operating or planned plants).

The process is optimized on green waste and kitchen waste for fermentation to biogas. The biogas will run small engines for heat and power or in some cases, it is upgraded to natural gas standards (remove CO2 and H20 and other diluents) and goes into Switzerland's well developed natural gas vehicle fueling systems, thus converting household organic wastes into a transportation fuel.

The Kompogas system is a high solids, thermophilic single stage digestion system(Verma 2002). It can be classified as a mechanical biological treatment plant (MBT). The reaction vessel is a horizontal cylinder into which feed is introduced daily. Movement of material through the digester is in a horizontal plug-flow manner with digested material being removed from the far end of the reactor after approximately 20 days. An agitator within the reaction vessel mixes the material intermittently. The digestate is de-watered, with some of the press water being used as an inoculum source and the remainder being sent to an anaerobic waste water treatment facility which also produces biogas.

ISKA (U-plus Umweltservice AG, Ettlingen, Germany)

The ISKA Percolation process is used for the putrescible fraction of the waste stream. It involves a high degree of mechanical sorting/separating in the preprocessing steps as well as in the hydrolysis and digestion portions of the process finishing with the dewatering of the digestate. This is classified as mechanical-biological treatment (MBT) of MSW.

Biodegradable material is first separated from the stream and then is subjected to a hybrid aerobic/anaerobic degradation process. The ISKA process uses **aerobic** means for hydrolysis of insoluble organic material to reduce the overall process (retention) time. After this percolation step, the material passes to standard anaerobic methods for production of biogas and reduction of mass. The digestate is then dewatered and sent to aerobic composting or conversion by thermal means to energy or other products. ISKA literature[40] indicates that the energy available from the biogas production is roughly sufficient to power the process. To create exportable energy, the dewatered digestate and the non-digested stream must be converted (thermally). The ISKA company information also indicates it is pretreating MSW and sending the residual solid to SVS Schwarze Pumpe gasification facility which makes methanol and power.

The commercial scale demonstration plant at Buchen, Germany will be expanded (to150,000 metric tons/y) to accept MSW from the Ludwigsburg area. The ISKA process was chosen for a new facility near Sydney, Australia. The capacity will be 170,000 metric tons/y at full build-out. The construction broke ground July, 2003 (See below).

Sydney waste processing, resource recovery centre.

Sydney's publicly owned waste management company, Waste Service NSW investigated alternative technologies and chose Global Renewables Ltd. (GRL) and Novera Energy. A review of thermal technologies for additional treatment (or in stead of the chosen GRL system) was carried out. The website for GRD[41] (Australian parent company to GRL) states that use of existing thermal technologies for organic solid waste processing would have substantially higher capital and operating costs and higher emissions. The details of the study are not given.

The GRL process, 'UR-3R' is an integrated MSW plan for reduction, recovery, recycling (3R), accepting the full waste stream including green and food waste. Essentially is a mechanical-biological (MBT) separation and conversion process. The process utilizes advanced material sorting, the ISKA Percolation process, energy recovery (from biogas only), and composting.

17000 MWh/y [42] (2.2 MWe based on 0.9 capacity factor) from 170,000 metric tons/y of mixed household waste. The company is involved in joint venture with a the Taizhou municipality (China) to develop a similar system.

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[40] http://www.iska-gmbh.de/allgemeine%20grafiken/iska_engl.pdf

[41] http://www.grd.com.au/index.php?c=global&article_id=314

[42] http://www.wme.com.au/categories/waste_managemt/dec1_02.

The largest potentially useable product stream from the process is composted material (their term is Organic Growth Material , OGM) in the amount of ~20% of the input mass. See table A2-3 (adapted from company charts)[43].

Table A2-3

Waste Profile (Input to Process)	Wt. %		UR-3R Process Outputs	Wt. %	
Green Waste	32		Evaporation	31	
Food Waste	27		CO2	11	
Paper	12		Compost Matl.	20	
			Biogas	5	
			Paper	6	
Category Total		**71**	**Category Total**		**73**
Film Plastic	5				
Other Plastic	2				
PVC	1				
PET	1				
HDPE	1		Plastic	1	
Category Total		**10**	**Category Total**		**1**
Metals	3		Metals	3	
Glass	4		Glass	3	
Category Total		**7**	**Category Total**		**6**
Sand	2		Residuals	11	
Other	13		ADC	10	
Category Total		**15**	**Category Total**		**21**
Total	**103**		**Total**	**101**	

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[43] http://www.grd.com.au/index.php?c=global&article_id=314

Eco Tec (Finland)

WABIO Process

Another anaerobic digestion process targeted for the MSW stream. The system includes receiving, sorting, mechanical pre-conditioning, digestion, dewatering of the digestate for possible further composting processing.

The digestion process occurs in a single-stage low-solids reactor. It operates in the mesophilic temperature region.

Three plants in Europe are listed in a partner company website[44]. Their locations are Vaasa and Forssa, Finland, and Bottrop, Germany (6500 t/y source separated waste).

A United Nations Development Program website[45] discusses a proposed Wabio AD facility for the city of Kalyan, India. The scale would be 55,000 t/y. No schedule is given for the project and further searching could not determine existence or status of the project.

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[44] http://www.casa2000.net/wsludgewabioplants.htm

[45] http://www.undp.org.in/programme/GEF/september/page16-20.htm

Organic Waste Systems (Gent, Belgium)

Dranco Process and Sordisep System

Dranco (Dry Anaerobic Composting) is the biological conversion portion of the Soridsep (Sorting – Digestion-Separation) integrated waste system.

The Dranco process was developed in Gent, Belgium in the late 1980's. It is a high solids, single stage anaerobic digestion system that operates at thermophilic temperatures(Verma 2002). Feed is introduced daily into the top of the reactor, and digested material is removed from the base at the same time. Part of the digestate is recycled as inoculation material, while the rest is de-watered to produce an organic compost material. There is no mixing within the reactor, other than that brought about by the downward, plug-flow movement of the waste and some gas bubbling upwards.

The company seems well established with a number of operating facilities in Europe.

Table A2-4 Organic Waste Systems' Dranco References[46]

Dranco Process Locations		Scale (ktonne/y)	Year Began Operation
Villeneuve	Switzerland	10	1999
Aarberg	Switzerland	11	1998
Bassum	Germany	13.5	1997
Salzburg	Austria	20	1993
Kaiserslautern	Germany	20	1999
Alicante	Spain	30	2002
Rome	Italy	40	2002
Brecht	Belgim	50	2000

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[46] http://www.ows.be/

BTA (Munich, Germany)

Single or multistage anaerobic digestion process for the organic fraction of MSW, creating methane and compostable solid residue and a liquid residue marketed as liquid fertilizer. The process uses a 'low solids' concentration slurry and can be operated in meso or thermophilic temperature ranges.

The process includes equipment to separate inorganic and some non-digestible organic (plastics) from the incoming waste material. After sorting, the organic fraction is diluted to ~ 10% (low solids concentration) and digested in single or multiple stages depending on facility and waste stream requirements. BTA has licensed the Process to MAT Müll- und Abfalltechnik (for Western Europe), to Biotec Sistemi, Genua, (for Italy) and Niigata Engineering, Tokyo, for Japan. An exclusive license for Canada and North America was given to Canada Composting, Newmarket/Ontario (CCI). Furthermore several co-operation agreements were made with non-European partners. The BTA license owner (Biotechnische Abfallverwertung) website[47] was responsive in Spring, 2003 but is not available in August, 2003. This may be a temporary website problem or an indication of a larger company problem (note next paragraph).

Canada Composting indicates a facility in Toronto has been operating since September, 2002. The capacity is 25,000 ton y^{-1} using source separated organics. The Canada Composting Newmarket Plant was operating for a period. It produced 5 MWe from burning the biogas in reciprocating IC engines. The plant consumed 2 MWe for a net of 3. Capacity was 150,000 metric tonnes per year. 5.4 acre site. According to Jeff Flewelling at York Region (Canada), CCI Newmarket is in receivership due odor problems and inadequate financial ability to remediate.

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[47] http://www.bta-technologie.de/

Arrow Ecology (Haifa, Israel)
The company is a large environmental services firm in Israel.

The Arrow Bio Process

The process is among the short list of companies that have passed screening and critical review from both the Santa Barbara and Coachella Valley searches for alternatives to landfills.

An innovative process which accepts unsorted MSW, processes and pretreats the biodegradable portion of the feedstock and recovers recyclables and recalcitrant material. The biodegradable material is digested in a two stage digester, an acidogenic reactor followed by the methane forming step in an up flow anaerobic sludge blanket (UASB) bioreactor.

Arrow Ecology has a patent (Asa and Faig 2002) for a MSW separator. It is clever, though elaborate. It uses a water pit as primary separator creating two material streams, the heavier materials that sink (metals, glass, plastic w/ SG>1, mineral matter, etc.), and the water soluble and 'floater' fraction. The floating light plastics are eventually skimmed and the remaining hydrolyzed stream contains most of the biodegradable.

The non soluble particles (e.g., cheese smeared pizza boxes) in the slurried stream are first comminuted to some degree and then pass through the 'hydro-crusher' (an aspect of the patent) which utilizes a series of high pressure liquid jets injected into the slurry to further disintegrate the particulate material. A further series separators follows in which larger plastic items are removed from the stream. Finally, the stream is fed to anaerobic digesters for production of methane and compost material.

The system is designed to receive unsorted MSW. The process cleans and separates non biodegradable materials from biodegradable material. The outputs can be sorted ferrous and non ferrous metals, glass, and other mineral matter, plastics, biogas, and nondigestible residue.

The company web page [48]claims overall residue is "3%" and the system has "lower costs than other new methods".

A pilot facility has operated routinely since 1999 in Hadera, Israel.

A full scale unit (one 220 ton per day module) began operation in December 2002. Located at the Tel Aviv, Israel, Municipal Solid Waste (MSW) transfer station. The site occupies 1.5 acres and is expected to export 2-3MWe once in full operation.

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[48] http://www.arrowecology.com/mainpage/index2.htm

Masada Resource Group (Birmingham, Alabama)

Masada CES Oxynol

The company has been working with Orange County and Middletown, NY for a number of years (since 1996[49]) to site a facility to separate and then convert the organic fraction of the waste stream to ethanol using an acid hydrolysis technique. Current status of the project is not available on the Masada website[50]. According to timeline in[49] there have been delays due to local activism and permitting issues.

There was a pilot facility operating on 50 t/d in Muscle Shoals, Alabama in 1996.

The relevant patent of the CES Oxynol process is titled 'Municipal solid waste processing facility and commercial ethanol production process, (Chieffalo and Lightsey 1998) The abstract is reproduced below,

> *Abstract*
>
> *A method of processing waste is disclosed wherein the municipal solid waste is segregated and processed to recover reusable rubber, metal, plastic, glass and the remaining organic portion of the waste stream is used to make ethanol and other chemicals. One process utilizes a pretreatment step with dilute sulfuric acid to reduce the heavy metal content of the cellulosic component of the municipal solid waste which can inhibit the fermentation of the sugars obtained from such waste. In another, the heavy metal content of the cellulosic component of municipal solid waste is removed via an ionic exchange process, after hydrolysis with sulfuric acid. A process for an economical, energy efficient production of ethanol from municipal solid waste is also disclosed.*

Related patent 'Method for separating acid from sugars' (Russo and Lawrence 2002)

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[49] http://www.recordonline.com/archive/2002/11/15/editedti.htm Accessed 3 Sept., 2003

[50] http://www.masada.com/mocopro.html

References for Appendix 2

Asa, A. and I. Faig (2002). System for treatment of waste. US Patent 6368500, Arrow Ecology & Engineering Overseas(1999) Ltd (Haifa, IL).

Calaminus, B. and R. Stahlberg (1998). "Continuous in-line gasification/vitrification process for thermal waste treatment: process technology and current status of projects." Waste Management **18**: 547-556.

Chieffalo, R. and G. R. Lightsey (1998). Municipal solid waste processing facility and commercial ethanol production process. US Patent 5,779,164, Controlled Environmental Systems Corporation.

Farneti, A., C. Cozzolino, et al. (1999). Semi-dry anaerobic digestion of OFMSW: the new full-scale plant of Verona (Italy). II Int. Symp. Anaerobic Dig. Solid Waste, Barcelona, June 15-17 (eds. J. Mata-Alvarez, A. Tilche and F. Cecchi), Int. Assoc. Wat. Qual.

Fruteau de Laclos, H., S. Desbois, et al. (1997). "Anaerobic disgestion of municipal solid organic waste: Valorga full-scale plant in Tilburg, the Netherlands." **36**: 457-462.

Granatstein, D. L. (2003). Case study- Waste fueled gasification project-Greve in Chianti, Italy, CANMET**:** 20.

Heermann, C., F. J. Schwager, et al. (2001). Pyrolysis & Gasification of Waste: A worldwide technology and business review, Juniper Consultancy Services LTD. **2001**.

Jaeger, M. and M. Mayer (2000). "The Noell Conversion Process – a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials." Water Science & Technology **41**(8): 37-44.

Lorson, H. and M. Schingnitz (1994). "Conversion process for the thermic utilization of residual and waste materials." Bwk **46**(5): 214-217.

OPET (2002). Review of Finnish biomass gasification technologies. Espoo, VTT**:** 21.

Russo, J. and J. Lawrence (2002). Method for the separation of acid from sugars. US Patent 6391204, Controlled Environmental Systems Corporation.

RWBeck (2003). City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal, R.W.Beck,Inc**:** 32.

Themelis, N. J., Y. H. Kim, et al. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research **20**(3): 223-233.

Towill-Corporation, R. M. (2000). New Systems Research for Refuse Disposal- Oahu Municipal Refuse Disposal Alternatives Study. Honolulu, City&County of Honolulu.

Verma, S. (2002). Anaerobic digestion of biodegradable organics in municipal solid wastes. Earth Resources Engineering. New York, Columbia University**:** 56.

Appendix 3 -Jurisdictions actively searching for landfill alternatives

Santa Barbara City/County

- http://www.countyofsb.org/pwd/swud/MJSWTG/AltDisp.htm

Fairly extensive evaluation and ranking process has been developed. Weighted criteria can be viewed from a slide presentation on the subgroup website. Paul Rellis' company has proposed, working with EPI, and/or Prime energy. Two rounds of RFI have been issued, and a short list of seven companies meeting requirements developed by the task group has been developed.

Final report with recommendations is released and should be available on the website in the near future.

Alameda Power and Telecom

http://www.alamedapt.com/newsroom/reports.html

The utility district is considering options for increasing generation capacity. Goals of the project include, meet future electricity demands, facilitate economic development for Alameda, local reliability, maintain power content label (renewable component).

Advanced Energy Strategies, Inc, (W. Richard Maclay) is consulting company that did study detailing power supply options for the City of Alameda and is handling review of the proposals.

The two options considered viable are 'MSW gasification' which would be 12-27MWe project located at a current MRF.

The other option is combined cycle fired by natural gas. This would be sized between 60 and 150 MWe which is more than the city requires for it's own use, so sale of excess power is required.

A request for qualifications was issued with submission deadline of 13 May, 2003. Results or review and names of respondents are not yet available.

Coachella Valley Association of Governments

http://www.cvag.org/ (for some meeting minutes which may have information)

Edom Hill Landfill closure. Waste Management is to select a conversion technology for a transfer station to be located at the closed landfill. Brightstar (SWERF) and ESI (Romoland pyrolysis) were known to have submitted proposals

City of Los Angeles

RFQ for engineering consulting services was released in spring. Possible that company has been selected by now.

City&County of Honolulu

http://www.opala.org/plasma.html

RFP for gasification/plasma arc MSW facility
Have received more than one response and the agency is currently evaluating proposals and in negotiation with suppliers. The names of the responding companies are not yet public information.

Landfill capacity and environmental justice issues forcing agency to consider landfill alternatives.

Preliminary technology survey by RM Towill Corporation (with Allied Technology Group and Pacific Waste Consulting)[51] did not find any technologies/suppliers that met the requirements of County for an alternative to landfill disposal facility, yet gives favorable mention to plasma arc gasification. Report recommends that this be investigated further. A following report[52] reviews in some detail plasma arc gasification, indicating no commercial scale facilities could be found world wide operating on MSW (Hitachi facility in Japan in start-up to commingle MSW and auto shredder residue).

City of Toronto

http://www.city.toronto.on.ca/taskforce2010/2010_report.htm

Ambitious goals of 60% diversion by 2006 and 100% by 2010. First steps in achieving this are to implement source separation of food wastes and green wastes which will be composted. The dry organic fraction of the waste stream will require other means for diversion and report recommends investigating new Estimate that the 60% diversion amount for year 2006 would be accomplished by ~16% recycling, ~20% wet organics to compost, ~20% dry matter 'new technology' conversion, and small amounts diverted by 'other' means. City estimates 2006 generation to be ~ 1 Mton, diversion to be ~600 kton. Costs are estimated to be ~Canadian $160 per household.

Toronto maintains a database of possible suppliers of landfill alternatives. A request for expression of interest (REOI) has been returned from 50 interested entities. The distribution according to process type is as follows (City of Toronto's classification terms),

Thermal	29
Biological	12
Physical	5
Chemical	4

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[51] Towill-Corporation, R. M. (2000). New Systems Research for Refuse Disposal- Oahu Municipal Refuse Disposal Alternatives Study. Honolulu, City&County of Honolulu.

[52] RWBeck (2003). City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal, R.W.Beck,Inc

Toronto is in the process of evaluating the responses and may issue requests for proposals in the future depending on results of the analysis. Toronto documents indicate there is a database of suppliers maintained by the Toronto work group. Efforts are underway to contact the responsible person (Lawson Oates) at the City of Toronto. Links to a brief review of the results[53] of the REOI and the responders[54] are footnoted.

Regional Municipality of Niagara, Ontario

http://www.regional.niagara.on.ca/works/solid/wmacstudy.shtml

Niagara is currently in developing a long-term integrated waste management plan with implementation planned for end of 2004.

The municipality anticipates running out of landfill space by 2013. Is implementing a wet organics diversion program. This is a source separated and central compost yard plan. This can divert 60% of the waste stream by 2005. For the dryer portion of the waste stream, Niagara is considering and evaluating combustion and gasification technologies for conversion before landfilling the residues.

Task F draft report (available at website) if comprehensive and has results of technology evaluations and list of technology suppliers. Figure 3-1 (page 36) of the Task F report has a standardized mass balance form utilized in a follow-up survey of interested process suppliers.

A request for expression of interest was let to alternative to landfill suppliers and 14 responses were received. Screening led to recommending further consideration for only full mass burn combustion, RDF (processed MSW) combustion and RDF gasification. Executive summary indicates there were no submissions from composting and anaerobic digestion technologies and MSW gasification option was eliminated due to high cost and required waste volume.

Region of York, Ontario

York is believed to be cooperating with the City of Toronto in the search for alternatives to landfills.

North South Wales, Australia

Report of the Alternative Waste Management Technologies and Practices Inquiry[55]. Well researched report on worldwide solid waste management practices (landfill alternatives). Contains Technology evaluation table with results. This report is available through the Australian EPA website.[56]

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[53] http://www.toronto.ca/wes/techservices/involved/swm/net/pdf/presentation_aug_13.pdf

[54] http://www.toronto.ca/wes/techservices/involved/swm/net/pdf/sumbission.pdf

[55] Wright, T., C. Zoi, et al. (2000). Alternative Waste Management Technologies and Practices. Sydney, Panel on Waste Inquiry, Australia EPA**:** 134.

[56] http://www.epa.nsw.gov.au/waste/inquirytext.pdf

Appendix 4

-Bibliography

General Waste and Waste Conversion References

1. Upreti, B.R. and D. van der Horst, *National renewable energy policy and local opposition in the UK: the failed development of a biomass electricity plant.* Biomass and Bioenergy, in press. **In Press, Corrected Proof**.
2. Frey, H.-H., et al., *Characterization of municipal solid waste combustion in a grate furnace.* Waste Management, In Press. **In Press, Corrected Proof**.
3. Tangri, N., *Waste Incineration: A dying technology*. 2003, Global Anti-Incinerator Alliance: Berkeley, CA. p. 107.
4. RWBeck, *City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal*. 2003, R.W.Beck,Inc. p. 32.
5. Na, J.I., et al., *Characteristics of oxygen-blown gasification for combustible waste in a fixed-bed gasifier.* Applied Energy, 2003. **75**(3-4): p. 275-285.
6. Marano, J.J., *Refinery Technology Profiles Gasification and Supporting Technologies*. 2003, US Department of Energy National Energy Technology Laboratory Energy Information Administration.
7. Lucia, A., et al., *High-Resolution Record of Pyrogenic Polycyclic Aromatic Hydrocarbon Deposition during the 20th Century.* Environ, Sci, Technol., 2003. **37**(1): p. 53-61.
8. Komilis, D.P. and R.K. Ham, *The effect of lignin and sugars to the aerobic decomposition of solid wastes.* Waste Management, 2003. **23**(5): p. 419-423.
9. Granatstein, D.L., *Case study- Waste fueled gasification project-Greve in Chianti, Italy*. 2003, CANMET. p. 20.
10. *Landfill Oversight Committee*. 2003.
11. *Authority to distribute a request for qualifications for professional engineering consultant services for the indentification, study, and evaluation of alternative technologies for the processing of residual municipal waste generated by the city of LA*. 2003. p. 6.
12. *Request For Information #2: Pre-Qualified Conversion Technologies*. 2003, Santa Barbara County Multi-Jufisdictional Solid Waste Task Group.
13. *DRAFT Technical Memorandum for the Conversion Technologies Market Impact Assessment*. 2003, Hilton Farnkope & Hobson, LLC.
14. *CITY OF HONOLULU REVIEW OF PLASMA ARC GASIFICATION AND VITRIFICATION TECHNOLOGY FOR WASTE DISPOSAL*. 2003, R. W. Beck, Inc. p. 32.
15. Zhang, R. and Z. Zhang, *Biogasification of solid waste with an anaerobic-phased solids-digester system*, in *US Patent No. 6,342,378*. 2002, Regents of the University of California: USA.
16. Zadik, B. and M.S. Finstein, *The ArrowBio Processfor Comprehensive Recycling of Biodegradable and Non-biodegradable Materials in Unsorted Municipal Solid Waste*. 2002.
17. Yesodharan, S., *Supercritical water oxidation: An environ- mentally safe method for the disposal of organic wastes.* Current Science, 2002. **82**(9): p. 1112-1122.
18. Wyk, J.P.H.v., *Biodevelopment of Wastepaper as a Resource of Renewable Energy: Influence of Enzyme Concentration and Paper Amount on the Bioconversion Process.* Energy & Fuels, 2002. **16**(5): p. 1277-1279.
19. Weber, R., et al., *Correlation of PCDD/PCDF and CO values in a MSW incinerator--indication of memory effects in the high temperature/cooling section.* Chemosphere, 2002. **49**(2): p. 127-134.
20. Walsh, D.C., *Urban Residential Refuse Composition and Generation Rates for the 20th Century.* Environ. Sci. Technol., 2002. **36**(22): p. 4936-4942.

21. Verma, S., *Anaerobic digestion of biodegradable organics in municipal solid wastes*, in *Earth Resources Engineering*. 2002, Columbia University: New York. p. 56.
22. Vandevivere, P., L. De Baere, and W. Verstraete, *Types of anaerobic digestors for solid wastes*, in *Biomethanization of organic fraction of MSW*, M.J. Alvarez, Editor. 2002, IAWQ.
23. Themelis, N.J. and Y.H. Kim, *Material and energy balances in a large-scale aerobic bioconversion cell.* Waste Management & Research, 2002. **20**(3): p. 234-242.
24. Themelis, N.J., Y.H. Kim, and M.H. Brady, *Energy recovery from New York City municipal solid wastes.* Waste Management & Research, 2002. **20**(3): p. 223-233.
25. Sipila, K. and M. Rossi, *Power production from waste and biomass IV Advanced concepts and technologies*. 2002, VTT, EC DG TREN, IEA Bioenergy, Novem,Tekes,KTM. p. 354.
26. Sipila, K., ed. *Overview of Finnish waste to energy R&D program*. Power production from waste and biomass IV -Advanced concepts and technologies, ed. K. Sipila and M. Rossi. 2002, VTT: Espoo, Finland. 31-45.
27. Singh, S.K., B.C. Mohanty, and S. Basu, *Synthesis of SiC from rice husk in a plasma reactor.* 2002. **25**(6): p. 561-563.
28. Simons, G., Z. Zhang, and P.T. Redding, *Landfill Gas-To-Energy Potential In California*. 2002. p. 59.
29. Shiro, T., Toshiyuki Kanno, Kyohei Aratani, Yasuhiro Katsura, Na-oki Ikenaga, and Toshimitsu Suzuki, *Promoting Effect of Sulfur Compounds on the Degradation of Polyethylene.* Energy & Fuels, 2002. **16**(5): p. 1314-1320.
30. Scoditti, E. and N. Barker, *Task 33: Thermal Gasification of Biomass (2001-2003) Subtask: Review of Energy Conversion Devices.* 2002: p. 41.
31. Scoditti, E., *Review of Energy Conversion Devices.* 2002.
32. Russo, J. and J. Lawrence, *Method for the separation of acid from sugars*. 2002, Controlled Environmental Systems Corporation: US Patent 6391204.
33. Quapp, W.J., *General Description of the Plasma Enhance Melter*. 2002, Integrated Environmental Technologies, LLC.
34. Pickin, J.G., S.T.S. Yuen, and H. Hennings, *Waste management options to reduce greenhouse gas emissions from paper in Australia.* Atmospheric Environment, 2002. **36**(4): p. 741-752.
35. OPET, *Review of Finnish biomass gasification technologies*. 2002, VTT: Espoo. p. 21.
36. Mastellone, M.L., et al., *Fluidized bed pyrolysis of a recycled polyethylene.* Polymer Degradation & Stability, 2002. **76**(3): p. 479-487.
37. Lu, J., Shibai Ma, and Jinsheng Gao, *Study on the Pressurized Hydrolysis Dechlorination of PVC.* Energy & Fuels, 2002. **16**(5): p. 1251-1255.
38. Loschel, A., *Technological change in economic models of environmental policy: a survey.* Ecological Economics, 2002. **43**(2-3): p. 105-126.
39. Koufodimos, G. and Z. Samaras, *Waste management options in southern Europe using field and experimental data.* Waste Management, 2002. **22**(1): p. 47-59.
40. Kottner, M., *Dry Fermentation-A new method for biological treatment*. 2002, International Biogas and Bioenergy Centre of Competence (IBBC): Jagst, Germany. p. 16.
41. Korobitsyn, M., *Industrial applications of the air bottoming cycle.* Energy Conversion & Management, 2002. **43**(9-12 Special Issue SI): p. 1311-1322.
42. Klein, A., *Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes*, in *Department of Earth and Environmental Engineering Fu Foundation School of Engineering and Applied Science*. 2002, Columbia University: New York. p. 50.

43. Kim, K.-H. and M.-Y. Kim, *Mercury emissions as landfill gas from a large-scale abandoned landfill site in Seoul.* Atmospheric Environment, 2002. **36**(31): p. 4919-4928.
44. Karagöz, S., Jale Yanik,* Suat Uçar, and Chunshan Song, *Catalytic Coprocessing of Low-Density Polyethylene with VGO Using Metal Supported on Activated Carbon.* Energy & Fuels, 2002. **16**(5): p. 1301-1308.
45. Ikonomou, M.G., et al., *PCB levels and congener patterns from Korean municipal waste incinerator stack emissions.* Chemosphere, 2002. **49**(2): p. 205-216.
46. Heermann, C. and F.J. Schwager, *The worldwide directory of gasification & pyrolysis technology suppliers and processes*. 2002, Juniper Consultancy Services Ltd. p. 102.
47. Fulcheri, L., *Plasma processing: a step towards the production of new grades of carbon black.* Carbon, 2002. **40**(2): p. 169-176.
48. Finstein, M.S., *The ArrowBio Process for Comprehensive Recycling of Biodegradable and Non-biodegradable Materials in Unsorted Municipal Solid Waste*. 2002.
49. Corella, J. and J.M. Toledo, *Testing total oxidation catalysts for gas cleanup in waste incineration at pilot scale.* Industrial & Engineering Chemistry Research, 2002. **41**(5): p. 1171-1181.
50. Chavez-Vaszquez, M. and D.M. Bagley, *Evaluation of the performance of different anaerobic digestion technologies for solid waste treatment.* CSCE/EWRI of ASCE Environmental Engineering Conf., Niagara, 2002.
51. Caputo, A.C. and P.M. Pelagagge, *RDF production plants: II Economics and profitability.* Applied Thermal Engineering, 2002. **22**(4): p. 439-448.
52. Caputo, A.C. and P.M. Pelagagge, *RDF production plants: I Design and costs.* Applied Thermal Engineering, 2002. **22**(4): p. 423-437.
53. Bebar, L., et al., *Waste to energy in the field of thermal processing of waste.* Applied Thermal Engineering, 2002. **22**(8): p. 897-906.
54. Asa, A. and I. Faig, *System for treatment of waste. US Patent 6368500*. 2002, Arrow Ecology & Engineering Overseas(1999) Ltd (Haifa, IL).
55. *Regional Niagara Long-term Waste Disposal Planning Study Request for Expressions of Internet (REOI).* 2002.
56. *Evaluation of the Green Power and Public Benefits Programs of the LA Department of Water and Power*. 2002, Barrington-Wellesley Group, Inc.
57. *Power Supply Alternatives and Recommendations for Reliability in the 21st Century*. 2002, Alameda Power and Telecom.
58. *Organics Processing in Alameda County*. 2002, Alameda County Waste Management Authority Alameda County Source Reduction and Recycling Board.
59. *Plastics White Paper*. 2002, New Point Group: Sacramento. p. 67.
60. Wilson, E.J., F.R. McDougall, and J. Willmore, *Euro-trash: searching Europe for a more sustainable approach to waste management.* Resources, Conservation and Recycling, 2001. **31**(4): p. 327-346.
61. van Wyk, J.P.H., *Biotechnology and the utilization of biowaste as a resource for bioproduct development.* Trends in Biotechnology, 2001. **19**(5): p. 172-177.
62. Tolman, R., J. Parkinson, and B. Rickman, *Process for Converting Sewage Sludge and Municipal Solid Wastes to Clean Fuels, Feasibility Analysis*. 2001, Environmental Energy Systems, Inc.: Oceanside, CA. p. 17.
63. Toledo, J.M., J. Corella, and A. Sanz, *Noble metal-based catalysts for total oxidation of chlorinated hydrocarbons.* Environmental Progress, 2001. **20**(3): p. 167-174.

64. Tao, D., et al., *An investigation of a thermochemical process for conversion of gypsum and pyrite wastes into useful products.* Advances in Environmental Research, 2001. **5**(3): p. 277-284.
65. Stulir, R., et al., *Fully integrated unit for thermal treatment of gas wastes.* Applied Thermal Engineering, 2001. **21**(13-14): p. 1383-1395.
66. Stehlik, P., *New equipment for thermal treatment of wastes equals utilization of experience plus application of theory (heat transfer, modeling).* Heat Transfer Engineering, 2001. **22**(2): p. 1-2.
67. Spliethoff, H., *Status of biomass gasification for power production.* IFRF Combustion Journal, 2001. **Article no. 200109**.
68. Sorum, L., et al., *Formation of NO from combustion of volatiles from municipal solid wastes.* Combustion & Flame, 2001. **124**(1-2): p. 195-212.
69. Miranda, M.L. and B. Hale, *Protecting the forest from the trees: the social costs of energy production in Sweden.* Energy, 2001. **26**(9): p. 869-889.
70. Marxsen, C.S., *Potential world garbage and waste carbon sequestration.* Environmental Science & Policy, 2001. **4**(6): p. 293-300.
71. Maizza, V. and A. Maizza, *Unconventional working fluids in organic Rankine-cycles for waste energy recovery systems.* Applied Thermal Engineering, 2001. **21**(3): p. 381-390.
72. Liu, G.Q., et al., *Fundamental study of the behavior of chlorine during the combustion of single RDF.* Waste Management, 2001. **21**(5): p. 427-433.
73. Larson, E.D., R.H. Williams, and R.L.V. Leal, *A review of biomass integrated-gasifier/gas turbine combined cycle technology and its application in sugarcane industries, with an analysis for Cuba.* Energy for Sustainable Development, 2001. **5**(1): p. 54-76.
74. Hinshaw, G.D. and A.R. Trenholm, *Hazardous waste incineration emissions in perspective.* Waste Management, 2001. **21**(5): p. 471-475.
75. Hellman, K.H. and R.M. Heavenrich, *Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001.* 2001, US Environmental Protection Agency. p. 68.
76. Heermann, C., F.J. Schwager, and K.J. Whiting, *Pyrolysis & Gasification of Waste: A worldwide technology and business review*. 2001, Juniper Consultancy Services LTD.
77. Hazlebeck, D.A., *Hydrothermal processing with phosphate additive*. 2001, General Atomics: USA.
78. Guo, L., G. Shi, and Y. Liang, *Poly(ethylene glycol)s catalyzed homogeneous dehydrochlorination of poly(vinyl chloride) with potassium hydroxide.* Polymer, 2001. **42**(13): p. 5581-5587.
79. Gohlke, O. and M. Busch, *Reduction of combustion by-products in WTE plants: O-2 enrichment of underfire air in the MARTIN SYNCOM process.* Chemosphere, 2001. **42**(5-7): p. 545-550.
80. Fletcher, E.A., *Solarthermal processing: A review.* Journal of Solar Energy Engineering-Transactions of the Asme, 2001. **123**(2): p. 63-74.
81. Delay, I., J. Swithenbank, and B.B. Argent, *Prediction of the distribution of alkali and trace elements between the condensed and gaseous phases generated during clinical waste incineration.* Journal of Alloys & Compounds, 2001. **320**(2): p. 282-295.
82. Cocero, M.J. and M.T. Sanz, *Study of alternatives for the design of a mobile unit for wastewater treatment by supercritical water oxidation.* Journal of Chemical Technology and Biotechnology, 2001. **76**: p. 257-264.
83. Chynoweth, D.P., J.M. Owens, and R. Legrand, *Renewable methane from anaerobic digestion of biomass.* Renewable Energy, 2001. **22**(1-3): p. 1-8.

84. Caputo, A.C. and P.M. Pelagagge, *Waste-to-energy plant for paper industry sludges disposal: technical-economic study.* Journal of Hazardous Materials, 2001. **81**(3): p. 265-283.
85. Bjorklund, A., M. Melaina, and G. Keoleian, *Hydrogen as a transportation fuel produced from thermal gasification of municipal solid waste: an examination of two integrated technologies.* International Journal of Hydrogen Energy, 2001. **26**(11): p. 1209-1221.
86. . 2001.
87. *IGCC Financial Model Version 3.01 Users'Guide*. 2001, US Department of Energy. p. 23.
88. *Energy Technology Export Directory of California Companies*. 2001.
89. *China to build large-scale supercritical coal plant*, in *Power*. 2001. p. 14-+.
90. Zhou, J. *Supercritical pulverized coal firing for power generation in China*. in *Annual Int. Pittsburgh Coal Conf.* 2000.
91. Wright, T., et al., *Alternative Waste Management Technologies and Practices*. 2000, Panel on Waste Inquiry, Australia EPA: Sydney. p. 134.
92. Worl, L.A., et al., *Hydrothermal oxidation of radioactive combustible waste.* Waste Management, 2000. **20**(5-6): p. 417-423.
93. Vieitez, E.R., J. Mosquera, and S. Ghosh, *Kinetics of accelerated solid-state fermentation of organic-rich municipal solid waste.* Water Science & Technology, 2000. **41**(3): p. 231-238.
94. Subramanian, P.M., *Plastics recycling and waste management in the US.* Resources Conservation & Recycling, 2000. **28**(3-4): p. 253-263.
95. Stehlik, P., R. Puchyr, and J. Oral, *Simulation of processes for thermal treatment of wastes.* Waste Management, 2000. **20**(5-6): p. 435-442.
96. Scherer, P.A., et al., *Development of a methanogenic process to degrade exhaustively the organic fraction of municipal "grey waste" under thermophilic and hyperthermophilic conditions.* Water Science & Technology, 2000. **41**(3): p. 83-91.
97. Schaffner, B., et al., *Recycling of Hazardous Solid Waste Material Using High-Temperature Solar Process Heat. 1. Thermodynamic Analysis.* Environ. Sci. Technol., 2000. **34**(19): p. 4177-4184.
98. Remias, J.E., T.A. Pavlosky, and A. Sen, *Oxidative chemical recycling of polyethene.* Comptes Rendus De L Academie Des Sciences Serie Ii Fascicule C- Chimie, 2000. **3**(7): p. 627-629.
99. Rao, M.S., et al., *Bioenergy conversion studies of the organic fraction of MSW: assessment of ultimate bioenergy production potential of municipal garbage.* Applied Energy, 2000. **66**(1): p. 75-87.
100. Patel, M., et al., *Recycling of plastics in Germany.* Resources Conservation & Recycling, 2000. **29**(1-2): p. 65-90.
101. Orr, D. and D. Maxwell, *A Comparison of Gasification and Incineration of Hazardous Wastes*. 2000. p. 93.
102. Miranda, M.L., J.N. Miller, and T.L. Jacobs, *Talking trash about landfills: Using quantitative scoring schemes in landfill siting processes.* Journal of Policy Analysis & Management, 2000. **19**(1): p. 3-22.
103. Larson, E.D. and S. Kartha, *Expanding roles for modernized biomass energy.* Energy for Sustainable Development, 2000. **4**(3): p. 15-25.
104. Korobitsyn, M., *Enhancing direct-fired power plants performance by use of gas turbine technology.* Journal of Propulsion & Power, 2000. **16**(4): p. 568-571.
105. Kaminsky, W. and F. Hartmann, *New pathways in plastics recycling.* Angewandte Chemie, International Edition, 2000. **39**(2): p. 331-333.

106. Jaeger, M. and M. Mayer, *The Noell Conversion Process – a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials.* Water Science & Technology, 2000. **41**(8): p. 37-44.
107. Hsu, P.C., et al., *Treatment of solid wastes with molten salt oxidation.* Waste Management, 2000. **20**(5-6): p. 363-368.
108. Gimouhopoulos, K., et al., *Coliquefaction studies of waste polymers and lignite influenced by acidic and oil-soluble catalysts.* Journal of Applied Polymer Science, 2000. **75**(11): p. 1323-1330.
109. Gimouhopoulos, K., et al., *Optimization studies of waste plastics-lignite catalytic coliquefaction.* Waste Management & Research, 2000. **18**(4): p. 352-357.
110. Ecke, H., et al., *State-of-the-art treatment processes for municipal solid waste incineration residues in Japan.* Waste Management & Research, 2000. **18**(1): p. 41-51.
111. Corella, J., J.M. Toledo, and A.M. Padilla, *On the selection of the catalyst among the commercial platinum-based ones for total oxidation of some chlorinated hydrocarbons.* Applied Catalysis B-Environmental, 2000. **27**(4): p. 243-256.
112. Corella, J. and J.M. Toledo, *Incineration of doped sludges in fluidized bed. Fate and partitioning of six targeted heavy metals. I. Pilot plant used and results.* Journal of Hazardous Materials, 2000. **80**(1-3): p. 81-105.
113. Caputo, A.C. and P.M. Pelagagge, *Baghouse system design based on economic optimization.* Environmental Progress, 2000. **19**(4): p. 238-245.
114. Camacho, S.L. and C.Z. Nunn, *Plasma Heat: Worldwide developments using a demonstrated, unique heat source for waste treatment & industrial applications.* 2000.
115. Bjornsson, L., *Intensification of the biogas process by improved process monitoring and biomass retention*, in *Dept. of Biotechnology*. 2000, Lund University: Solvegatan. p. 124.
116. Arena, U. and M.L. Mastellone, *A systematic approach to fixed carbon balance during the fluidized bed combustion of a packaging-derived fuel.* Powder Technology, 2000. **110**(1-2 Special Issue SI): p. 110-116.
117. *Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media*. 2000, US Environmental Protection Agency. p. 88.
118. *New Systems Research for Refuse Disposal, Oahu Municipal Refuse Disposal Alternatives Study.* 2000.
119. *Biosolids Technology Facts Sheet In-Vessel Compostion of Biosolids*. 2000, US Envronmental Protection Agency. p. 9.
120. *Experience Curves for Energy Technology Policy*. 2000: International Energy Agency. 132.
121. *Waste Management Plan, Appendix B*. 2000, County of Donegal, Ireland.
122. Zhang, R.H. and Z.Q. Zhang, *Biogasification of rice straw with an anaerobic-phased solids digester system.* Bioresource Technology, 1999. **68**(3): p. 235-245.
123. Vieitez, E.R. and S. Ghosh, *Biogasification of solid wastes by two-phase anaerobic fermentation.* Biomass & Bioenergy, 1999. **16**(5): p. 299-309.
124. Padilla, A.M., J. Corella, and J.M. Toledo, *Total oxidation of some chlorinated hydrocarbons with commercial chromia based catalysts.* Applied Catalysis B-Environmental, 1999. **22**(2): p. 107-121.
125. Morris, M., *ELECTRICITY PRODUCTION FROM SOLID WASTE FUELS USING ADVANCED GASIFICATION TECHNOLOGY.* 1999, PRESENTED AT SWANA'S WASTECON 1998/ISWA WORLD CONGRESS. p. 11.

126. Matsunami, J., et al., *GASIFICATION OF WASTE TYRE AND PLASTIC (PET) BY SOLAR THERMOCHEMICAL PROCESS FOR SOLAR ENERGY UTILIZATION.* Solar Energy, 1999. **65**(1): p. 21-23.
127. Matsunami, J., et al., *GASIFICATION OF WASTE TYRE AND PLASTIC (PET) BY SOLAR THERMOCHEMICAL PROCESS FOR SOLAR ENERGY UTILIZATION.* Solar Energy, 1999. **65**(1): p. 21-23.
128. Mastellone, M.L. and U. Arena, *Carbon attrition during the circulating fluidized bed combustion of a packaging-derived fuel.* Combustion & Flame, 1999. **117**(3): p. 562-573.
129. Korobitsyn, M.A., P. Jellema, and G.G. Hirs, *Possibilities for gas turbine and waste incinerator integration.* Energy, 1999. **24**(9): p. 783-793.
130. Joo, H.K., J.N. Hool, and C.W. Curtis, *Determination of effective conditions for two-stage coprocessing of coal with waste plastics and petroleum resid.* Energy & Fuels, 1999. **13**(6): p. 1128-1134.
131. Jaraysi, M., et al., *Mixed waste facility risk assessment for a commercial plasma-based gasification and vitrification system*. 1999.
132. Gimouhopoulos, K., et al., *Waste plastics-lignite coliquefaction innovations.* Resources Conservation & Recycling, 1999. **26**(1): p. 43-52.
133. Gimouhopoulos, K., et al., *Waste plastics: lignite mixtures co-liquefaction over Si/Al catalysts.* Waste Management & Research, 1999. **17**(3): p. 181-185.
134. Genon, G., *Economic assessemnt of MSW anaerobic digestion in comparison with composting plants.* Proceedings of II Int. IAWQ Symp. on Anaerobic Digestion of Solid Waste. Barcelona 15-17 June, 1999: p. 282-289.
135. Franke, H.J., et al., *Improvement of carbon burn-up during fluidized bed incineration of plastic by using porous bed materials.* Energy & Fuels, 1999. **13**(4): p. 773-777.
136. Farneti, A., et al. *Semi-dry anaerobic digestion of OFMSW: the new full-scale plant of Verona (Italy).* in *II Int. Symp. Anaerobic Dig. Solid Waste, Barcelona, June 15-17 (eds. J. Mata-Alvarez, A. Tilche and F. Cecchi)*. 1999: Int. Assoc. Wat. Qual.
137. DiPippo, M.M., K. Sako, and J.W. Tester, *Ternary phase equilibria for the sodium chloride–sodium sulfate–water system at 200 and 250 bar up to 4008C*. 1999, Elsevier. p. 229-255.
138. CIWMB, *(CA) Statewide Waste Characterization Study Results and Final Report*. 1999, Cascadia Consulting Group, Inc. Sky Valley Associates, Inc. Sheri Eiker-Wiles Associates Pacific Waste Consulting Group Veterans Assistance NetworkE. Tseng and AssociatesE. Ashley Steel
    California Integrated Waste Management Board: Sacramento. p. 206.
139. Chynoweth, D. and A.L. Young, *CO-COMPOSTING OF ORGANIC WASTE BLENDS*. 1999, US Environmental Protection Agency Region 4, Atlanta Georgia. p. 39.
140. *Waste Composition study, Oahu Municipal Refuse Disposal Alternatives Study*. 1999, City and County of Honolulu Department of Public Works.
141. *Waste Composition Study Oahu Municipal Refuse Disposal Alternatives Study*. 1999.
142. *Statewide Waste Characterization Study*. 1999.
143. *A Multiyear Plan for the Hydrogen R&D Program Rationale, Structure, and Technology Roadmaps*. 1999. p. 55.
144. *Business and theUnited Nations, Partners in Sustainable Development*. 1999, United Nations: New York. p. 171.
145. *Council Directive 1999/31/EC Environment, consumers and health protection - Environment - Space, environment and natural resources - Waste management and clean technology*. 1999.

146. *California Waste Tire Program Evaluation and Recommendations*. 1999, California Integrated Waste Management Board: Sacramento. p. 102.
147. Zamansky, V., P. Maly, and M.K. Klosky, *Synergistic Utilization of Coal Fines and Municipal Solid Waste in Coal-Fired Boilers. Phase I Final Report*. 1998, GEEER: Irvine. p. 61.
148. Watanabe, M., et al., *Polyethylene conversion in supercritical water.* Journal of Supercritical Fluids, 1998. **13**: p. 247-252.
149. Solomon, J., *Synergistic Utilization of Coal Fines and Municipal Solid Waste in Coal-Fired Boilers.* 1998.
150. Sasaki, M., et al., *Cellulose Hydrolysis in subcritical and supercritical water.* Journal of Supercritical Fluids, 1998. **13**: p. 261-268.
151. Ruth, L.A., *Energy from municipal solid waste - a comparison with coal combustion technology.* Progress in Energy & Combustion Science, 1998. **24**(6): p. 545-564.
152. Pifer, A. and A. Sen, *Chemical recycling of plastics to useful organic compounds by oxidative degradation.* Angewandte Chemie-International Edition, 1998. **37**(23): p. 3306-3308.
153. Piao, G., et al., *Combustion of refuse derived fuel in a fluidized bed.* Waste Management, 1998. **18**(6-8): p. 509-512.
154. Miranda, M.L. and J.E. Aldy, *Unit pricing of residential municipal solid waste - lessons from nine case study communities.* Journal of Environmental Management, 1998. **52**(1): p. 79-93.
155. Maly, P.M., W.R. Seeker, and M.K. Klosky, *Evaluation of air toxics emissions from rdf slurry combustion.* Environmental Engineering Science, 1998. **15**(2): p. 107-116.
156. Lee, P.H., et al., *Characterization, decontamination and health effects of fly ash from waste incinerators.* Environmental Progress, 1998. **17**(4): p. 261-269.
157. LaMotta, E. and J.C. Josse, *FECAL COLIFORM REMOVAL IN HIGH-RATE ANAEROBIC WASTEWATER TREATMENT UNITS.* 1998: p. 46.
158. Joo, H.K., J.N. Hool, and C.W. Curtis, *Anova analysis of two-stage coprocessing of low-density polyethylene, coal, and petroleum resid.* Energy & Fuels, 1998. **12**(4): p. 704-714.
159. Holbert, C. and J.S. Lighty, *Trace metals behavior during the thermal treatment of paper-mill sludge.* Waste Management, 1998. **18**(6-8): p. 423-431.
160. He, B.J., et al., *Thermaochemical Conversion of Swine Manure Temperature and Pressure Responses*. 1998, ASAE Annual International Meeting 1998. p. 5.
161. Gimouhopoulos, K., et al., *Organic solvent effects on waste plastics-lignite coliquefaction.* Resources Conservation & Recycling, 1998. **23**(1-2): p. 47-56.
162. Dufaud, V.R. and J.M. Basset, *Catalytic hydrogenolysis at low temperature and pressure of polyethylene and polypropylene to diesels or lower alkanes by a zirconium hydride supported on silica-alumina: A step toward polyolefin degradation by the microscopic reverse of Ziegler-Natta polymerization.* Angewandte Chemie-International Edition, 1998. **37**(6): p. 806-810.
163. Chieffalo, R. and G.R. Lightsey, *Municipal solid waste processing facility and commercial ethanol production process*. 1998, Controlled Environmental Systems Corporation: US Patent 5,779,164.
164. Calaminus, B. and R. Stahlberg, *Continuous in-line gasi®cation/vitri®cation process for thermal waste treatment: process technology and current status of projects.* Waste Management, 1998. **18**: p. 547-556.
165. Calaminus, B. and R. Stahlberg, *Thermal waste treatment - a better approach.* Chemtech, 1998. **28**(10): p. 40-46.
166. Calaminus, B. and R. Stahlberg, *Continuous in-line gasification/vitrification process for thermal waste treatment: process technology and current status of projects.* Waste Management, 1998. **18**(6-8): p. 547-556.

167. Bockhorn, H., A. Hornung, and U. Hornung, *Stepwise pyrolysis for raw material recovery from plastic waste.* Journal of Analytical & Applied Pyrolysis, 1998. **46**(1): p. 1-13.

168. Bardos, P., R. Booth, and D. Dopkin, *NATO/CCMS Pilot Study: Evaluation of Demonstrated and Emerging Technologies for the Treatment and Clean Up of Contaminated Land and Groundwater*. 1998, Committee on the challenges of modern society.

169. *Partners in Sustainable Development.* 1998.

170. *Advanced Thermal Conversion Technologies for Energy from Solid Waste*. 1998, IEA/CADDET Center for Renewable Energy. p. 51.

171. *Energy From Biomass; Summaries of Biomass Projects for DTI (UK); Vol. 4 Anaerobic Digestion for Biogas*. 1998, ETSU / DTI (UK). p. 94.

172. Zevenhoven, R., et al., *Combustion and gasification properties of plastics particles.* Journal of the Air and Waste Management Association, 1997. **47**(8): p. 861-870.

173. Tchobanoglous, G., H. Theisen, and R. Eliassen, *Solid Wastes- Engineering Principles and Management Issues*. 1997, New York: McGraw-Hill. 621.

174. Swithenbank, J., et al., *Research investigations at the municipal and clinical waste incinerators in sheffield, uk.* Environmental Progress, 1997. **16**(1): p. 65-81.

175. Sebghati, J.M. and M.H. Eley, *Preliminary study of the pyrolysis of steam classified municipal solid waste.* Applied Biochemistry & Biotechnology, 1997. **5**: p. 35-44.

176. Miranda, M.L. and B. Hale, *Waste not, want not - the private and social costs of waste-to-energy production.* Energy Policy, 1997. **25**(6): p. 587-600.

177. McManis, K.L., M. Nataraj, and A.T. Knecht, *TIRE MONOFILL LINER/LEACHATE COMPATIBILITY*. 1997, LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY.

179. Joo, H.K. and C.W. Curtis, *Effect of reaction time on the coprocessing of low-density polyethylene with coal and petroleum resid.* Energy & Fuels, 1997. **11**(4): p. 801-812.

180. Hendrix, J., et al., *Technologies for the identification, separation, and recycling of automotive plastics.* Intl. J. of Environmentally Conscious Design and Manufacturing, 1997. **6**(2): p. 37-50.

181. Hellenbrand, R., et al., *KINETICS, CATALYSIS, AND REACTION ENGINEERING Integration of Wet Oxidation and Nanofiltration for Treatment of Recalcitrant Organics in Wastewater.* 1997. **35**: p. 5054-5062.

182. Fruteau de Laclos, H., S. Desbois, and C. Saint-Joly, *Anaerobic disgestion of municipal solid organic waste: Valorga full-scale plant in Tilburg, the Netherlands.* 1997. **36**: p. 457-462.

183. Daskalopoulos, E., O. Badr, and S.D. Probert, *Economic and environmental evaluations of waste treatment and disposal technologies for municipal solid waste.* Applied Energy, 1997. **58**(4): p. 209-255.

184. Astrand, L., *Waste not, want not - the private and social costs of waste-to-energy production - comment.* Energy Policy, 1997. **25**(6): p. 601-603.

185. *State of The Art (SOTA) Manual For Non-Hazardous Onsite Remediation Processes*. 1997.

186. *Municipal Solid Waste Management: A Bibliography of US DOE Contractor Reports through 1995*. 1997, NREL: Golden, CO.

187. *Proceedings of the Air & Waste Management Association's 89th & 90th Annual Meeting and Exhibition (CD ROM).* 1996/1997.

188. Tyson, K.S., M. Rymes, and E. Hammond, *Future potential for MSW energy development.* Biomass and Bioenergy, 1996. **10**(2-3): p. 111-124.

189. Sakaki, T., et al., *Reaction Model of Cellulose Decomposition in Near-Critical Water and Fermentation of Products.* Bioresource Technology, 1996. **58**: p. 197-202.

190. Sakaki, T., et al., *Decomposition of Cellulose in Near-Critical Water and Fermentability of the Products.* Energy & Fuels, 1996. **10**(3): p. 684-688.

191. Larson, E.D., E. Worrell, and J.S. Chen, *Clean fuels from municipal solid waste for fuel cell buses in metropolitan areas.* Resources, Conservation and Recycling, 1996. **17**(4): p. 273-298.

192. LaMotta, E.J., et al., *GOALS, PRINCIPLES AND OBJECTIVES OF THE ECUADORIAN ENVIRONMENTAL REGULATIONS*. 1996. p. 33.

193. Kilgroe, J.D., *Control of dioxin, furan, and mercury emissions from municipal waste combustors.* Journal of Hazardous Materials, 1996. **47**(1-3): p. 163-194.

195. Berenyi, E.B., *The status of municipal waste combustion in the United States.* Journal of Hazardous Materials, 1996. **47**(1-3): p. 1-17.

196. Abatzoglou, N., et al. *Perspectives on the Gasification of Urban and Industrial Wastes.* in *Proceedings of the 17th Canadian Waste Management Conference, 11-14 September 1995, Quebec, Canada. Toward a Sustainable Future: Waste Minimization - New Solutions for Challenging Times.* 1996: Canada: Environment Canada.

198. *Proceedings: 18th Canadian Waste Management Conference : the evolution of waste management to pollution prevention and resource recovery.* in *18th Canadian Waste Management Conference : the evolution of waste management to pollution prevention and resource recovery*. 1996. Winnipeg, Manitoba: : Environment Canada : Canadian Environment Industry Association.

199. *Proceedings of the 1996 International Conference on Incineration and Thermal Treatment Technologies.* in *International Incineration Conference (15th : 1996 : Savannah, Ga.)*. 1996. Savannah, Ga.: Air & Waste Management Association.

200. Takahashi, P., *The 1995 Progress Report of the Secretary of Energy's Hydrogen Technical Advisory Panel*. 1995. p. 26.

201. Calaminus, B. and R. Stahlberg, *Thermoselect - extraction of energy and raw materials .4. safety and processing features of the process with regard to environmental aspects and the quality of its final products from thermal waste treatment.* Chemische Technik, 1995. **47**(5): p. 233-241.

202. Benjamin Levie, D.M., Marc Tormey, *Ash Quantification and Characterization Study- Co-Firing and Dedicated Combustion of Waste Tires*. 1995, California Integrated Waste Management Board: Sacramento. p. 19 (+ appendix).

203.

207. Alexander, R.H., et al., *A Risk Analysis of the*
Louisiana Toxic Release Inventory Data as an Environmental Indicator. 1995. p. 3.

208. *Proceedings: 17th Canadian Waste Management Conference : towards a sustainable future: waste minimization, new solutions for challenging times.* in *17th Canadian Waste Management Conference : towards a sustainable future: waste minimization, new solutions for challenging times*. 1995. Quebec City: Environnment Canada : Canadian Environment

210. Lorson, H. and M. Schingnitz, *Conversion process for the thermic utilization of residual and waste materials.* Bwk, 1994. **46**(5): p. 214-217.

211. Lea, W.R., M. Tittlebaum, and R. Kowalewski, *Solid Waste Management Study*
Part II: Regional Analysis. 1994: p. 3.

212. Lea, W.R., M. Tittlebaum, and R. Kowalewski, *Solid Waste Management Study*
Part 1: Individual Parish Analysis. 1994. p. 3.

213. Lea, W.R. and R. Kwalewski, *Regional Solid Waste Management Study.* 1994, the Urban Waste Management and Research Center
Department of Civil and Environmental Engineering
the University of New Orleans

and the Institute for Recyclable MaterialsCollege of EngineeringLouisiana State University. p. 4.

214. Halonen, I., et al., *The effect of inorganic and organic chlorine on formation of highly chlorinated organic compounds during incineration - laboratory pilot study.* Chemosphere, 1994. **28**(12): p. 2129-2138.

215. Eley, M.H., *An improved prototype apparatus and process for separating cellulosic materials from municipal solid waste.* Applied Biochemistry & Biotechnology, 1994. **6**: p. 69-79.

217. Anom, *Waste utilization as an energy source: Municipal wastes. (Latest citations from the NTIS bibliographic database). Published Search*. 1994, NERAC, Inc., Tolland: Tolland, CT. p. 10.

218. *Proceedings : 16th Canadian Waste Management Conference*. in *16th Canadian Waste Management Conference*. 1994. Calgary, Alberta: Environnment Canada : Canadian Environment Industry Association.

219. *Waste combustion in boilers and industrial furnaces : proceedings of the A&WMA International Specialty Conference*. in *A&WMA International Specialty Conference*. 1994. Kansas City, MO: Air & Waste Management Association.

220. Tchobanoglous, G., H. Theisen, and S. Bigil, *Integrated Solid Waste Management-Engineering Principles and Management Issues*. 1993, New York: McGraw-Hill, Inc. 978.

222. *Proceedings : 15th Canadian Waste Management Conference "Innovative Waste Management Solution - an Outlook for the Future"*. in *15th Canadian Waste Management Conference "Innovative Waste Management Solution - an Outlook for the Future"*. 1993. Saint John, New Brunswick.: Environment Canada.

227. Knecht, A.L., K.L. McManis, and H. Hewitt, *REGIONAL SOLID WASTE MANAGEMENT STRATEGY For Michoud Assembly Facility New Orleans, Louisiana*. 1992. p. 8.

228. Knecht, A.L., K.L. McManis, and H. Hewitt, *REGIONALSOLID WASTE MANAGEMENT STRATEGY*. 1992.

229. Hannoura, A.A., *THE INFLUENCE OF NONLINEAR FLOW ON THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE BY THE "HELP" PROGRAM*. 1992, UNO URBAN WASTE MANAGEMENT & RESEARCH CENTER

232. Barrett, R., Krause, HH, Engdahl, RB, *Municipal waste to energy technology assessment.* 1992, EPRI
(Prepared by Battelle Memorial Inst.).

235. Anom, *RD D priorities for energy production and resource conservation from municipal solid waste*. 1992, National Renewable Energy Lab: Golden, CO. p. 268.

236. *Proceedings, 14th Canadian Waste Management Conference*. in *14th Canadian Waste Management Conference*. 1992. Regina: : Environment Canada.

237. *RD and D priorities for energy production and resource conservation from municipal solid waste.* 1992, NREL. p. 268.

238. *Energy from Municipal Waste Program. Program plan.* 1992.

239. McManis, K.L., *State of "Sanitary Emergency" in Guayaquil, Ecuador*. 1991.

240. Goodman, B.J.S.E.R.I., Golden, CO (USA)); Walter, D.K. (Biofuels and Municipal Waste Technology Div., US DOE, Washington, DC (US)), *Opportunities for energy from municipal waste technology.* Energy Sources, 1991. **13**(2): p. 179-188.

241. Brunner, C.R., *Handbook of Incineration Systems*. 1991, New York: McGraw-Hill.

242. *Proceedings, Wastetech'91, Canadian Waste Management Conference*. in *Canadian Waste Management Conference*. 1991. Toronto, Ontario: Environmental Protection, Environment Canada.

243. *Proceedings : 12th Canadian Waste Management Conference*. in *12th Canadian Waste Management Conference*. 1990. St. John's, Newfoundland: Environnment Canada.
244. *Proceedings : 11th Canadian Waste Management Conference*. in *11th Canadian Waste Management Conference*. 1989. Montreal: Ottawa, Ont. : Environment Canada, c1989.
246. Henriksson, M.W., Bjorn, *Kinetics of formation of hydrochloric acid(g) by the reaction between sodium chloride(s) and sulfur dioxide, oxygen, and water(g).* Ind. Eng. Chem. Process Des. Dev., 1979. **18**(2): p. 249-54.
247. Modell, M., R.C. Reid, and S.I. Amin, *Gasification process*. 1978, Massachusetts Institute of Technology: USA.
248. Azuma, H.T., Yusuke; Kondo, Takakazu, *Decrease of hydrogen chloride in an incinerator.* KOTTAM (Japanese), 1978. **14**(10): p. 1059-67.
249. Ybos, C. and M.M. Banbury, *Button up the wetlands.*
250. Smith-Gratto, K. and M.M. Banbury, *Food Chains and Filmstrips.*
253. Pascual, C. and P. Bajeat, *Storage of household waste Evaluation of the performance of wrapped bale technique.*
254. Morris, M. and L. Waldheim, *UPDATE ON PROJECT ARBRE, UK - A wood-fuelled combined-cycle demonstration plant.* p. 11.
255. McManis, K.L. and M. Nataraj, *CHARACTERIZATION OF FILTER CAKE ASH AND APPLICATIONS FOR SOIL STABILIZATION.* p. 13.
256. McManis, K.L., E. LaMotta, and R. Lea, *A New Paradigm For International Projects And Education.*
257. Lyons, S.E. and M.M. Banbury, *Urban Stormwater Runoff: How to Stem the Toxic Tide.*
258. Larson, E.D., et al., *Exploring Implications to 2050 of Engergy Technology options for China.*
261. LaMotta, E. and W.R. Lea, *International Cooperative Agreements for Environmental Education Projects - A Case Study*.
262. LaMotta, E., R. Lea, and K.L. McManis, *Case Study of an International Environmental Education Project*. p. 10.
263. LaMotta, E., et al., *Academic and Practical Training in Environmental Engineering Through International Projects.* p. 6.
266. Jones, G.M. and A.A. Hannoura, *GIS-Based Storm Water Management In The Urban Environment, Modelling Storm Water in the Urban Environment and Assessment Via GIS Technology.*
267. Horton, R., K. Kindig, and M. Gregory, *Hydromax: Brdge to the Hydrogen Economy.*
268. Glass, R., *The Mobile Tire Shredding System.*
269. Freeman, H., et al., *Industrial Pollution Prevention:A Critical Review.*
270. Frantzis, L. and R. Katofsky, *A Renewable Energy Vision*, Navigant Consulting, Inc.
271. Eden, R.
272. Cotheren, G.M., J. Fardue, and S. Chen, *LONGITUDINAL DISPERSION AND INTERSTITIAL VELOCITY RELATIONSHIP IN SUBSURFACE FLOW CONSTRUCTED WETLANDS.* p. 12.
273. Cedzynska, K., et al., *Plasma Vitrification of Waste Incinerator Ashes*, State Committe of Scientific Research.
274. Carter, G.W., *Plasma Gasification Feasibility Study of Biomedical Waste.*
275. Buhl, R., *DEVELOPMENTS IN PVC FEEDSTOCK RECYCLING.* p. 4.

General Biomass References

1. Mozaffarian, M. and R.W.R. Zwart, *Feasibility of biomass/waste-related SNG production technologies*. 2003, Energy Research Center of the Netherlands (ECN). p. 117.
2. Zhang, C., W. Han, and X. Jing, *Life cycle economic analysis of fuel ethanol derived from cassava in Southwest China.* 2003.
3. Thunman, H. and B. Leckner, *Co-current and counter-current fixed bed combustion of biofuel--a comparison**. Fuel, 2003. **82**(3): p. 275-283.
4. Simoneit, B.R.T., et al., *Alkyl Amides and Nitriles as Novel Tracers for Biomass Burning.* Environ. Sci. Technol., 2003. **37**(1): p. 16-21.
5. Sathe, C., et al., *Release of alkali and alkaline earth metallic species during rapid pyrolysis of a Victorian brown coal at elevated pressures**. Fuel, 2003. **82**(12): p. 1491-1497.
6. Risnes, H., et al., *Calcium addition in straw gasification**. Fuel, 2003. **82**(6): p. 641-651.
7. Rezzoug, S.A. and R. Capart, *Assessment of wood liquefaction in acidified ethylene glycol using experimental design methodology.* Energy Conversion and Management, 2003. **44**(5): p. 783-794.
8. Meraz, L., et al., *A thermochemical concept-based equation to estimate waste combustion enthalpy from elemental composition**. Fuel, 2003. **82**(12): p. 1499-1507.
9. Koppolu, L. and L.D. Clements, *Pyrolysis as a technique for separating heavy metals from hyperaccumulators. Part I: Preparation of synthetic hyperaccumulator biomass.* Biomass and Bioenergy, 2003. **24**(1): p. 69-79.
10. Iwasaki, W., *A consideration of the economic efficiency of hydrogen production from biomass.* International Journal of Hydrogen Energy, 2003. **28**(9): p. 939-944.
11. Grotkjaer, T., et al., *An experimental study of biomass ignition**. Fuel, 2003. **82**(7): p. 825-833.
12. Gross, R., M. Leach, and A. Bauen, *Progress in renewable energy.* Environment International, 2003. **29**(1): p. 105-122.
13. Friedli, H.R., et al., *Mercury emissions from burning of biomass from temperate North American forests: laboratory and airborne measurements.* Atmospheric Environment, 2003. **37**(2): p. 253-267.
14. Franco, C., et al., *The study of reactions influencing the biomass steam gasification process**. Fuel, 2003. **82**(7): p. 835-842.
15. Chen, G., J. Andries, and H. Spliethoff, *Biomass conversion into fuel gas using circulating fluidised bed technology: the concept improvement and modelling discussion.* Renewable Energy, 2003. **28**(6): p. 985-994.
16. Brooksbank, W.J., *HydroMax: Bridge to a Hydrogen Economy*. 2003, Alchemix Corp.
17. Bridgwater, A.V., *Renewable fuels and chemicals by thermal processing of biomass.* Chemical Engineering Journal, 2003. **91**(2-3): p. 87-102.
18. Bourgeois, T.G., B. Hedman, and F. Zalcman, *Creating markets for combined heat and power and clean distributed generation in New York State.* Environmental Pollution, 2003. **123**(3): p. 451-462.
19. Borgne, S.L. and R. Quintero, *Biotechnological processes for the refining of petroleum.* Fuel Processing Technology, 2003. **81**(2): p. 155-169.
20. Bellais, M., et al., *Pyrolysis of large wood particles: a study of shrinkage importance in simulations**. Fuel, 2003. **82**(12): p. 1541-1548.
21. Barroso, J., et al., *On the optimization of boiler efficiency using bagasse as fuel**. Fuel, 2003. **82**(12): p. 1451-1463.

22. Barber, T.R., et al., *Aquatic ecological risks due to cyanide releases from biomass burning.* Chemosphere, 2003. **50**(3): p. 343-348.
23. Xiaolin Wei, C.L., Thore von Puttkamer, Uwe Schnell, Sven Unterberger, and Klaus R. G. Hein, *Assessment of Chlorine-Alkali-Mineral Interactions during Co-Combustion of Coal and Straw.* Energy & Fuels, 2002. **16**(5): p. 1095-1108.
24. Suarez-Garcia, F., et al., *Inorganic matter characterization in vegetable biomass feedstocks.* Fuel, 2002. **81**(9): p. 1161-1169.
25. Spalding-Fecher, R., et al., *The economics of energy efficiency for the poor--a South African case study.* Energy, 2002. **27**(12): p. 1099-1117.
26. Sipila, K. and M. Rossi, *Power production from waste and biomass IV-Advanced concepts and technologies*. 2002, VTT, EC DG TREN, IEA Bioenergy, Novem,Tekes,KTM. p. 354.
27. Scoditti, E. and N. Barker, *Task 33: Thermal Gasification of Biomass (2001-2003)-Subtask: Review of Energy Conversion Devices.* 2002: p. 41.
28. Ratafia-Brown, J., et al., *Major Environmental Aspects of Gasification-Based Power Generation Technologies - Final Report, DOE/NETL*. 2002, SAIC. p. 270.
29. Olofsson, G., Wuyin Wang, Zhicheng Ye, Ingemar Bjerle, and Arne Andersson, *Repressing NOx and N2O Emissions in a Fluidized Bed Biomass Combustor.* Energy & Fuels, 2002. **16**(4): p. 915-919.
30. Mukherji, S., A.K. Swain, and C. Venkataraman, *Comparative mutagenicity assessment of aerosols in emissions from biofuel combustion.* Atmospheric Environment, 2002. **36**(36-37): p. 5627-5635.
31. McLaughlin, S.B., et al., *High-value renewable energy from prairie grasses.* Environmental Science & Technology, 2002. **36**(10): p. 2122-2129.
32. McIlveen-Wright, D. and D.J. Guiney, *Wood-fired fuel cells in an isolated community.* Journal of Power Sources, 2002. **106**(1-2 Special Issue SI): p. 93-101.
33. Lynd, L.R., et al., *Microbial cellulose utilization: Fundamentals and biotechnology.* Microbiology & Molecular Biology Reviews, 2002. **66**(3): p. 506-+.
34. Kelly, G.J., F. King, and M. Kett, *Waste elimination in condensation reactions of industrial importance.* Green Chemistry, 2002. **4**(4): p. 392-399.
35. Jarvinen, M.P., R. Zevenhoven, and E.K. Vakkilainen, *Auto-gasification of a biofuel.* Combustion and Flame, 2002. **131**(4): p. 357-370.
36. Haas, M.J., G.J. Piazza, and T.A. Foglia, *Enzymatic approaches to the production of biodiesel fuels.* Lipid Biotechnology. Pg., 2002: p. 587-598.
37. Gottwald, U., et al., *In-situ study of the effect of operating conditions and additives on alkali emissions in fluidised bed combustion.* Fuel Processing Technology, 2002. **75**(3): p. 215-226.
38. Garcia, L., A. Benedicto, E. Romeo, M. L. Salvador, J. Arauzo, and R. Bilbao, *Hydrogen Production by Steam Gasification of Biomass Using Ni-Al Coprecipitated Catalysts Promoted with Magnesium.* Energy & Fuels, 2002. **16**(5): p. 1222-1230.
39. Davidsson, K.O., et al., *The effects of fuel washing techniques on alkali release from biomass.* Fuel, 2002. **81**(2): p. 137-142.
40. Davidsson, K.O., B.J. Stojkova, and J.B.C. Pettersson, *Alkali Emission from Birchwood Particles during Rapid Pyrolysis.* Energy & Fuels, 2002. **16**(5): p. 1033-1039.
41. Corella, J., J.M. Toledo, and M.P. Aznar, *Improving the modeling of the kinetics of the catalytic tar elimination in biomass gasification.* Industrial & Engineering Chemistry Research, 2002. **41**(14): p. 3351-3356.
42. McIlveen-Wright, D.R., J.T. McMullan, and D.J. Guiney, *Wood-fired fuel cells in selected buildings.* Journal of Power Sources, 2003. **In Press, Corrected Proof**.

43. Kalligeros, S., et al., *An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine.* Biomass and Bioenergy, 2003. **In Press, Corrected Proof**.
44. Ciferno, J.P. and J.J. Marano, *Benchmarking Biomass Gasification Technologies for Fuels, Chemicals and Hydrogen Production*. 2002, DOE- NETL. p. 65.
45. Chow, J.C., et al., *Chapter one: exposure measurements.* Chemosphere, 2002. **49**(9): p. 873-901.
46. Channiwala, S.A. and P.P. Parikh, *A unified correlation for estimating HHV of solid, liquid and gaseous fuels.* Fuel, 2002. **81**(8): p. 1051-1063.
47. Brown, R.C., G. Norton, and A. Suby, *Biomass-Derived Hydrogen from a Thermally Ballasted Gasifier*. 2002. p. 20.
48. Bridgwater, A.V., A.J. Toft, and J.G. Brammer, *A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion.* Renewable & Sustainable Energy Reviews, 2002. **6**(3): p. 181-248.
49. Asikainen, A.H., et al., *Occurrence and destruction of PAHs, PCBs, ClPhs, ClBzs, and PCDD/Fs in ash from gasification of straw.* Environmental Science & Technology, 2002. **36**(10): p. 2193-2197.
50. Asadullah, M., et al., *Novel biomass gasification method with high efficiency: catalytic gasification at low temperature.* Green Chemistry, 2002. **4**(4): p. 385-389.
51. Arbon, I.M., *Worldwide use of biomass in power generation and combined beat and power schemes.* Proceedings of the Institution of Mechanical Engineers Part A-Journal of Power & Energy, 2002. **216**(A1): p. 41-57.
52. Zolin, A., et al., *The influence of inorganic materials on the thermal deactivation of fuel chars.* Energy & Fuels, 2001. **15**(5): p. 1110-1122.
53. Stevens, D., *Hot gas conditioning: Recent progress with larger-scale biomass gasification systems*. 2001, NREL.
54. Stenseng, M., A. Jensen, and K. Dam-Johansen, *Investigation of biomass pyrolysis by thermogravimetric analysis and differential scanning calorimetry.* Journal of Analytical & Applied Pyrolysis, 2001. **58**: p. 765-780.
55. Staniforth, J. and M. Ormerod, *Running fuel cells on biogas - a renewable fuel.* Green Chemistry, 2001. **3**(5): p. G61-G63.
56. Sorensen, C.O., J.E. Johnsson, and A. Jensen, *Reduction of NO over wheat straw char.* Energy & Fuels, 2001. **15**(6): p. 1359-1368.
57. Sensoz, S., et al., *Fixed bed pyrolysis of the rapeseed cake.* Energy Sources, 2001. **23**(10): p. 873-876.
58. Salzmann, R. and T. Nussbaumer, *Fuel staging for NOx reduction in biomass combustion: Experiments and modeling.* Energy & Fuels, 2001. **15**(3): p. 575-582.
59. Reed, G.P., et al., *Control of gasifier mercury emissions in a hot gas filter: the effect of temperature.* Fuel, 2001. **80**(5): p. 623-634.
60. Reed, G.P., D.R. Dugwell, and R. Kandiyoti, *Control of trace elements in gasification: Distribution to the output streams of a pilot scale gasifier.* Energy & Fuels, 2001. **15**(4): p. 794-800.
61. Reed, G.P., D.R. Dugwell, and R. Kandiyoti, *Control of trace elements in a gasifier hot gas filter: A comparison with predictions from a thermodynamic equilibrium model.* Energy & Fuels, 2001. **15**(6): p. 1480-1487.
62. Pian, C.C.P. and K. Yoshikawa, *Development of a high-temperature air-blown gasification system.* Bioresource Technology, 2001. **79**(3): p. 231-241.

63. Paulrud, S., C. Nilsson, and M. Ohman, *Reed canary-grass ash composition and its melting behaviour during combustion.* Fuel, 2001. **80**(10): p. 1391-1398.
64. Newman, R., *Ely Straw Project: Development Issues of a Generic Nature*. 2001, ETSU DTI. p. 72.
65. McGowin, C., et al., *Renewable Energy Technical Assessment Guide -TAG-RE 2001*. 2001, EPRI: Palo Alto, CA.
66. Marquevich, M., et al., *Hydrogen production from biomass: steam-reforming of vegetable oils and pyrolisis oils.* Afinidad, 2001. **58**(493): p. 181-189.
67. Marquevich, M., et al., *Hydrogen production by steam reforming of vegetable oils using nickel-based catalysts.* Industrial & Engineering Chemistry Research, 2001. **40**(22): p. 4757-4766.
68. Lede, J., E. Elorza-Ricart, and M. Ferrer, *Solar thermal splitting of zinc oxide: A review of some of the rate controlling factors.* Journal of Solar Energy Engineering-Transactions of the ASME, 2001. **123**(2): p. 91-97.
69. Lathouwers, D. and J. Bellan, *Yield optimization and scaling of fluidized beds for tar production from biomass.* Energy & Fuels, 2001. **15**(5): p. 1247-1262.
70. Lathouwers, D. and J. Bellan, *Modeling of dense gas-solid reactive mixtures applied to biomass pyrolysis in a fluidized bed.* International Journal of Multiphase Flow, 2001. **27**(12): p. 2155-2187.
71. Kwant, K.W., *Status of Gasification in countries participating in the IEA Bioenergy gasification activity Mar 2001*. 2001. p. 74.
72. Karaosmanoglu, F. and E. Culcuoglu, *Pyrolysis of rapeseed cake.* Energy Sources, 2001. **23**(4): p. 377-382.
73. Karaosmanoglu, F., B.D. Cift, and A. Isigigur-Ergudenler, *Determination of reaction kinetics of straw and stalk of rapeseed using thermogravimetric analysis.* Energy Sources, 2001. **23**(8): p. 767-774.
74. Jensen, P.A., B. Sander, and K. Dam-Johansen, *Removal of K and Cl by leaching of straw char.* Biomass & Bioenergy, 2001. **20**(6): p. 447-457.
75. Jensen, P.A., B. Sander, and K. Dam-Johansen, *Pretreatment of straw for power production by pyrolysis and char wash.* Biomass & Bioenergy, 2001. **20**(6): p. 431-446.
76. Hooper, R., A.K.N. Potter, and M.M. Singh, *Diversion from landfill: mechanical recycling of plastics from materials recovery facilities and from shredder residue.* Green Chemistry, 2001. **3**(2): p. 57-60.
77. Hardy, J., *A greener future with biodiesel.* Green Chemistry, 2001. **3**(4): p. G56-G58.
78. Haas, M.J., et al., *Engine performance of biodiesel fuel prepared from soybean soapstock: A high quality renewable fuel produced from a waste feedstock.* Energy & Fuels, 2001. **15**(5): p. 1207-1212.
79. Gabra, M., et al., *Alkali retention/separation during bagasse gasification: a comparison between a fluidised bed and a cyclone gasifier.* Biomass & Bioenergy, 2001. **21**(6): p. 461-476.
80. Coda, B., et al., *Behavior off chlorine and enrichment of risky elements in bubbling fluidized bed combustion of biomass and waste assisted by additives.* Energy & Fuels, 2001. **15**(3): p. 680-690.
81. Clark, J., *Renewable energy and resources.* Green Chemistry, 2001. **3**(4): p. G46.
82. Brown, A.L., et al., *Design and characterization of an entrained flow reactor for the study of biomass pyrolysis chemistry at high heating rates.* Energy & Fuels, 2001. **15**(5 September/October): p. 1276-1285.
83. Brown, A.L., D.C. Dayton, and J.W. Daily, *A study of cellulose pyrolysis chemistry and global kinetics at high heating rates.* Energy & Fuels, 2001. **15**(5 September/October): p. 1286-1294.

84. Brink, A., P. Kilpinen, and M. Hupa, *A simplified kinetic rate expression for describing the oxidation of volatile fuel-N in biomass combustion.* Energy & Fuels, 2001. **15**(5): p. 1094-1099.
85. Blander, M., et al., *Equilibrium chemistry of biomass combustion: A round-robin set of calculations using available computer programs and databases.* Energy & Fuels, 2001. **15**(2): p. 344-349.
86. Bhandarkar, P.G., *Solid fuels gasification - an overview.* Chem. Ind. Dig., 2001. **14**(3): p. 62-71.
87. Abedi, J., Y.D. Yeboah, and M. Realff, *An Integrated Approach To Hydrogen Production From Agricultural Residues For Use In Urban Transportation*. 2001. p. 27.
88. *Plasma Gasification Waste Treatment Technology*. 2001, Resorption Canada Limited. p. 12.
89. Zhuo, Y., et al., *An attempt to correlate conversions in pyrolysis and gasification with FT-IR spectra of coals.* Energy & Fuels, 2000. **14**(5): p. 1049-1058.
90. Zamansky, V.M., et al., *Biomass Reburning- Modeling/Engineering Studies*. 2000, GEEER: Irvine.
91. Zamansky, V.M., et al., *Advanced Biomass Reburning for High Efficiency NOx Control*. 2000, GEEER: Irvine, CA.
92. Ozaktas, T., et al., *Ignition delay and soot emission characteristics of methanol-diesel fuel blends.* Petroleum Science & Technology, 2000. **18**(1-2): p. 15-32.
93. Ohman, M., et al., *Bed agglomeration characteristics during fluidized bed combustion of biomass fuels.* Energy & Fuels, 2000. **14**(1): p. 169-178.
94. Ohman, M. and A. Nordin, *The role of kaolin in prevention of bed agglomeration during fluidized bed combustion of biomass fuels (vol 14, pg 618, 2000).* Energy & Fuels, 2000. **14**(3): p. 737.
95. Ohman, M. and A. Nordin, *The role of kaolin in prevention of bed agglomeration during fluidized bed combustion of biomass fuels.* Energy & Fuels, 2000. **14**(3): p. 618-624.
96. Nowak, M.e.a. *Strategies for advanced research and commercialization in synthesis gas conversion*. in *Annual Int. Pittsburgh Coal Conference*. 2000.
97. Norstrom, T., et al., *Comparisons of the validity of different simplified NH3-oxidation mechanisms for combustion of biomass.* Energy & Fuels, 2000. **14**(5): p. 947-952.
98. Nielsen, H.P., et al., *Deposition of potassium salts on heat transfer surfaces in straw-fired boilers: a pilot-scale study.* Fuel, 2000. **79**(2): p. 131-139.
99. Nielsen, H.P., et al., *The implications of chlorine-associated corrosion on the operation of biomass-fired boilers.* Progress in Energy & Combustion Science, 2000. **26**(3): p. 283-298.
100. MClellan, R., *DESIGN OF A 2.5MW(e) BIOMASS GASIFICATION POWER GENERATION MODULE*. 2000, ETSU: Oldbury, UK. p. 43.
101. Marquevich, M., R. Coll, and D. Montane, *Steam reforming of sunflower oil for hydrogen production. (vol 39, pg 2144, 2000).* Industrial & Engineering Chemistry Research, 2000. **39**(7): p. 2632.
102. Marquevich, M., R. Coll, and D. Montane, *Steam reforming of sunflower oil for hydrogen production.* Industrial & Engineering Chemistry Research, 2000. **39**(7): p. 2140-2147.
103. Lynd, L. and R. Dorsch, *Life cycle analysis and sustainability - Open forum.* Applied Biochemistry & Biotechnology, 2000. **6**(877): p. 877.
104. Lede, J., *The cyclone: A multifunctional reactor for the fast pyrolysis of biomass.* Industrial & Engineering Chemistry Research, 2000. **39**(4): p. 893-903.
105. Lathouwers, D. and J. Bellan. *Modeling and simulation of bubbling fluidized beds containing particle mixtures*. in *Proceedings of the Combustion Institute*. 2000.

106. Larson, E.D., S. Consonni, and T.G. Kreutz, *Preliminary economics of black liquor gasifier/gas turbine cogeneration at pulp and paper mills.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 2000. **122**(2): p. 255-261.
107. Kwant, K.W., *Status of Gasification in countries participating in theIEA Bioenergy gasification activity March 2001*. 2000, IEA Bioenergy Gasification Coutnry. p. 74.
108. Karaosmanoglu, F., G. Kurt, and T. Ozaktas, *Long term CI engine test of sunflower oil.* Renewable Energy, 2000. **19**(1-2): p. 219-221.
109. Karaosmanoglu, F., A. Isigigur-Ergundenler, and A. Sever, *Biochar from the straw-stalk of rapeseed plant.* Energy & Fuels, 2000. **14**(2): p. 336-339.
110. Karaosmanoglu, F., G. Kurt, and T. Ozaktas, *Direct use of sunflower oil as a compression-ignition engine fuel.* Energy Sources, 2000. **22**(7): p. 659-672.
111. Jensen, P.A., et al., *Experimental investigation of the transformation. and release to gas phase of potassium and chlorine during straw pyrolysis.* Energy & Fuels, 2000. **14**(6): p. 1280-1285.
112. Hansen, L.A., et al., *Influence of deposit formation on corrosion at a straw-fired boiler.* Fuel Processing Technology, 2000. **64**(1-3): p. 189-209.
113. Hagstrom, M., K. Engvall, and J.B.C. Pettersson, *Desorption kinetics at atmospheric pressure: Alkali metal ion emission from hot platinum surfaces.* Journal of Physical Chemistry B, 2000. **104**(18): p. 4457-4462.
114. Fernandez, M.J., A. Lyngfelt, and F. Johnsson, *Gas concentrations in the lower part of the combustion chamber of a circulating fluidized bed boiler: Influence of bed height.* Energy & Fuels, 2000. **14**(6): p. 1127-1132.
115. Demirbas, A., *Mechanisms of liquefaction and pyrolysis reactions of biomass.* Energy Conversion and Management, 2000. **41**(6): p. 633-646.
116. Demirbas, A., *Conversion of biomass using glycerin to liquid fuel for blending gasoline as alternative engine fuel.* Energy Conversion and Management, 2000. **41**(16): p. 1741-1748.
117. Caballero, M.A., et al., *Biomass gasification with air in fluidized bed. Hot gas cleanup with selected commercial and full-size nickel-based catalysts.* Industrial & Engineering Chemistry Research, 2000. **39**(5): p. 1143-1154.
118. Bridgwater, A.V. and G.V.C. Peacocke, *Fast pyrolysis processes for biomass.* Renewable & Sustainable Energy Reviews, 2000. **4**(1): p. 1-73.
119. Andersen, K.H., et al., *Deposit formation in a 150 MWe utility PF-boiler during co-combustion of coal and straw.* Energy & Fuels, 2000. **14**(4): p. 765-780.
120. Wen, H., et al., *Advances in Biomass Gasification Power Plants.* 1999.
121. Skrifvars, B.J., et al., *Predicting bed agglomeration tendencies for biomass fuels fired in FBC boilers: A comparison of three different prediction methods.* Energy & Fuels, 1999. **13**(2): p. 359-363.
122. Nielsen, H.P., F.J. Frandsen, and K. Dam-Johansen, *Lab-scale investigations of high-temperature corrosion phenomena in straw-fired boilers.* Energy & Fuels, 1999. **13**(6): p. 1114-1121.
123. Marquevich, M., et al., *Hydrogen from biomass: Steam reforming of model compounds of fast-pyrolysis oil.* Energy & Fuels, 1999. **13**(6): p. 1160-1166.
124. Mann, M.K., P.L. Spath, and W.A. Amos, *Studies on the Production and Delivery of Hydrogen From Renewable Resources*. 1999. p. 19.
125. Lede, J. and M. Ferrer, *Solar thermochemical reactors.* Journal de Physique IV, 1999. **9**(P3): p. 253-258.
126. Lede, J., *SOLAR THERMOCHEMICAL CONVERSION OF BIOMASS.* Solar Energy, 1999. **65**(1): p. 3-13.

127. Larson, E.D., T.G. Kreutz, and S. Consonni, *Combined biomass and black liquor gasifier/gas turbine cogeneration at pulp and paper mills.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1999. **121**(3): p. 394-400.
128. Korsgren, J.G. and J.B.C. Pettersson, *Collision dynamics and decomposition of NaCl nanometer particles on hot platinum surfaces.* Journal of Physical Chemistry B, 1999. **103**(47): p. 10425-10432.
129. Karaosmanoglu, F. and E. Tetik, *Fuel properties of pyrolytic oil of the straw and stalk of rape plant.* Renewable Energy, 1999. **16**(1-4): p. 1090-1093.
130. Karaosmanoglu, F., *Vegetable oil fuels: A review.* Energy Sources, 1999. **21**(3): p. 221-231.
131. Karaosmanoglu, F., E. Tetik, and E. Gollu, *Biofuel production using slow pyrolysis of the straw and stalk of the rapeseed plant.* Fuel Processing Technology, 1999. **59**(1): p. 1-12.
132. Karaosmanoglu, F. and E. Tetik, *Charcoal from the pyrolysis of rapeseed plant straw-stalk.* Energy Sources, 1999. **21**(6): p. 503-510.
133. Karaosmanoglu, F., et al., *Fuel properties of cottonseed oil.* Energy Sources, 1999. **21**(9): p. 821-828.
134. Karaosmanoglu, F., et al., *Characterization of the straw stalk of the rapeseed plant as a biomass energy source.* Energy Sources, 1999. **21**(9): p. 801-810.
135. Hansen, L.A., et al., *Characterization of ashes and deposits from high-temperature coal-straw co-firing.* Energy & Fuels, 1999. **13**(4): p. 803-816.
136. Gil, J., et al., *Biomass gasification with air in a fluidized bed: Effect of the in-bed use of dolomite under different operation conditions.* Industrial & Engineering Chemistry Research, 1999. **38**(11): p. 4226-4235.
137. Gil, J., et al., *Biomass gasification in atmospheric and bubbling fluidized bed: Effect of the type of gasifying agent on the product distribution.* Biomass & Bioenergy, 1999. **17**(5): p. 389-403.
138. Corella, J., A. Orio, and J.M. Toledo, *Biomass gasification with air in a fluidized bed: Exhaustive tar elimination with commercial steam reforming catalysts.* Energy & Fuels, 1999. **13**(3): p. 702-709.
139. Corella, J., et al., *Biomass gasification in fluidized bed: Where to locate the dolomite to improve gasification?* Energy & Fuels, 1999. **13**(6): p. 1122-1127.
140. Bridgwater, A.V., D. Meier, and D. Radlein, *An overview of fast pyrolysis of biomass.* Organic Geochemistry, 1999. **30**(12): p. 1479-1493.
141. Brammer, J.G. and A.V. Bridgwater, *Drying technologies for an integrated gasification bio-energy plant.* Renewable & Sustainable Energy Reviews, 1999. **3**(4): p. 243-289.
142. *Energy From Biomass; Summaries of Biomass Projects for DTI (UK); Vol. 5: Straw, Poultry Litter, and Energy Crops as Energy Sources*. 1999. p. 144.
143. Wiltsee, G., *Urban Wood Waste Resource Assessment*. 1998, NREL. p. 224.
144. Olsson, J.G., et al., *Alkali metal emission from filter ash and fluidized bed material from pfb gasification of biomass.* Energy & Fuels, 1998. **12**(3): p. 626-630.
145. Ohman, M. and A. Nordin, *A new method for quantification of fluidized bed agglomeration tendencies - a sensitivity analysis.* Energy & Fuels, 1998. **12**(1): p. 90-94.
146. Natarajan, E., et al., *Experimental determination of bed agglomeration tendencies of some common agricultural residues in fluidized bed combustion and gasification.* Biomass & Bioenergy, 1998. **15**(2): p. 163-169.
147. Mann, M.K., P.L. Spath, and W.A. Amos, *Technoeconomic Analysis of Different Options for the production of Hydrogen from sunlight, wind, and biomass*. 1998. p. 24.
148. Lede, J., *SOLAR THERMOCHEMICAL CONVERSION OF BIOMASS.* Solar Energy, 1998. **65**(1): p. 3-13.

149. Hughes, W.E.M. and E.D. Larson, *Effect of fuel moisture content on biomass-igcc performance.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1998. **120**(3): p. 455-459.
150. Hansen, P.F.B., et al., *Co-firing straw and coal in a 150-mwe utility boiler - in situ measurements.* Fuel Processing Technology, 1998. **54**(1-3): p. 207-225.
151. Corella, J., A. Orio, and P. Aznar, *Biomass gasification with air in fluidized bed: Reforming of the gas composition with commercial steam reforming catalysts.* Industrial & Engineering Chemistry Research, 1998. **37**(12): p. 4617-4624.
152. Consonni, S., et al., *Black liquor gasifier gas turbine cogeneration.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1998. **120**(3): p. 442-449.
153. Aznar, M.P., et al., *Commercial steam reforming catalysts to improve biomass gasification with steam-oxygen mixtures - 2 - catalytic tar removal.* Industrial & Engineering Chemistry Research, 1998. **37**(7): p. 2668-2680.
154. Perez, P., et al., *Hot gas cleaning and upgrading with a calcined dolomite located downstream a biomass fluidized bed gasifier operating with steam-oxygen mixtures.* Energy & Fuels, 1997. **11**(6): p. 1194-1203.
155. Ozaktas, T., K.B. Cigizoglu, and F. Karaosmanoglu, *Alternative diesel fuel study on four different types of vegetable oils of turkish origin.* Energy Sources, 1997. **19**(2): p. 173-181.
156. Orio, A., J. Corella, and I. Narvaez, *Performance of different dolomites on hot raw gas cleaning from biomass gasification with air.* Industrial & Engineering Chemistry Research, 1997. **36**(9): p. 3800-3808.
157. Olivares, A., et al., *Biomass gasification - produced gas upgrading by in-bed use of dolomite.* Industrial & Engineering Chemistry Research, 1997. **36**(12): p. 5220-5226.
158. Narvaez, I., J. Corella, and A. Orio, *Fresh tar (from a biomass gasifier) elimination over a commercial steam-reformimg catalyst - kinetics and effect of different variables of operation.* Industrial & Engineering Chemistry Research, 1997. **36**(2): p. 317-327.
159. Larson, E.D. and C.I. Marrison, *Economic scales for first-generation biomass-gasifier gas turbine combined cycles fueled from energy plantations.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1997. **119**(2): p. 285-290.
160. Kucuk, M.M. and A. Demirbas, *Biomass conversion processes.* Energy Conversion and Management, 1997. **38**(2): p. 151-165.
161. Jensen, P.A., M. Stenholm, and P. Hald, *Deposition investigation in straw-fired boilers.* Energy & Fuels, 1997. **11**(5): p. 1048-1055.
162. Ergeneman, M., et al., *Effect of some turkish vegetable oil diesel fuel blends on exhaust emissions.* Energy Sources, 1997. **19**(8): p. 879-885.
163. Cigizoglu, K.B., T. Ozaktas, and F. Karaosmanoglu, *Used sunflower oil as an alternative fuel for diesel engines.* Energy Sources, 1997. **19**(6): p. 559-566.
164. Bangala, D.N., et al., *Catalytic gas conditioning - application to biomass and waste gasification.* Industrial & Engineering Chemistry Research, 1997. **36**(10): p. 4184-4192.
165. *Energy From Biomass Summaries of the Biomass Projects carried out as part of the Department of Trade and Industry's New and Renewable Energy Programme Volume 4: Anaerobic Digestion For Biogas*. 1997. p. 94.
166. Pian, C.C.P., R. Kessler, and E.W. Schmitt, *Magnetohydrodynamic generator design for a combined-cycle demonstration powerplant.* Journal of Propulsion & Power, 1996. **12**(2): p. 390-397.
167. Pedersen, L.S., et al., *Full-scale co-firing of straw and coal.* Fuel, 1996. **75**(13): p. 1584-1590.

168. Narvaez, I., et al., *Biomass gasification with air in an atmospheric bubbling fluidized bed - effect of six operational variables on the quality of the produced raw gas.* Industrial & Engineering Chemistry Research, 1996. **35**(7): p. 2110-2120.
169. Lynd, L.R., *Overview and evaluation of fuel ethanol from cellulosic biomass - technology, economics, the environment, and policy.* Annual Review of Energy & the Environment, 1996. **21**: p. 403-465.
170. Karaosmanoglu, F., et al., *Investigation of the refining step of biodiesel production.* Energy & Fuels, 1996. **10**(4): p. 890-895.
171. Karaosmanoglu, F., A. Akdag, and K.B. Cigizoglu, *Biodiesel from rapeseed oil of turkish origin as an alternative fuel.* Applied Biochemistry & Biotechnology, 1996. **61**(3): p. 251-265.
172. Jaglid, U., J.G. Olsson, and J.B.C. Pettersson, *Detection of sodium and potassium salt particles using surface ionization at atmospheric pressure.* Journal of Aerosol Science, 1996. **27**(6): p. 967-977.
173. Consonni, S. and E.D. Larson, *Biomass-gasifier/aeroderivative gas turbine combined cycles .b. performance calculations and economic assessment.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1996. **118**(3): p. 516-525.
174. Consonni, S. and E.D. Larson, *Biomass-gasifier/aeroderivative gas turbine combined cycles .a. technologies and performance modeling.* Journal of Engineering for Gas Turbines & Power-Transactions of the ASME, 1996. **118**(3): p. 507-515.
175. Bridgwater, A.V., *Production of high grade fuels and chemicals from catalytic pyrolysis of biomass.* Catalysis Today, 1996. **29**(1-4): p. 285-295.
176. Nordin, A., L. Eriksson, and M. Ohman, *No reduction in a fluidized bed combustor with primary measures and selective non-catalytic reduction - a screening study using statistical experimental designs.* Fuel, 1995. **74**(1): p. 128-135.
177. Bridgwater, A.V., *The technical and economic feasibility of biomass gasification for power generation.* Fuel, 1995. **74**(5): p. 631-653.
178. Isigigur, A., F. Karaosmanoglu, and H.A. Aksoy, *Methyl ester from safflower seed oil of turkish origin as a biofuel for diesel engines.* Applied Biochemistry & Biotechnology, 1994. **6**: p. 103-112.
179. Bridgwater, A.V., *Catalysis in thermal biomass conversion.* Applied Catalysis A-General, 1994. **116**(1-2): p. 5-47.
180. Larson, E.D., *Technology for electricity and fuels from biomass.* Annual Review of Energy & the Environment, 1993. **18**: p. 567-630.
181. Aho, M.H., J.; Tummavuori, J., *Importance of solid fuel properties to nitrogen oxide formation through HCN and NH3 in small particle combustion.* Combust. Flame, 1993. **95**: p. 22-30.
182. Bridgwater, A.V., *The Thermochemical Processing System*, in *Thermochemical Processing of Biomass*, A.V. Bridgwater, Editor. 1984, Butterworths: London. p. 35-52.
183. Chynoweth, *Hybrid bio-thermal liquefaction*. 1982.
184. Norbeck, J.M. and K. Johnson, *Evaluation of a Process to Convert Biomass to Methanol Fuel*, U.S. Environmental Protection Agency Office of Research and Development Washington, DC 20460. p. 62.
185. Milne, T.A., C.C. Elam, and R. Evans, *Hydrogen from Biomass State of the Art and Research Challenges*, IEA. p. 82.
186. Larson, E.D., et al., *Exploring Implications to 2050 of Energy Technology options for China.*
187. Hauserman, W.B., *Combustion vs. Gasification and Dioxin-Furan Hazards.* p. 14.
188. Bremer, W., *International standard for future automotive 42 V supply voltages (PowerNet).* Journal of Power Sources. **In Press, Corrected Proof**.

189. Barducci, G., *THE RDF GASIFIER OF THE FLORENTINE AREA (GRÈVE-IN-CHIANTI, ITALY)*, PRESENTED AT THE FIRST ITALIAN-BRAZILIAN SYMPOSIUM ON SANITARY AND ENVIRONMENTAL ENGINEERING. p. 11.

Pyrolysis References

1. Srivastava, R.C., et al., *Nickel catalysed steam gasification of chars obtained from coal-alkali reaction at 600 [deg]C.* Fuel, 2003. **82**(1): p. 93-96.
2. Sheth, A., et al., *Catalytic gasification of coal using eutectic salts: reaction kinetics with binary and ternary eutectic catalysts.* Fuel, 2003. **82**(3): p. 305-317.
3. Shen, L. and D.-K. Zhang, *An experimental study of oil recovery from sewage sludge by low-temperature pyrolysis in a fluidised-bed*.* Fuel, 2003. **82**(4): p. 465-472.
4. Rath, J., et al., *Heat of wood pyrolysis.* Fuel, 2003. **82**(1): p. 81-91.
5. Pasel, C. and W. Wanzl, *Experimental investigations on reactor scale-up and optimisation of product quality in pyrolysis of shredder waste.* Fuel Processing Technology, 2003. **80**(1): p. 47-67.
6. Karagoz, S., et al., *Liquefaction of municipal waste plastics in VGO over acidic and non-acidic catalysts*.* Fuel, 2003. **82**(4): p. 415-423.
7. Evans, C. and B. Dellinger, *Mechanisms of Dioxin Formation from the High-Temperature Pyrolysis of 2-Chlorophenol.* Environmental Science & Technology, 2003. **37**(7): p. 1325-1330.
8. *Request for Qualifications for Power Generation Utilizing Pyrolysis/Gasification of Municipal Solid Waste.* 2003.
9. Williams, P.T. and A.J. Brindle, *Catalytic pyrolysis of tyres: influence of catalyst temperature.* Fuel, 2002. **81**(18): p. 2425-2434.
10. Wang, Z., Haitao Huang, Haibin Li, Chuangzhi Wu, and Yong Chen, *Pyrolysis and Combustion of Refuse-Derived Fuels in a Spouting-Moving Bed Reactor.* Energy & Fuels, 2002. **16**(1): p. 136-142.
11. Wang, Z., Haitao Huang, Haibin Li, Chuangzhi Wu, and Yong Chen, *HCl Formation from RDF Pyrolysis and Combustion in a Spouting-Moving Bed Reactor.* Energy & Fuels, 2002. **16**(3): p. 608-614.
12. Uddin, M.A., et al., *Dehydrohalogenation during pyrolysis of brominated flame retardant containing high impact polystyrene (HIPS-Br) mixed with polyvinylchloride (PVC).* Fuel, 2002. **81**(14): p. 1819-1825.
13. Shihadeh, A. and S. Hochgreb, *Impact of Biomass Pyrolysis Oil Process Conditions on Ignition Delay in Compression Ignition Engines.* Energy & Fuels, 2002. **16**(3): p. 552-561.
14. Sharypov, V.I., et al., *Co-pyrolysis of wood biomass and synthetic polymer mixtures. Part 1: influence of experimental conditions on the evolution of solids, liquids and gases.* Journal of Analytical & Applied Pyrolysis, 2002. **64**(1): p. 15-28.
15. Senneca, O., R. Chirone, and P. Salatino, *A thermogravimetric study of nonfossil solid fuels. 2. Oxidative pyrolysis and char combustion.* Energy & Fuels, 2002. **16**(3): p. 661-668.
16. Senneca, O., et al., *A thermogravimetric study of nonfossil solid fuels. 1. Inert pyrolysis.* Energy & Fuels, 2002. **16**(3): p. 653-660.
17. Rath, J., et al., *Tar cracking from fast pyrolysis of large beech wood particles.* Journal of Analytical & Applied Pyrolysis, 2002. **62**(1): p. 83-92.
18. Ohbayashi, H., et al., *Removal of polychlorinated biphenyls from capacitors and pressure-sensitive paper by vacuum thermal recycling.* Waste Management, 2002. **22**(1): p. 91-98.
19. Newborough, M., D. Highgate, and P. Vaughan, *Thermal depolymerisation of scrap polymers.* Applied Thermal Engineering, 2002. **22**(17): p. 1875-1883.

20. Marin, N., et al., *Copyrolysis of wood biomass and synthetic polymers mixtures. Part II: characterisation of the liquid phases.* Journal of Analytical & Applied Pyrolysis, 2002. **65**(1): p. 41-55.
21. Ma, S.J.L., * and Jinsheng Gao, *Study of the Low Temperature Pyrolysis of PVC.* Energy & Fuels, 2002. **16**(2): p. 338-342.
22. Lappas, A.A., et al., *Biomass pyrolysis in a circulating fluid bed reactor for the production of fuels and chemicals.* Fuel, 2002. **81**(16): p. 2087-2095.
23. Karaduman, A., *Pyrolysis of Polystyrene Plastic Wastes with Some Organic Compounds for Enhancing Styrene Yield.* Energy Sources, 2002. **24**(7): p. 667-674.
24. Garcia-Perez, M., A. Chaala, and C. Roy, *Co-pyrolysis of sugarcane bagasse with petroleum residue. Part II. Product yields and properties.* Fuel, 2002. **81**(7): p. 893-907.
25. Galvagno, S., et al., *Pyrolysis process for the treatment of scrap tyres: preliminary experimental results.* Waste Management, 2002. **22**(8): p. 917-923.
26. Davidsson, K.O. and J.B.C. Pettersson, *Birch wood particle shrinkage during rapid pyrolysis.* Fuel, 2002. **81**(3): p. 263-270.
27. Davidsson, K.O., J.B.C. Pettersson, and R. Nilsson, *Fertiliser influence on alkali release during straw pyrolysis.* Fuel, 2002. **81**(3): p. 259-262.
28. Davidsson, K.O., B.J. Stojkova, and J.B.C. Pettersson, *Alkali emission from birchwood particles during rapid pyrolysis.* Energy & Fuels, 2002. **16**(5): p. 1033-1039.
29. Czernik, S., R. French, and C. Feik, *Production of Hydrogen From Post-Consumer Wastes*. 2002. p. 10.
30. Borgianni, C., et al., *Gasification process of wastes containing PVC.* Fuel, 2002. **81**(14): p. 1827-1833.
31. Berrueco, C., F. J. Mastral, E. Esperanza, and J. Ceamanos, *Production of Waxes and Tars from the Continuous Pyrolysis of High Density Polyethylene. Influence of Operation Variables.* Energy & Fuels, 2002. **16**(5): p. 1148-1153.
32. Yanik, J., M.A. Uddin, and Y. Sakata, *The effect of red mud on the liquefaction of waste plastics in heavy vacuum gas oil.* Energy & Fuels, 2001. **15**(1): p. 163-169.
33. Sorum, L., M.G. Gronli, and J.E. Hustad, *Pyrolysis characteristics and kinetics of municipal solid wastes.* Fuel, 2001. **80**(9): p. 1217-1227.
34. Reyes, J.A., J.A. Conesa, and A. Marcilla, *Pyrolysis and combustion of polycoated cartons: kinetic model and MS-analysis.* Journal of Analytical & Applied Pyrolysis, 2001. **58**: p. 747-763.
35. Rath, J. and G. Staudinger, *Cracking reactions of tar from pyrolysis of spruce wood.* Fuel, 2001. **80**(10): p. 1379-1389.
36. Ono, A., et al., *Evaluation of waste pyrolysis characteristics in a pressurized fluidized bed reactor.* Waste Management, 2001. **21**(5): p. 451-456.
37. Marcilla, A., M. Beltran, and J.A. Conesa, *Catalyst addition in polyethylene pyrolysis - Thermogravimetric study.* Journal of Analytical & Applied Pyrolysis, 2001. **58**: p. 117-126.
38. Lingaiah, N., et al., *Catalytic dechlorination of chloroorganic compounds from PVC-containing mixed plastic-derived oil.* Applied Catalysis A: General, 2001. **207**(1-2): p. 79-84.
39. Kim, S., *Pyrolysis kinetics of waste PVC pipe.* Waste Management, 2001. **21**(7): p. 609-616.
40. Garcia-Perez, M., et al., *Co-pyrolysis of sugarcane bagasse with petroleum residue. Part I: thermogravimetric analysis.* Fuel, 2001. **80**(9): p. 1245-1258.
41. Font, R., et al., *Analysis of the pyrolysis and combustion of different sewage sludges by TG.* Journal of Analytical & Applied Pyrolysis, 2001. **58**: p. 927-941.

42. Evans, R., S. Czernik, and E. Chornet, *Engineering Scale Up of Renewable Hydrogen Production by Catalytic Steam Reforming of Peanut Shells Pyrolysis Products*. 2001. p. 10.
43. Darmstadt, H., et al., *Co-pyrolysis under vacuum of sugar cane bagasse and petroleum residue - Properties of the char and activated char products.* Carbon, 2001. **39**(6): p. 815-825.
44. Brebu, M., et al., *Catalytic degradation of acrylonitrile-butadiene-styrene into fuel oil 2. Changes in the structure and catalytic activity of iron oxides.* Energy & Fuels, 2001. **15**(3 May/June): p. 565-570.
45. Brebu, M., et al., *Catalytic degradation of acrylonitrile-butadiene-styrene into fuel oil 1. The effect of iron oxides on the distribution of nitrogen-containing compounds.* Energy & Fuels, 2001. **15**(3 May/June): p. 559-564.
46. *Pyrolysis & Gasification of Waste A Worldwide Technology and Business Review*. 2001. p. 622.
47. Zhuo, Y., et al., *An attempt to correlate conversions in pyrolysis and gasification with FT-IR spectra of coals.* Energy & Fuels, 2000. **14**(5): p. 1049-1058.
48. Shihadeh, A. and S. Hochgreb, *Diesel engine combustion of biomass pyrolysis oils.* Energy & Fuels, 2000. **14**(2): p. 260-274.
49. Samolada, M.C., A. Papafotica, and I.A. Vasalos, *Catalyst evaluation for catalytic biomass pyrolysis.* Energy & Fuels, 2000. **14**(6): p. 1161-1167.
50. Marcilla, A., et al., *Thermal treatment and foaming of chars obtained from almond shells: kinetic study.* Fuel, 2000. **79**(7): p. 829-836.
51. Jaksland, C., E. Rasmussen, and T. Rohde, *A new technology for treatment of PVC waste.* Waste Management, 2000. **20**(5-6): p. 463-467.
52. Fullana, A., et al., *Evolution of products in the combustion of scrap tires in a horizontal, laboratory scale reactor.* Environmental Science & Technology, 2000. **34**(11): p. 2092-2099.
53. El harfi, K., et al., *Pyrolysis of the Moroccan (Tarfaya) oil shales under microwave irradiation.* Fuel, 2000. **79**(7): p. 733-742.
54. De Witt, M.J. and L.J. Broadbelt, *Binary interactions between high-density polyethylene and 4-(1-naphthylmethyl)bibenzyl during low-pressure pyrolysis.* Energy & Fuels, 2000. **14**(2): p. 448-458.
55. De Witt, M.J., D.J. Dooling, and L.J. Broadbelt, *Computer generation of reaction mechanisms using quantitative rate information: Application to long-chain hydrocarbon pyrolysis.* Industrial & Engineering Chemistry Research, 2000. **39**(7): p. 2228-2237.
56. Dai, X.W., et al., *The fast pyrolysis of biomass in CFB reactor.* Energy & Fuels, 2000. **14**(3): p. 552-557.
57. Cozzani, V., *Reactivity in oxygen and carbon dioxide of char formed in the pyrolysis of refuse-derived fuel.* Industrial & Engineering Chemistry Research, 2000. **39**(4): p. 864-872.
58. Conesa, J.A., A. Fullana, and R. Font, *Tire pyrolysis: Evolution of volatile and semivolatile compounds.* Energy & Fuels, 2000. **14**(2): p. 409-418.
59. Chang, C.Y. and e. al. *Major products obtained from the pyrolysis of oil sludge*. in *Air and Waste Management Association 93rd Annual Conference and Exhibition*. 2000.
60. Arena, U. and M.L. Mastellone, *Defluidization phenomena during the pyrolysis of two plastic wastes.* Chemical Engineering Science, 2000. **55**(15): p. 2849-2860.
61. Abatzoglou, N., et al., *The development of a draft protocol for the sampling and analysis of particulate and organic contaminants in the gas from small biomass gasifiers.* Biomass & Bioenergy, 2000. **18**(1): p. 5-17.

62. Uddin, M.A., et al., *Dechlorination of chlorine compounds in poly(vinyl chloride) mixed plastics derived oil by solid sorbents.* Industrial and Engineering Chemistry Research, 1999. **38**(4): p. 1406-1410.
63. Senneca, O., P. Salatino, and R. Chirone, *A fast heating-rate thermogravimetric study of the pyrolysis of scrap lyres.* Fuel, 1999. **78**(13): p. 1575-1581.
64. Samolada, M.C., *Catalysts in biomass flash pyrolysis.* Microporous & Mesoporous Materials, 1999. **27**(1): p. 122-124.
65. Sakata, Y., M.A. Uddin, and A. Muto, *Degradation of polyethylene and polypropylene into fuel oil by using solid acid and non-acid catalysts.* Journal of Analytical and Applied Pyrolysis, 1999. **51**(1-2): p. 135-155.
66. Orfao, J.J.M., F.J.A. Antunes, and J.L. Figueiredo, *Pyrolysis kinetics of lignocellulosic materials - three independent reactions model.* Fuel, 1999. **78**(3): p. 349-358.
67. Milne, B.J., L.A. Behie, and F. Berruti, *Recycling of waste plastics by ultrapyrolysis using an internally circulating fluidized bed reactor.* Journal of Analytical & Applied Pyrolysis, 1999. **51**(1-2): p. 157-166.
68. Horvat, N. and F.T.T. Ng, *Tertiary polymer recycling: study of polyethylene thermolysis as a first step to synthetic diesel fuel.* Fuel, 1999. **78**(4): p. 459-470.
69. Esperanza, M.M., et al., *Pyrolysis of varnish wastes based on a polyurethane.* Journal of Analytical & Applied Pyrolysis, 1999. **52**(2): p. 151-166.
70. De Witt, M.J. and L.J. Broadbelt, *Binary interactions between tetradecane and 4-(1-naphthylmethyl)bibenzyl during low- and high-pressure pyrolysis.* Energy & Fuels, 1999. **13**(5): p. 969-983.
71. Day, M., Z. Shen, and J.D. Cooney, *Pyrolysis of auto shredder residue: experiments with a laboratory screw kiln reactor.* Journal of Analytical and Applied Pyrolysis, 1999. **51**(1-2): p. 181-200.
72. Conesa, J.A. and R. Font, *Kinetic severity function as a test for kinetic analysis. Application to polyethylene pyrolysis.* Energy & Fuels, 1999. **13**(3): p. 678-685.
73. Bockhorn, H., et al., *Dehydrochlorination of plastic mixtures.* Journal of Analytical and Applied Pyrolysis, 1999. **49**(1-2): p. 97-106.
74. Bockhorn, H., A. Hornung, and U. Hornung, *Mechanisms and kinetics of thermal decomposition of plastics from isothermal and dynamic measurements.* Journal of Analytical and Applied Pyrolysis, 1999. **50**(2): p. 77-101.
75. Westerhout, R.W.J., J.A.M. Kuipers, and W.P.M. Vanswaaij, *Experimental determination of the yield of pyrolysis products of polyethene and polypropene - influence of reaction conditions.* Industrial & Engineering Chemistry Research, 1998. **37**(3): p. 841-847.
76. Westerhout, R.W.J., et al., *Techno-economic evaluation of high temperature pyrolysis processes for mixed plastic waste.* Chemical Engineering Research & Design, 1998. **76**(A3): p. 427-439.
77. Westerhout, R.W.J., et al., *Development of a continuous rotating cone reactor pilot plant for the pyrolysis of polyethene and polypropene.* Industrial & Engineering Chemistry Research, 1998. **37**(6): p. 2316-2322.
78. Westerhout, R.W.J., et al., *Recycling of polyethene and polypropene in a novel bench-scale rotating cone reactor by high-temperature pyrolysis.* Industrial & Engineering Chemistry Research, 1998. **37**(6): p. 2293-2300.
79. Samolada, M.C., W. Baldauf, and I.A. Vasalos, *Production of a bio-gasoline by upgrading biomass flash pyrolysis liquids via hydrogen processing and catalytic cracking.* Fuel, 1998. **77**(14): p. 1667-1675.

80. Coulter, S., et al., *Designing for material separation - lessons from automotive recycling.* Journal of Mechanical Design, 1998. **120**(3): p. 501-509.
81. Conesa, J.A., et al., *Evolution of gases in the primary pyrolysis of different sewage sludges.* Thermochimica Acta, 1998. **313**(1): p. 63-73.
82. Conesa, J.A., et al., *Kinetic model for the combustion of tyre wastes.* Fuel, 1998. **77**(13): p. 1469-1475.
83. Bockhorn, H., A. Hornung, and U. Hornung, *Stepwise pyrolysis for raw material recovery from plastic waste.* Journal of Analytical & Applied Pyrolysis, 1998. **46**(1): p. 1-13.
84. *Advanced Thermal Conversion Technologies for Energy from Solid Waste, IEA Bioenergy*. 1998, Caddet Renewable Energy Technologies Programme. p. 50.
85. Westerhout, R.W.J., et al., *Kinetics of the low-temperature pyrolysis of polyethene, polypropene, and polystyrene modeling, experimental determination, and comparison with literature models and data.* Industrial & Engineering Chemistry Research, 1997. **36**(6): p. 1955-1964.
86. Westerhout, R.W.J., et al., *Examination and evaluation of the use of screen heaters for the measurement of the high temperature pyrolysis kinetics of polyethene and polypropene.* Industrial & Engineering Chemistry Research, 1997. **36**(8): p. 3360-3368.
87. Ranzi, E., et al., *Kinetic modeling of polyethylene and polypropylene thermal degradation.* Journal of Analytical & Applied Pyrolysis, 1997. **1**: p. 305-319.
88. Olsson, J.G., et al., *Alkali metal emission during pyrolysis of biomass.* Energy & Fuels, 1997. **11**(4): p. 779-784.
89. Hendrix, J., et al., *Technologies for the identification, separation, and recylcing of automotive plastics.* International Journal of Environmentally Conscious Design and Manufacturing, 1997. **6**(2): p. 37-50.
90. Cozzani, V., et al., *Influence of gas-phase reactions on the product yields obtained in the pyrolysis of polyethylene.* Industrial & Engineering Chemistry Research, 1997. **36**(2): p. 342-348.
91. Cozzani, V., et al., *A new method to determine the composition of biomass by thermogravimetric analysis.* Canadian Journal of Chemical Engineering, 1997. **75**(1): p. 127-133.
92. Cozzani, V., *Characterization of coke formed in the pyrolysis of polyethylene.* Industrial & Engineering Chemistry Research, 1997. **36**(12): p. 5090-5095.
93. Conesa, J.A., R. Font, and A. Marcilla, *Comparison between the pyrolysis of two types of polyethylenes in a fluidized bed reactor.* Energy & Fuels, 1997. **11**(1): p. 126-136.
94. Conesa, J.A., et al., *Kinetic model for the continuous pyrolysis of two types of polyethylene in a fluidized bed reactor.* Journal of Analytical & Applied Pyrolysis, 1997. **1**: p. 419-431.
95. Conesa, J.A., R. Font, and A. Marcilla, *Mass spectrometry validation of a kinetic model for the thermal decomposition of tyre wastes.* Journal of Analytical & Applied Pyrolysis, 1997. **43**(1): p. 83-96.
96. Conesa, J.A., A. Marcilla, and J.A. Caballero, *Evolution of gases from the pyrolysis of modified almond shells - effect of impregnation with cocl2.* Journal of Analytical & Applied Pyrolysis, 1997. **43**(1): p. 59-69.
97. Caballero, J.A., A. Marcilla, and J.A. Conesa, *Thermogravimetric analysis of olive stones with sulphuric acid treatment.* Journal of Analytical & Applied Pyrolysis, 1997. **44**(1): p. 75-88.
98. Bangala, D.N., et al., *Catalytic gas conditioning - application to biomass and waste gasification.* Industrial & Engineering Chemistry Research, 1997. **36**(10): p. 4184-4192.

99. *CMPS&F-Environment Australia Appropriate Technologies for the Treatment of Scheduled Wastes*. 1997.
100. Sakata, Y.U., Md. Azhar; Muto, Akinori; Koizumi, Kazuo; Narazaki, Masaya; Murata, Katsuhide; Kaji, Mitsuo, *Thermal and catalytic degradation of municipal waste plastics into fuel oil.* Polymer Recycling, 1996. **2**(4): p. 309-315.
101. Helton, J.C., et al., *Uncertainty and sensitivity analysis results obtained in the 1992 performance assessment for the waste isolation pilot plant.* Reliability Engineering & System Safety, 1996. **51**(1): p. 53-100.
102. Cozzani, V., et al., *Modeling and experimental verification of physical and chemical processes during pyrolysis of a refuse-derived fuel.* Industrial & Engineering Chemistry Research, 1996. **35**(1): p. 90-98.
103. Conesa, J.A., R. Font, and A. Marcilla, *Gas from the pyrolysis of scrap tires in a fluidized bed reactor.* Energy & Fuels, 1996. **10**(1): p. 134-140.
104. Conesa, J.A., et al., *Thermogravimetric studies on the thermal decomposition of polyethylene.* Journal of Analytical & Applied Pyrolysis, 1996. **36**(1): p. 1-15.
105. Conesa, J.A. and A. Marcilla, *Kinetic study of the thermogravimetric behavior of different rubbers.* Journal of Analytical & Applied Pyrolysis, 1996. **37**(1): p. 95-110.
106. Avenell, C.S., C.I. Sainz-Diaz, and A.J. Griffiths, *Solid waste pyrolysis in a pilot-scale batch pyrolyser.* Fuel, 1996. **75**(10): p. 1167-1174.
107. Wey, M.Y., et al., *The autothermal pyrolysis of waste tires.* Journal of the Air & Waste Management Association, 1995. **45**(11): p. 855-863.
108. Shen, Z., Day, M., Cooney, J.D., Lu, G., Briens, C.L., Bergougnou, and M.A, *Ultrapyrolysis of automobile shredder residue.* The Canadian journal of chemical engineering, 1995. **73**: p. 357-363.
109. Gasso, S., et al., *Wet oxidation of refractory organic compounds in industrial aqueous wastes via the oxyjet technology.* Waste Management & Research, 1995. **13**(1): p. 37-46.
110. Cozzani, V., L. Petarca, and L. Tognotti, *Devolatilization and pyrolysis of refuse derived fuels - characterization and kinetic modelling by a thermogravimetric and calorimetric approach.* Fuel, 1995. **74**(6): p. 903-912.
111. Cozzani, V., et al., *A fundamental study on conventional pyrolysis of a refuse-derived fuel.* Industrial & Engineering Chemistry Research, 1995. **34**(6): p. 2006-2020.
112. Conesa, J.A., et al., *Analysis of different kinetic models in the dynamic pyrolysis of cellulose.* Thermochimica Acta, 1995. **254**: p. 175-192.
113. Atal, A. and Y.A. Levendis, *Comparison of the combustion behaviour of pulverized waste tyres and coal.* Fuel, 1995. **74**(11): p. 1570-1581.
114. Antal, M.J.J.V., Gabor, *Cellulose Pyrolysis Kinetics: The Current State of Knowledge.* Industrial & Engineering Chemistry Research, 1995. **34**(3): p. 703-17.
115. Agblevor, F.A., S. Besler, and A.E. Wiselogel, *Fast pyrolysis of stored biomass feedstocks.* Energy & Fuels, 1995. **9**(4): p. 635-640.
116. Conesa, J.A., A. Marcilla, and R. Font, *Kinetic model of the pyrolysis of polyethylene in a fluidized bed reactor.* Journal of Analytical & Applied Pyrolysis, 1994. **30**(1): p. 101-120.
117. Conesa, J.A., et al., *Pyrolysis of polyethylene in a fluidized bed reactor.* Energy & Fuels, 1994. **8**(6): p. 1238-1246.
118. Kiligroe, J.D.P.N., L.; Schindler, P. J.; Lanier, W. S, Combust. Sci. Technol., 1990. **74**: p. 223-244.
119. Buekens, A.G.S., J. G., *European experience in the pyrolysis and gasification of solid wastes.* Conservation & Recycling, 1986. **9**(3): p. 253-69.

120. Mauchien, J. and P. Oudenne, *Pyrolysis, An Original Multi Product Solution For The Thermal Valorisation Of Used Tyres.* p. 11.

121. Damberger, T.A., *Plasma Pyrolysis*, HI Disposal Systems.

122. Czernik, S., French, R., Feik, C., and Chornet, E., *Production of Hydrogen from Biomass by Pyrolysis/Steam Reforming, in Advances in Hydrogen Energy, Grégoire-Padró, C. and Lau, F., Eds., Kluwer Academic/Plenum Publishers, New York 2000, pp. 87-91.*

Microwave Pyrolysis References

1. *City of Honolulu Review of plasma arc gasification and vitrification technology for waste disposal*. 2003, R.W.Beck,Inc. p. 32.
2. Purta, D.A. and A.M. Guzman, *Microwave assisted cleaning and reclamation of industrial wastes*. 2002.
3. Perry, W.L., et al., *Microwave Heating of Endothermic Catalytic Reactions: Reforming of Methanol.* AIChE Journal, 2002. **48**(4): p. 820-831.
4. Arbon, I.M., *Worldwide use of biomass in power generation and combined beat and power schemes.* Proceedings of the Institution of Mechanical Engineers Part A-Journal of Power & Energy, 2002. **216**(A1): p. 41-57.
5. Al-Mayman, S.I. and S.M. Al-Zahrani, *Catalytic cracking of gas oils in electromagnetic fields: reactor design and performance.* Fuel Processing Technology, 2002. **80**(2): p. 169-182.
6. *Environmental Testing Report Synopsis MD-1000 Clinical Waste Treatment System Located at Recycled Waste PLC Speke, Liverpool U.K.* 2002, Environmental Waste International. p. 12.
7. Miura, M., et al., *Microwave pyrolysis of cellulosic materials for the production of anhydrosugars.* Journal of Wood Science, 2001. **47**(6): p. 502-506.
8. Miura, M., et al., *Rapid microwave pyrolysis of wood.* Journal of Chemical Engineering of Japan, 2000. **33**(2): p. 299-302.
9. Clark, D.E., D.C. Folz, and J.K. West, *Processing materials with microwave energy.* Materials Science & Engineering A-Structural Materials Properties Microstructure & Processing, 2000. **287**(2): p. 153-158.
10. Martin, M.J., M.D. Balaguer, and M. Rigola. *Microwave treatment as a new option for sludge recycling.* in *IAWQ Specialised Conference on Disposal and Utilisation of Sewage Sludge: Thermal Methods and Application Modalities.* 1999. Greece.
11. Ravi, B.G., et al., *Microwave-assisted preparation and sintering of mullite and mullite-zirconia composites from metal organics.* Materials Research Bulletin, 1998. **33**(10): p. 1527-1536.
12. Meredith, R., *Engineers' Handbook of Industrial Microwave Heating*. IEE Power Series, ed. A.T. Johns and D.F. Warne. Vol. 25. 1998, London: The Institution of Electrical Engineers. 363.
13. Ravindran, M., et al., *A simple non-invasive optical pyrometric method for plotting temperature time profiles of high temperature reactions in microwave ovens.* Journal of Thermal Analysis, 1995. **44**(1): p. 25-30.
14. Monsefmirzai, P., et al., *Rapid microwave pyrolysis of coal - methodology and examination of the residual and volatile phases.* Fuel, 1995. **74**(1): p. 20-27.
15. Mehdizadeh, M., *Engineering and Scale-Up Considerations for Microwave Induced Reactions.* Res. Chem. Intermed., 1994. **20**(1): p. 79-84.
16. Kuester, J.L., *Design, operation and analysis of microwave heated chemical reactors.* Research on Chemical Intermediates, 1994. **20**(1): p. 51-59.
17. Kriegerbrockett, B., *Microwave pyrolysis of biomass.* Research on Chemical Intermediates, 1994. **20**(1): p. 39-49.
18. Monsefmirzai, P., et al., *The Use of Microwave-Heating for the Pyrolysis of Coal Via Inorganic Receptors of Microwave-Energy.* Fuel, 1992. **71**(6): p. 716-717.
19. Karn, J., *Chemical composition of forage and feces as affected by microwave oven drying.* Journal of Range Management, 1991. **44**(5): p. 512-14.
20. Djebabra, D., O. Dessaux, and P. Goudmand, *Coal-Gasification by Microwave Plasma in Water-Vapor.* Fuel, 1991. **70**(12): p. 1473-1475.

21. Schuman, G.E., and Frank Rauzi, *Microwave drying of rangeland forage samples*, in *Journal of Range Management*. 1981. p. 426-8.
22. Annadurai, G., et al., *Use of thermally treated waste biological sludge as dye absorbent.* Advances in Environmental Research. **In Press, Uncorrected Proof**.

Supercritical Water References

1. Watanabe, M., et al., *Catalytic effects of NaOH and ZrO2 for partial oxidative gasification of n-hexadecane and lignin in supercritical water**. Fuel, 2003. **82**(5): p. 545-552.
2. Yesodharan, S., *Supercritical water oxidation: An environmentally safe method for the disposal of organic wastes.* Current Science, 2002. **82**(9): p. 1112-1122.
3. Xie, X.F., et al., *Phase-transfer catalyst separation by CO2 enhanced aqueous extraction.* Chemical Communications, 2002(10): p. 1156-1157.
4. Smith, J., Richard L., T. Adschiri, and K. Arai, *Energy integration of methane's partial-oxidation in supercritical water and exergy analysis.* Applied Energy, 2002. **71**(3): p. 205-214.
5. Serikawa, R.M., et al., *Hydrothermal flames in supercritical water oxidation: investigation in a pilot scale continuous reactor.* Fuel, 2002. **81**(9): p. 1147-1159.
6. Sarrade, S., C. Guizard, and G.M. Rios, *Membrane technology and supercritical fluids: chemical engineering for coupled processes.* Desalination, 2002. **144**(1-3): p. 137-142.
7. Sakaki, T., et al., *Saccharification of Cellulose Using a Hot-Compressed Water-Flow Reactor.* Industrial & Engineering Chemistry Research, 2002. **41**(4): p. 661-665.
8. Lee, I.G., M.S. Kim, and S.K. Ihm, *Gasification of glucose in Supercritical water.* Industrial & Engineering Chemistry Research, 2002. **41**(5): p. 1182-1188.
9. Kubatova, A., A.J.M. Lagadec, and S.B. Hawthorne, *Dechlorination of lindane, dieldrin, tetrachloroethane, trichloroethene, and PVC in subcritical water.* Environmental Science & Technology, 2002. **36**(6): p. 1337-1343.
10. Hong, G.T. and M.H. Spritzer, *Supercritical Water Partial*. 2002. p. 18.
11. Hayward, T.M., I.M. Svishchev, and R.C. Makhija, *Stainless steel flow reactor for supercritical water oxidation: corrosion tests.* Journal of Supercritical Fluids, 2002: p. 1-7.
12. Ehara, K. and S. Saka, *A comparative study on chemical conversion of cellulose between the batch-type and flow-type systems in supercritical water.* Cellulose, 2002. **9**(3-4): p. 301-311.
13. Demirbas, A., *Biodiesel from vegetable oils via transesterification in supercritical methanol.* Energy Conversion and Management, 2002. **43**(17): p. 2349-2356.
14. Calvo, L. and D. Vallejo, *Formation of organic acids during the hydrolysis and oxidation of several wastes in sub- and supercritical water.* Industrial & Engineering Chemistry Research, 2002. **41**(25): p. 6503-6509.
15. Buhler, W., et al., *Ionic reactions and pyrolysis of glycerol as competing reaction pathways in near- and supercritical water.* Journal of Supercritical Fluids, 2002. **22**(1): p. 37-53.
16. Tolman, R., J. Parkinson, and B. Rickman, *PROCESS FOR CONVERTING SEWAGE SLUDGE AND MUNICIPAL SOLID WASTES TO CLEAN FUELS*. 2001, ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM. p. 21.
17. Tachibana, S., *Method for fuel production from biomass by fermentation.* Kokai Tokkyo Koho JP 2001 262.162 (Cl. ClOLl:O2), 26 Sep 2001, Appl. 2000'72,735. 15 Mar 2000. 5. (In Japanese), 2001.
18. Suppes, G.J., S. Roy, and J. Ruckman, *Impact of common salts on oxidation of alcohols and chlorinated hydrocarbons.* Aiche Journal, 2001. **47**(7): p. 1623-1631.
19. Sasaki, M., et al., *Super-rapid enzymatic hydrolysis of cellulose with supercritical water solubilization pretreatment.* Kobunshi Ronbunshu, 2001. **58**(10): p. 527-532.
20. Rice, S.F. and E. Croiset, *Oxidation of simple alcohols in supercritical water III. Formation of intermediates from ethanol.* Industrial & Engineering Chemistry Research, 2001. **40**(1): p. 86-93.

21. Re, G.D. and G.D. Giacomo, *Removal and destruction of toxic micropolluting organic compounds from waste waters by a combined NF and SCWO process*. 2001, Elsevier. p. 61-64.
22. Quitain, A.T., et al., *Production of valuable materials by hydrothermal treatment of shrimp shells.* Industrial & Engineering Chemistry Research, 2001. **40**(25): p. 5885-5888.
23. Park, C.Y., Y.W. Ryu, and C. Kim, *Kinetics and rate of enzymatic hydrolysis of cellulose in supercritical carbon dioxide.* Korean Journal of Chemical Engineering, 2001. **18**(4): p. 475-478.
24. Mantzavinos, D., T. Hodgkiess, and S.L.C. Lai, *Corrosion of condenser tube materials in distilled water.* Desalination, 2001. **138**(1-3 Special Issue SI): p. 365-370.
25. Kritzer, P. and E. Dinjus, *An assessment of supercritical water oxidation (SCWO) - Existing problems, possible solutions and new reactor concepts.* Chemical Engineering Journal, 2001. **83**(3): p. 207-214.
26. Kim, K.H. and J. Hong, *Supercritical CO2 pretreatment of lignocellulose enhances enzymatic cellulose hydrolysis.* Bioresource Technology, 2001. **77**(2): p. 139-144.
27. Johanson, N.W., M.H. Spritzer, and G.T. Hong, *Supercritical Water Partial Oxidation*. 2001. p. 16.
28. Hauthal, W.H., *Advances with supercritical fluids review.* Chemosphere, 2001. **43**(1): p. 123-135.
29. Gidner, A.V., L.B. Stenmark, and K.M. Carlsson, *Treatment of Different Wastes by Supercritical Water Oxidation.* 2001: p. 7.
30. Demirbas, A., *Biomass resource facilities and biomass conversion processing for fuels and chemicals.* Energy Conversion and Management, 2001. **42**(11): p. 1357-1378.
31. Demirbas, A., *Supercritical fluid extraction and chemicals from biomass with supercritical fluids.* Energy Conversion and Management, 2001. **42**(3): p. 279-294.
32. Cocero, M.J., M.T. Sanz, and F. Fernandez-Polanco, *Study of alternatives for the design of a mobile unit for wastewater treatment by supercritical water oxidation.* Journal of Chemical Technology and Biotechnology, 2001. **76**(3): p. 257-264.
33. Clark, H., *PROCESS FOR CONVERTING SEWAGE SLUDGE AND MUNICIPAL SOLID WASTES TO CLEAN FUELS.* 2001, California Energy Commission ENERGY INNOVATIONS SMALL GRANT PROGRAM Renewable Energy Technologies. p. 8.
34. Sasaki, M., et al., *Dissolution and hydrolysis of cellulose in subcritical and supercritical water.* Industrial & Engineering Chemistry Research, 2000. **39**(8): p. 2883-2890.
35. Saenz-Barrio, C. and T. Cedron-Fernandez, *Microextraction of volatile compounds from wine samples and their determination by GC-FID. The effect of the salts and extraction solvents used.* Chromatographia, 2000. **51**(3-4): p. 221-225.
36. Rice, S.F. and J.J. Wickham, *Hydrogen Raman linewidths in supercritical water and carbon dioxide.* Journal of Raman Spectroscopy, 2000. **31**(7): p. 619-624.
37. Perrut, M., *Supercritical fluid applications: Industrial developments and economic issues.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4531-4535.
38. Muthukumaran, P. and R.B. Gupta, *Sodium-carbonate-assisted supercritical water oxidation of chlorinated waste.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4555-4563.
39. Mitton, D.B., et al., *Corrosion behavior of nickel-based alloys in supercritical water oxidation systems.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4689-4696.
40. Mendez-Santiago, J. and A.S. Teja, *Solubility of solids in supercritical fluids: Consistency of data and a new model for cosolvent systems.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4767-4771.

41. Mantzavinos, D., et al., *Beneficial combination of wet oxidation, membrane separation and biodegradation processes for treatment of polymer processing wastewaters.* Canadian Journal of Chemical Engineering, 2000. **78**(2): p. 418-422.
42. Lu, X.Y., A. Sakoda, and M. Suzuki, *Decomposition of cellulose by continuous near-critical water reactions.* Chinese Journal of Chemical Engineering, 2000. **8**(4): p. 321-325.
43. Kritzer, P. and E. Dinijus, *An assessment of supercritical water oxidation (SCWO)Existing problems, possible solutions and new reactor concepts.* Chemical Engineering Journal, 2000. **83**: p. 207-214.
44. Funazukuri, T., *Rates of weight loss for lignocellulosic materials subjected to supercritical fluid/mixtures.* Journal of Chemical Engineering of Japan, 2000. **33**(2): p. 292-296.
45. Fang, Z., S.K. Xu, and J.A. Kozinski, *Behavior of metals during combustion of industrial organic wastes in supercritical water.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4536-4542.
46. Eckert, C.A. and A.S. Teja, *SUPERCRITICAL FLUIDS CONFERENCE IN ATLANTA Preface.* Ind. Eng. Chem. Res., 2000. **39**(12): p. 4441.
47. Eckert, C.A., et al., *Tuning solvents for sustainable technology.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4615-4621.
48. Drews, M.J., M. Williams, and M. Barr, *The corrosion of sol-gel-coated type 316 SS in chlorinated SC water.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4772-4783.
49. Drews, M.J., M. Barr, and M. Williams, *A kinetic study of the SCWO of a sulfonated lignin waste stream.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4784-4793.
50. Crooker, P.J., et al., *Operating results from supercritical water oxidation plants.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4865-4870.
51. Cocero, M.J., et al., *Supercritical water oxidation (SCWO) for poly(ethylene terephthalate) (PET) industry effluents.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4652-4657.
52. Blanchard, L.A. and J.F. Brennecke, *Recovery of Organic Products from Ionic Liquids Using Supercritical Carbon Dioxide.* Ind. Eng. Chem. Res., 2000. **40**(1): p. 287-292.
53. Aymonier, C., et al., *Ultrasound for hydrothermal treatments of aqueous wastes: Solution for overcoming salt precipitation and corrosion.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4734-4740.
54. Arai, K., T. Adschiri, and M. Watanabe, *Hydrogenation of hydrocarbons through partial oxidation in supercritical water.* Industrial & Engineering Chemistry Research, 2000. **39**(12): p. 4697-4701.
55. Antal, M.J. and S.G. Allen, *Biomass Gasification in Supercritical Water.* 2000. **39**: p. 4040-4053.
56. Antal, M.J., et al., *Biomass gasification in supercritical water.* Industrial & Engineering Chemistry Research, 2000. **39**(11): p. 4040-4053.
57. *APPENDIX I SUPERCRITICAL WATER GASIFICATION OF BIOMASS/RDF COMPOST.* 2000.
58. Weinstein, R.D., et al., *Silica-promoted Diels-Alder reactions in carbon dioxide from gaseous to supercritical conditions.* Journal of Physical Chemistry B, 1999. **103**(15): p. 2878-2887.
59. Wagner, M., et al., *Materials for SCWO processes for the oxidation of chlorine containing residues in supercritical water.* Materials & Corrosion-Werkstoffe und Korrosion, 1999. **50**(9): p. 523-526.

60. Schmieder, H. and J. Abeln, *Review Supercritical Water Oxidation: State of the Art.* Chem.Eng. Technol, 1999. **22**(11): p. 6.
61. Schmieder, H. and J. Abeln, *Supercritical water oxidation: State of the art.* Chemical Engineering & Technology, 1999. **22**(11): p. 903-908.
62. Savage, P.E., *Organic chemical reactions in supercritical water.* Chemical Reviews, 1999. **99**(2): p. 603-621.
63. Saka, S. and T. Ueno, *Chemical conversion of various celluloses to glucose and its derivatives in supercritical water.* Cellulose, 1999. **6**(3): p. 177-191.
64. Reagan, M.T., J.G. Harris, and J.W. Tester, *Molecular simulations of dense hydrothermal NaCl-H2O solutions from subcritical to supercritical conditions.* Journal of Physical Chemistry B, 1999. **103**(37): p. 7935-7941.
65. Mantzavinos, D., et al., *Wastewater treatment: wet air oxidation as a precursor to biological treatment.* Catalysis Today, 1999. **53**(1): p. 93-106.
66. Li, L.X. and E.F. Gloyna, *Separation of ionic species under supercritical water conditions.* Separation Science & Technology, 1999. **34**(6-7): p. 1463-1477.
67. Laspidou, C.S., et al., *Heater effects on cyclone performance for the separation of solids from high temperature and pressure effluents.* Separation Science & Technology, 1999. **34**(15): p. 3059-3076.
68. Kritzer, P., N. Boukis, and E. Dinjus, *The corrosion of nickel-base alloy 625 in sub- and supercritical aqueous solutions of oxygen: A long time study.* Journal of Materials Science Letters, 1999. **18**(22): p. 1845-1847.
69. Kritzer, P., N. Boukis, and E. Dinjus, *Factors controlling corrosion in high-temperature aqueous solutions: a contribution to the dissociation and solubility data influencing corrosion processes.* The Journal of Supercritical Fluids, 1999. **15**(3): p. 205-227.
70. Divilio, R.J., *Modeling of the Supercritical Water Pyrolysis process*. 1999. p. 25.
71. DiPippo, M.M., K. Sako, and J.W. Tester, *Ternary phase equilibria for the sodium chloride-sodium sulfate-water system at 200 and 250 bar up to 400 degrees C.* Fluid Phase Equilibria, 1999. **157**(2): p. 229-255.
72. Choi, Y.H., et al., *Strategies for supercritical fluid extraction of hyoscyamine and scopolamine salts using basified modifiers.* Journal of Chromatography, 1999. **A.. 863**(1): p. 47-55.
73. Brown, J.S., et al., *Supercritical fluid separation for selective quaternary ammonium salt promoted esterification of terephthalic acid.* Industrial & Engineering Chemistry Research, 1999. **38**(10): p. 3622-3627.
74. Arai, K. and T. Adschiri, *Importance of phase equilibria for understanding supercritical fluid environments.* Fluid Phase Equilibria, 1999. **158-160**: p. 673-684.
75. Antal, M.J., S. Allen, and J. Lichwa, *Hydrogen Production From High-Moisture Content Biomass In Supercritical Water*. 1999. p. 24.
76. Zheng, Y.Z., H.M. Lin, and G.T. Tsao, *Pretreatment for cellulose hydrolysis by carbon dioxide explosion.* Biotechnology Progress, 1998. **14**(6): p. 890-896.
77. Wheeler, G.W., D.L. Tomasko, and J.J. Chalmers, *Dynamics of a linked supercritical extraction-biodegradation process for organic wastes.* Chemical Engineering Science, 1998. **53**(2): p. 189-201.
78. Watanabe, M., et al., *Polyethylene conversion in supercritical water.* Journal of Supercritical Fluids, The, 1998. **13**(1-3): p. 247-252.
79. Tester, J.W., et al., *Chemical reactions and phase equilibria of model halocarbons and salts in sub- and supercritical water (200-300 bar, 100-600-degrees-c).* Journal of Supercritical Fluids, 1998. **13**(1-3): p. 225-240.

80. Sasaki, M., et al., *Cellulose hydrolysis in subcritical and supercritical water.* Journal of Supercritical Fluids, 1998. **13**(1-3): p. 261-268.
81. Roda, A., F. Piazza, and M. Baraldini, *Separation techniques for bile salts analysis.* Journal of Chromatography B, 1998. **717**(1-2): p. 263-278.
82. Rice, S.F., R.R. Steeper, and J.D. Aiken, *Water density effects on homogeneous water-gas shift reaction kinetics.* Journal of Physical Chemistry, 1998. **102**(16): p. 2673-2678.
83. Rice, S.F. and R.R. Steeper, *Oxidation rates of common organic compounds in supercritical water.* Journal of Hazardous Materials, 1998. **59**(2-3): p. 261-278.
84. Minowa, T., F. Zhen, and T. Ogi, *Cellulose decomposition in hot-compressed water with alkali or nickel catalyst.* Journal of Supercritical Fluids, 1998. **13**(1-3): p. 253-259.
85. Li, B.W., *Comparison of microwave oven and convection oven for acid hydrolysis of dietary fiber polysaccharides.* Journal of AOAC International, 1998. **81**(6): p. 1277-1280.
86. Kritzer, P., N. Boukis, and E. Dinjus, *Corrosion of alloy 625 in aqueous solutions containing chloride and oxygen.* Corrosion, 1998. **54**(10): p. 824-834.
87. Kritzer, P., N. Boukis, and E. Dinjus, *The corrosion of alloy 625 (NiCr22Mo9Nb; 2.4856) in high- temperature, high-pressure aqueous solutions of phosphoric acid and oxygen. Corrosion at sub- and supercritical temperatures.* Materials and Corrosion-Werkstoffe Und Korrosion, 1998. **49**(11): p. 831-839.
88. Goto, M., et al., *Supercritical water oxidation for the destruction of municipal excess sludge and alcohol distillery wastewater of molasses.* Journal of Supercritical Fluids, The, 1998. **13**(1-3): p. 277-282.
89. Freeman, H.M., ed. *Standard handbook of hazardous waste treatment and disposal*. 2 ed. 1998, McGraw-Hill.
90. Divilio, R.J., *Modeling of Biomass To Hydrogen Via The Supercritical Water Pyrolysis Process*. 1998.
91. Demirbas, A., *Yields of oil products from thermochemical biomass conversion processes.* Energy Conversion and Management, 1998. **39**(7): p. 685-690.
92. Croiset, E. and S.F. Rice, *Direct observation of h2o2 during alcohol oxidation by o-2 in supercritical water.* Industrial & Engineering Chemistry Research, 1998. **37**(5): p. 1755-1760.
93. Casal, V. and H. Schmidt, *SUWOX - a facility for the destruction of chlorinated hydrocarbons.* Journal of Supercritical Fluids, 1998. **13**(1-3): p. 269-276.
94. Balitsky, V.S., et al., *Silica transfer and [beta]-quartz growth from supercritical aqueous fluids.* Journal of Supercritical Fluids, The, 1998. **13**(1-3): p. 357-362.
95. Arai, K., *Conversion of polymers and biomass to chemical intermediates with supercritical water.* Macromolecular Symposia, 1998. **135**: p. 205-214.
96. Park, S. and E.F. Gloyna, *Statistical study of the liquefaction of used rubber tyre in supercritical water.* Fuel, 1997. **76**(11): p. 999-1003.
97. Otal, E., et al., *Integrated wet air oxidation and biological treatment of polyethylene glycol-containing wastewaters.* Journal of Chemical Technology & Biotechnology, 1997. **70**(2): p. 147-156.
98. Minowa, T., F. Zhen, and T. Ogi, *Cellulose decomposition in hot-compressed water with alkali or nickel catalyst.* Journal of Supercritical Fluids, 1997. **13**: p. 253-259.
99. Mantzavinos, D., A.I. Bailey, and M.W. Rampling, *Flash freezing of erythrocyte suspensions.* Biorheology, 1997. **34**(1): p. 73-83.
100. Mantzavinos, D., et al., *Wet oxidation as a pretreatment method for wastewaters contaminated by bioresistant organics.* Water Science & Technology, 1997. **36**(2-3): p. 109-116.

101. Hellenbrand, R., et al., *Integration of wet oxidation and nanofiltration for treatment of recalcitrant organics in wastewater.* Industrial & Engineering Chemistry Research, 1997. **36**(12): p. 5054-5062.

102. Goemans, M.G.E., et al., *Separation of metal oxides from supercritical water by crossflow microfiltration.* Journal of Membrane Science, 1997. **124**: p. 129-145.

103. Dellorco, P.C., E.F. Gloyna, and S.J. Buelow, *Reactions nitrate salts with ammonia in supercritical water.* Industrial & Engineering Chemistry Research, 1997. **36**(7): p. 2547-2557.

104. Croiset, E., S.F. Rice, and R.G. Hanush, *Hydrogen peroxide decomposition in supercritical water.* AICHE Journal, 1997. **43**(9): p. 2343-2352.

105. Adschiri, T., et al., *Recovery of terephthalic acid by decomposition of pet in supercritical water.* Kagaku Kogaku Ronbunshu, 1997. **23**(4): p. 505-511.

106. Steeper, R.R., et al., *Kinetics measurements of methane oxidation in supercritical water.* Journal of Physical Chemistry, 1996. **100**(1): p. 184-189.

107. Sakaki, T., et al., *Reaction model of cellulose decomposition in near-critical water and fermentation of products.* Bioresource Technology, 1996. **58**(2): p. 197-202.

108. Sakaki, T., et al., *Decomposition of Cellulose in Near-Critical Water and Fermentability of the Products.* Energy Fuels, 1996. **10**(3): p. 684-688.

109. Rice, S.F., et al., *Raman spectroscopic measurement of oxidation in supercritical water .1. conversion of methanol to formaldehyde.* Industrial & Engineering Chemistry Research, 1996. **35**(7): p. 2161-2171.

110. Hunter, T.B., S.F. Rice, and R.G. Hanush, *Raman spectroscopic measurement of oxidation in supercritical water .2. conversion of isopropyl alcohol to acetone.* Industrial & Engineering Chemistry Research, 1996. **35**(11): p. 3984-3990.

111. Ding, Z.Y., et al., *Catalytic oxidation in supercritical water.* Industrial & Engineering Chemistry Research, 1996. **35**(10): p. 3257-3279.

112. Demirbas, A., et al., *Supercritical and catalytic fluid extractions of tea wastes.* Fuel Science & Technology International, 1996. **14**(3): p. 395-404.

113. Wofford, W.T., P.C. Dellorco, and E.F. Gloyna, *Solubility of potassium hydroxide and potassium phosphate in supercritical water.* Journal of Chemical & Engineering Data, 1995. **40**(4): p. 968-973.

114. Savage, P.E., et al., *Reactions at Supercritical Conditions - Applications and Fundamentals.* Aiche Journal, 1995. **41**(7): p. 1723-1778.

115. Holgate, H.R., J.C. Meyer, and J.W. Tester, *Glucose hydrolysis and oxidation in supercritical water.* AICHE Journal, 1995. **41**(3): p. 637-648.

116. Goemans, M.G.E., L. Li, and E.F. Gloyna, *Separation of inorganic salts from supercritical water by cross-flow microfiltration.* Separation Science & Technology, 1995. **30**(7-9): p. 1491-1509.

117. Gloyna, E.F. and L.X. Li, *Supercritical water oxidation research and development update.* Environmental Progress, 1995. **14**(3): p. 182-192.

118. Gloyna, E.F., L. Li, and R.N. McBrayer, *Engineering aspects of supercritical water oxidation.* Water Science & Technology, 1994. **30**(9): p. 1-10.

119. Gao, J., *Simulation of the Na+CI- Ion Pair in Supercritical Water.* The Journal of Physical Chemistry, 1994. **98**(24): p. 5.

120. Gao, J.L. and X.F. Xia, *Simulating Solvent Effects on Reactivity and Interactions in Ambient and Supercritical Water*, in *Structure and Reactivity in Aqueous Solution*. 1994, AMER CHEMICAL SOC: Washington. p. 212-228.

121. Demirbas, A., *Chemicals from Forest Products by Efficient Extraction Methods.* Fuel Science & Technology International, 1994. **12**(3): p. 417-431.
122. Armellini, F.J., J.W. Tester, and G.T. Hong, *Precipitation of Sodium-Chloride and Sodium-Sulfate in Water from Sub- to Supercritical Conditions - 150 to 550-Degrees-C, 100 to 300 Bar.* Journal of Supercritical Fluids, 1994. **7**(3): p. 147-158.
123. Tester, J.W., et al., *Supercritical Water Oxidation Technology - Process-Development and Fundamental Research.* Acs Symposium Series, 1993. **518**: p. 35-76.
124. Armellini, F.J. and J.W. Tester, *Solubility of Sodium-Chloride and Sulfate in Subcritical and Supercritical Water-Vapor from 450-550-Degrees-C and 100-250 Bar.* Fluid Phase Equilibria, 1993. **84**: p. 123-142.
125. Hong, G.T., *Process for oxidation of materials in water at supercritical temperatures and subcritical pressures*. 1992, Modar, Inc: USA.
126. Barner, H.E., et al., *Supercritical Water Oxidation - an Emerging Technology.* Journal of Hazardous Materials, 1992. **31**(1): p. 1-17.
127. Armellini, F.J. and J.W. Tester, *Experimental methods for studing salt nucleation and growth from supercritical water.* Journal of Supercritical Fluids, 1991. **4**: p. 254-264.
128. Johnston, S.C., *Supercriittiicall Watter Oxiidattiion of Hazardous Wasttes*. 1990. p. 12.
129. Modell, M., *Processing methods for the oxidation of organics in supercritical water*. 1982, Modar, Inc: USA.
130. Spritzer, M.H., et al., *THERMAL DESORPTION-SUPERCRITICAL WATER OXIDATION OF ORGANICS IN TRANSURANIC MIXED WASTES.* p. 13.
131. Delville, M.H., et al., *Electrochemical study of corrosion in aqueous high pressure, high temperature media and measurements of materials corrosion rates: applications to the hydrothermal treatments of organic wastes by SCWO.* The Journal of Supercritical Fluids. **In Press, Corrected Proof**.
132. Botella, P., et al., *Experimental set-up for electrochemical measurements in hydrothermal sub- and supercritical oxidation: polarization curves, determination of corrosion rates and evaluation of the degradability of reactors during hydrothermal treatments of aqueous wastes.* The Journal of Supercritical Fluids. **In Press, Corrected Proof**.
133. Botella, P., et al., *Experimental study, via current-potential curves, of the anodic behavior of Alloy C-276 and T60 titanium in chlorinated and oxygenated aqueous media under sub- to supercritical conditions.* The Journal of Supercritical Fluids. **In Press, Corrected Proof**.

Digestion References

1. *Industry Directory for On-farm Biogas Recovery Systems*. 2003, US Environmental Protection Agency.
2. Yu, H.Q., et al., *Hydrogen production from rice winery wastewater in an upflow anaerobic reactor by using mixed anaerobic cultures.* International Journal of Hydrogen Energy, 2002. **27**(11-12): p. 1359-1365.
3. Vogt, G.M., et al., *Super blue box recycling (SUBBOR) enhanced two-stage anaerobic digestion process for recycling municipal solid waste: laboratory pilot studies.* Bioresource Technology, 2002. **85**(3): p. 291-299.
4. van Niel, E.W.J., et al., *Distinctive properties of high hydrogen producing extreme thermophiles, Caldicellulosiruptor saccharolyticus and Thermotoga elfii.* International Journal of Hydrogen Energy, 2002. **27**(11-12): p. 1391-1398.
5. Thierbach, R.D. and H. Hanssen, *Utilisation of energy from digester gas and sludge incineration at Hamburg's Kohlbrandhoft WWTP.* Water Science & Technology, 2002. **46**(4-5): p. 397-403.
6. Themelis, N.J., Y.H. Kim, and M.H. Brady, *Energy recovery from New York City municipal solid wastes.* Waste Management & Research, 2002. **20**(3): p. 223-233.
7. Themelis, N.J. and Y.H. Kim, *Material and energy balances in a large-scale aerobic bioconversion cell.* Waste Management & Research, 2002. **20**(3): p. 234-242.
8. Salminen, E. and J. Rintala, *Anaerobic digestion of organic solid poultry slaughterhouse waste - a review.* Bioresource Technology, 2002. **83**(1): p. 13-26.
9. Misi, S.N. and C.F. Forster, *Semi-continuous anaerobic co-digestion of agro-wastes.* Environmental Technology, 2002. **23**(4): p. 445-451.
10. Liu, H.W., et al., *Steam pressure disruption of municipal solid waste enhances anaerobic digestion kinetics and biogas yield.* Biotechnology and Bioengineering, 2002. **77**(2): p. 121-130.
11. Liang, T.M., S.S. Cheng, and K.L. Wu, *Behavioral study on hydrogen fermentation reactor installed with silicone rubber membrane.* International Journal of Hydrogen Energy, 2002. **27**(11-12): p. 1157-1165.
12. Lee, Y.J., T. Miyahara, and T. Noike, *Effect of pH on microbial hydrogen fermentation.* Journal of Chemical Technology and Biotechnology, 2002. **77**(6): p. 694-698.
13. Klinke, H.B., et al., *Characterization of degradation products from alkaline wet oxidation of wheat straw.* Bioresource Technology, 2002. **82**(1): p. 15-26.
14. Kim, K.-H. and M.-Y. Kim, *Mercury emissions as landfill gas from a large-scale abandoned landfill site in Seoul.* Atmospheric Environment, 2002. **36**(31): p. 4919-4928.
15. Kaparaju, P., et al., *Co-digestion of energy crops and industrial confectionery by- products with cow manure: batch-scale and farm-scale evaluation.* Water Science and Technology, 2002. **45**(10): p. 275-280.
16. Jansen, J.L., K. Jonsson, and M. Hagman, *Biological detoxification of tar-water.* Water Science & Technology, 2002. **46**(4-5): p. 59-65.
17. Hawkes, F.R., et al., *Sustainable fermentative hydrogen production: challenges for process optimisation.* International Journal of Hydrogen Energy, 2002. **27**(11-12): p. 1339-1347.
18. Guocheng, D. and Y. Jian, *Green Technology for Conversion of Food Scraps to Biodegradable Thermoplastic Polyhydroxyalkanoates.* Environ. Sci. Technol., 2002. **36**(24): p. 5511-5516.
19. Fang, H.H.P., T. Zhang, and H. Liu, *Microbial diversity of a mesophilic hydrogen-producing sludge.* Applied Microbiology and Biotechnology, 2002. **58**(1): p. 112-118.

20. Fang, H.H.P. and H. Liu, *Effect of pH on hydrogen production from glucose by a mixed culture.* Bioresource Technology, 2002. **82**(1): p. 87-93.
21. Cheng, S.S., S.M. Chang, and S.T. Chen, *Effects of volatile fatty acids on a thermophilic anaerobic hydrogen fermentation process degrading peptone.* Water Science and Technology, 2002. **46**(4-5): p. 209-214.
22. Chen, C.C., C.Y. Lin, and M.C. Lin, *Acid-base enrichment enhances anaerobic hydrogen production process.* Applied Microbiology and Biotechnology, 2002. **58**(2): p. 224-228.
23. Callaghan, F.J., et al., *Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure.* Biomass & Bioenergy, 2002. **22**(1): p. 71-77.
24. Andersson, J. and L. Bjornsson, *Evaluation of straw as a biofilm carrier in the methanogenic stage of two-stage anaerobic digestion of crop residues.* Bioresource Technology, 2002. **85**(1): p. 51-56.
25. Ahring, B.K., et al., *State of the art and future perspectives of thermophilic anaerobic digestion.* Water Science & Technology, 2002. **45**(10): p. 293-298.
26. van Lier, J.B., et al., *New perspectives in anaerobic digestion.* Water Science & Technology, 2001. **43**(1): p. 1-18.
27. Van Ginkel, S., S.W. Sung, and J.J. Lay, *Biohydrogen production as a function of pH and substrate concentration.* Environmental Science & Technology, 2001. **35**(24): p. 4726-4730.
28. Nielsen, A.T., et al., *Hydrogen production from organic waste.* International Journal of Hydrogen Energy, 2001. **26**(6): p. 547-550.
29. Misi, S.N. and C.F. Forster, *Batch co-digestion of two-component mixtures of agro-wastes.* Process Safety and Environmental Protection, 2001. **79**(B6): p. 365-371.
30. Lee, Y.J., T. Miyahara, and T. Noike, *Effect of iron concentration on hydrogen fermentation.* Bioresource Technology, 2001. **80**(3): p. 227-231.
31. Lay, J.J., *Biohydrogen generation by mesophilic anaerobic fermentation of microcrystalline cellulose.* Biotechnology and Bioengineering, 2001. **74**(4): p. 280-287.
32. Chen, C.C., C.Y. Lin, and J.S. Chang, *Kinetics of hydrogen production with continuous anaerobic cultures utilizing sucrose as the limiting substrate.* Applied Microbiology and Biotechnology, 2001. **57**(1-2): p. 56-64.
33. *Biogas and More, IEA Bioenergy.* 2001.
34. *Systems and Markets Overview of Anaerobic digestion*. 2001, IEA Bioenergy.
35. Mizuno, O., et al., *Enhancement of hydrogen production from glucose by nitrogen gas sparging.* Bioresource Technology, 2000. **73**(1): p. 59-65.
36. Mata-Alvarez, J., S. Mace, and P. Llabres, *Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives.* Bioresource Technology, 2000. **74**(1): p. 3-16.
37. Lay, J.J., *Modeling and optimization of anaerobic digested sludge converting starch to hydrogen.* Biotechnology and Bioengineering, 2000. **68**(3): p. 269-278.
38. Kubler, H., et al., *Full scale co-digestion of organic waste.* Water Science & Technology, 2000. **41**(3): p. 195-202.
39. Kheshgi, H.S., R.C. Prince, and G. Marland, *The potential of biomass fuels in the context of global climate change: Focus on transportation fuels.* Annual Review of Energy and the Environment, 2000. **25**: p. 199-244.
40. Flanagan, T., *Fertilizer Manufacturing Through Enhanced Autothermal Thermoplilic Aerobic Digestion (ATAD)*. 2000. p. 42.
41. De Baere, L., *Anaerobic digestion of solid waste: State-of-the-art.* Water Science and Technology, 2000. **41**(3): p. 283-290.

42. Clarkson, W.W. and W. Xiao, *Bench-scale anaerobic bioconversion of newsprint and office paper.* Water Science & Technology, 2000. **41**(3): p. 93-100.
43. Okamoto, M., et al. *Influence of moisture content on biological hydrogen potential of organic fraction of municipal solid wastes.* in *Proceedings of the Second International Symposium on Anaerobic Digestion of Solid Wastes*. 1999. Barcelona, Spain: Graphiques 92.
44. Lay, J.-J., Y.-J. Lee, and T. Noike, *Feasibility of biological hydrogen production from organic fraction of municipal solid waste.* Water Research, 1999. **33**(11): p. 2579-2586.
45. Kayhanian, M., *Ammonia inhibition in high-solids biogasification: An overview and practical solutions.* Environmental Technology, 1999. **20**(4): p. 355-365.
46. Ecke, H. and A. Lagerkvist, *Swedish city uses anaerobic technology.* Biocycle, 1999. **40**(6): p. 55-57.
47. *Review of Current Status of Anaerobic Digestion Technology for Treatment of Municipal Solid Waste.* 1998: p. 30.
48. Gunaseelan, V.N., *Anaerobic digestion of biomass for methane production: a review.* Biomass and Bioenergy, 1997. **13**(1-2): p. 83-114.
49. Kayhanian, M., *Biodegradability of the organic fraction of municipal solid waste in a high-solids anaerobic digester.* Waste Management & Research, 1995. **13**(2): p. 123-136.
50. Braber, K., *Anaerobic digestion of municipal solid waste: a modern waste disposal option on the verge of breakthrough.* Biomass and Bioenergy, 1995. **9**(1-5): p. 365-376.
51. Okeefe, D.M., et al., *Sequential Batch Anaerobic Composting of Municipal Solid Waste MSW and Yard Waste.* Water Science and Technology., 1993. **27**(2): p. 77-86.
52. Klasson, K., et al., *Bioconversion of synthesis gas into liquid or gaseous fuels.* Enzym. Microb. Technol., 1992. **4**(602-8).
53. Tong, X.G., L.H. Smith, and P.L. McCarty, *Methane Fermentation of Selected Lignocellulosic Materials.* Biomass, 1990. **21**(4): p. 239-255.
54. Tarman, *Hybrid bio-thermal gasification*. 1981.
55. Xu, Q., T. Townsend, and D. Chynoweth, *Anaerobic Digestion for Reduction and Stabilization of Organic Solid Waste During Space Missions: Systems Analysis*. p. 11.
56. Sosnowski, P., A. Wieczorek, and S. Ledakowicz, *Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes.* Advances in Environmental Research. **In Press, Uncorrected Proof**.
57. Jomaa, S., et al., *Hydrothermal decomposition and oxidation of the organic component of municipal and industrial waste products.* Advances in Environmental Research. **In Press, Uncorrected Proof**.
58. Eden, R. "THE GASIFICATION OF DOMESTIC WASTE FOR ENERGY RECOVERY AND WASTE MINIMISATION." Organics Ltd, The Barclay Centre, University of Warwick Science Park, Coventry, CV4 7EZ, United Kingdom.
59. Chen, C. C., and Lin, C. Y. (2003). "Using sucrose as a substrate in an anaerobic hydrogen-producing reactor." *Advances in Environmental Research*, 7(3), 695-699.

LCA References

1. Sonnemann, G.W., M. Schuhmacher, and F. Castells, *Uncertainty assessment by a Monte Carlo simulation in a life cycle inventory of electricity produced by a waste incinerator.* Journal of Cleaner Production, 2003. **11**(3): p. 279-292.
2. *Draft Technical Memorandum for the Conversion Technologies Life Cycle Assessment*. 2003, RTI International.
3. Wilson, E.J., *Life cycle inventory for Municipal Solid Waste management Part 2: MSW management scenarios and modeling.* Waste Management & Research, 2002. **20**(1): p. 23-36.
4. Wilson, E.J., *Life cycle inventory for municipal solid waste management.* Waste Management & Research, 2002. **20**(1): p. 16-22.
5. Weitz, K.A., et al., *The impact of municipal solid waste management on greenhouse gas emissions in the United States.* Journal of the Air & Waste Management Association, 2002. **52**(9): p. 1000-1011.
6. Twardowska, I. and J. Szczepanska, *Solid waste: terminological and long-term environmental risk assessment problems exemplified in a power plant fly ash study.* Science of the Total Environment, 2002. **285**(1-3): p. 29-51.
7. Solano, E., et al., *Life-cycle-based solid waste management. II: Illustrative applications.* Journal of Environmental Engineering-ASCE, 2002. **128**(10): p. 993-1005.
8. Solano, E., et al., *Life-cycle-based solid waste management. I: Model development.* Journal of Environmental Engineering-ASCE, 2002. **128**(10): p. 981-992.
9. Saouter, E. and G. van Hoof, *A database for the life-cycle assessment of Procter & Gamble laundry detergents.* International Journal of Life Cycle Assessment, 2002. **7**(2): p. 103-114.
10. Rechberger, H. and P.H. Brunner, *A new, entropy based method to support waste and resource management decisions.* Environmental Science & Technology, 2002. **36**(4): p. 809-816.
11. Peterson, P.J. and A. Granados, *Towards sets of hazardous waste indicators - Essential tools for modern industrial management.* Environmental Science & Pollution Research, 2002. **9**(3): p. 204-214.
12. Nakaniwa, C. and T.E. Graedel, *Life cycle and matrix analyses for re-refined oil in Japan.* International Journal of Life Cycle Assessment, 2002. **7**(2): p. 95-102.
13. Mersiowsky, N., *Long-term fate of PVC products and their additives in landfills.* Progress in Polymer Science, 2002. **27**(10): p. 2227-2277.
14. Jungmeier, G., et al., *Allocation in LCA of wood-based products - Experiences of Cost Action E9 Part I. Methodology.* International Journal of Life Cycle Assessment, 2002. **7**(5): p. 290-294.
15. James, K.L., T. Grant, and K. Sonneveld, *Stakeholder involvement in Australian paper and packaging waste management LCA study.* International Journal of Life Cycle Assessment, 2002. **7**(3): p. 151-157.
16. Hekkert, M.P., et al., *The impact of material efficient end-use technologies on paper use and carbon emissions.* Resources Conservation & Recycling, 2002. **36**(3): p. 241-266.
17. Hansen, Y., P.J. Notten, and G. Petrie, *A life cycle impact assessment indicator for ash management in coal-based power generation.* Journal of the South African Institute of Mining & Metallurgy, 2002. **102**(5): p. 299-306.
18. Guo, X.Y., et al., *LCA case study for lead and zinc production by an imperial smelting process in China - A brief presentation.* International Journal of Life Cycle Assessment, 2002. **7**(5): p. 276.

19. Gielen, D.J. and Y. Moriguchi, *Waste benefits of CO2 policies in Japan.* Waste Management & Research, 2002. **20**(1): p. 2-15.
20. Gielen, D.J. and Y. Moriguchi, *Modelling of materials policies.* Environmental Modeling & Assessment, 2002. **7**(4): p. 231-241.
21. Eriksson, O., et al., *ORWARE - a simulation tool for waste management.* Resources Conservation & Recycling, 2002. **36**(4): p. 287-307.
22. Eide, M.H., *Life Cycle Assessment (LCA) of industrial milk production.* International Journal of Life Cycle Assessment, 2002. **7**(2): p. 115-126.
23. Dewulf, J. and H. Van Langenhove, *Assessment of the sustainability of technology by means of a thermodynamically based life cycle analysis.* Environmental Science & Pollution Research, 2002. **9**(4): p. 267-273.
24. Cornelissen, R.L. and G.G. Hirs, *The value of the exergetic life cycle assessment besides the LCA.* Energy Conversion & Management, 2002. **43**(9-12 Special Issue SI): p. 1417-1424.
25. Ciroth, A., et al., *Geographical and technological differences in Life Cycle Inventories - Shown by the use of process models for waste incinerators Part I. Technological and geographical differences.* International Journal of Life Cycle Assessment, 2002. **7**(5): p. 295-300.
26. Ciroth, A., et al., *Geographical and technological differences in life cycle inventories - Shown by the use of process models for waste incinerators part II: Technological and geographical differences.* International Journal of Life Cycle Assessment, 2002. **7**(6): p. 363-368.
27. Caplan, A.J., T.C. Grijalva, and P.M. Jakus, *Waste not or want not? A contingent ranking analysis of curbside waste disposal options.* Ecological Economics, 2002. **43**(2-3): p. 185-197.
28. Canals, L.M., et al., *Use of life cycle assessment in the procedure for the establishment of environmental criteria in the catalan eco-label of leather.* International Journal of Life Cycle Assessment, 2002. **7**(1): p. 39-46.
29. Barton, J.R., A. Schneider, and J. Jager, *Role of LCA in the design of research and development (R&D) of novel processes subject to IPPC and BAT.* International Journal of Life Cycle Assessment, 2002. **7**(1): p. 11-17.
30. Anex, R.P. and W. Focht, *Public participation in life cycle assessment and risk assessment: A shared need.* Risk Analysis, 2002. **22**(5): p. 861-877.
31. *SOLID WASTE MANAGEMENT AND GREENHOUSE GASES A Life-Cycle Assessment of Emissions and Sinks*. 2002, EPA. p. 160.
32. Vogtlander, J.G., H.C. Brezet, and C.F. Hendriks, *Allocation in recycling systems - An integrated model for the analyses of environmental impact and market value.* International Journal of Life Cycle Assessment, 2001. **6**(6): p. 344-355.
33. van Beukering, P.J.H. and M.A. Janssen, *Trade and recycling of used tyres in Western and Eastern Europe.* Resources Conservation & Recycling, 2001. **33**(4): p. 235-265.
34. Persson, J.G., *Eco-indicators in product development.* Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture, 2001. **215**(5): p. 627-635.
35. Pennington, D.W. and J.C. Bare, *Comparison of chemical screening and ranking approaches: The waste minimization prioritization tool versus toxic equivalency potentials.* Risk Analysis, 2001. **21**(5): p. 897-912.
36. Mroueh, U.M., P. Eskola, and J. Laine-Ylijoki, *Life-cycle impacts of the use of industrial by-products in road and earth construction.* Waste Management, 2001. **21**(3): p. 271-277.
37. Khan, F.I., B.R. Natrajan, and P. Revathi, *GreenPro: a new methodology for cleaner and greener process design.* Journal of Loss Prevention in the Process Industries, 2001. **14**(4): p. 307-328.

38. John, V.M. and S.E. Zordan, *Research & development methodology for recycling residues as building materials - a proposal.* Waste Management, 2001. **21**(3): p. 213-219.
39. Hellweg, S., T.B. Hofstetter, and K. Hungerbuhler, *Modeling waste incineration for life-cycle inventory analysis in Switzerland.* Environmental Modeling & Assessment, 2001. **6**(4): p. 219-235.
40. Harrison, K.W., et al., *Decision support tool for life-cycle-based solid waste management.* Journal of Computing in Civil Engineering, 2001. **15**(1): p. 44-58.
41. Englande, A.J. and R.S. Reimers, *Biosolids management - sustainable development status and future direction.* Water Science & Technology, 2001. **44**(10): p. 41-46.
42. Braam, J., et al., *Energy, transport and waste models availability and quality of energy, transport and waste models and data.* International Journal of Life Cycle Assessment, 2001. **6**(3): p. 135-139.
43. Bjorklund, A., M. Melaina, and G. Keoleian, *Hydrogen as a transportation fuel produced from thermal gasification of municipal solid waste: an examination of two integrated technologies.* International Journal of Hydrogen Energy, 2001. **26**(11): p. 1209-1221.
44. Beccali, G., M. Cellura, and M. Mistretta, *Managing municipal solid waste - Energetic and environmental comparison among different management options.* International Journal of Life Cycle Assessment, 2001. **6**(4): p. 243-249.
45. Viklund-White, C., *The use of LCA for the environmental evaluation of the recycling of galvanised steel.* ISIJ International, 2000. **40**(3): p. 292-299.
46. Subramanian, P.M., *Plastics recycling and waste management in the US.* Resources Conservation & Recycling, 2000. **28**(3-4): p. 253-263.
47. Sonesson, U., et al., *Environmental and economic analysis of management systems for biodegradable waste.* Resources Conservation & Recycling, 2000. **28**(1-2): p. 29-53.
48. Petts, J., *Municipal waste management: Inequities and the role of deliberation.* Risk Analysis, 2000. **20**(6): p. 821-832.
49. McDougall, F.R. and J.P. Hruska, *Report: the use of Life Cycle Inventory tools to support an integrated approach to solid waste management.* Waste Management & Research, 2000. **18**(6): p. 590-594.
50. Ekvall, T. and G. Finnveden, *The application of life cycle assessment to integrated solid waste management. Part 2 - Perspectives on energy and material recovery from paper.* Process Safety & Environmental Protection, 2000. **78**(B4): p. 288-294.
51. Ekvall, T., *A market-based approach to allocation at open-loop recycling.* Resources Conservation & Recycling, 2000. **29**(1-2): p. 91-109.
52. Curlee, T.R. and K.L. Yuracko, *The use of life cycle analysis within the US. Department of Energy.* Environmental Progress, 2000. **19**(2): p. 117-123.
53. Clift, R., A. Doig, and G. Finnveden, *The application of Life Cycle Assessment to Integrated Solid Waste Management - Part 1 - Methodology.* Process Safety & Environmental Protection, 2000. **78**(B4): p. 279-287.
54. Beaver, E., *LCA and Total Cost Assessment.* Environmental Progress, 2000. **19**(2): p. 130-139.
55. Barton, P.K., D.N. Bird, and J.W. Atwater, *Composting: An action that reduces greenhouse gas emissions?* Proceedings Of The International Composting Symposium, 2000. **1**(2): p. 579-611.
56. Amos, W.A., M.K. Mann, and P.L. Spath, *Process Analysis Work For The DOE Hydrogen Program - 2000*. 2000. p. 11.

57. Song, H.S., K.S. Moon, and J.C. Hyun, *A life-cycle assessment (LCA) study on the various recycle routes of PET bottles.* Korean Journal of Chemical Engineering, 1999. **16**(2): p. 202-207.
58. Song, H.S. and J.C. Hyun, *A study on the comparison of the various waste management scenarios for PET bottles using the life-cycle assessment (LCA) methodology.* Resources Conservation & Recycling, 1999. **27**(3): p. 267-284.
59. Ong, S.K., T.H. Koh, and A.Y.C. Nee, *Development of a semi-quantitative pre-LCA tool.* Journal of Materials Processing Technology, 1999. **90**(Special Issue SI): p. 574-582.
60. Maltbaek, C.S., *MRFs and municipal waste - bold success or heroic failure?* Proceedings of the Institution of Civil Engineers-Municipal Engineer, 1999. **133**(1): p. 19-24.
61. Heyde, M., W. Holley, and M. Kremer, *Recycling and Recovery of Plastics from Packagings in Domestic Waste: LCA-Type Analysis of Different Strategies*. 1999, Fraunhofer Institut Verfahrenstechnik und Verpackung: Freising, Germany. p. 424.
62. Granados, A.J. and P.J. Peterson, *Hazardous waste indicators for national decision makers.* Journal of Environmental Management, 1999. **55**(4): p. 249-263.
63. Finnveden, G., *Methodological aspects of life cycle assessment of integrated solid waste management systems.* Resources Conservation & Recycling, 1999. **26**(3-4): p. 173-187.
64. Edwards, D.W. and J. Schelling, *Municipal waste life cycle assessment - Part 2: Transport analysis and glass case study.* Process Safety & Environmental Protection, 1999. **77**(B5): p. 259-274.
65. Camobreco, V., et al., *Life-cycle inventory of a modern municipal solid waste landfill.* Waste Management & Research, 1999. **17**(6): p. 394-408.
66. Steele, N.L.C. and D.T. Allen, *Life-cycle assessment - an abridged life-cycle assessment of electric vehicle batteries.* Environmental Science & Technology, 1998. **32**(1): p. A 40-A 46.
67. Schroeter, J., *Creating the framework for a widespread use of biodegradable polymers (standardization, labelling, legislation, biowaste management).* Polymer Degradation & Stability, 1998. **59**(1-3 Special Issue SI): p. 377-381.
68. Riva, A., L. Morselli, and M. Furini, *LCA and LCI for the management of municipal solid waste (MSW).* Annali di Chimica, 1998. **88**(11-12): p. 915-924.
69. Reuter, M.A., *The simulation of industrial ecosystems.* Minerals Engineering, 1998. **11**(10): p. 891-918.
70. Heyde, M., *Ecological considerations on the use and production of biosynthetic and synthetic biodegradable polymers.* Polymer Degradation & Stability, 1998. **59**(1-3 Special Issue SI): p. 3-6.
71. Finnveden, G. and T. Ekvall, *Life-cycle assessment as a decision-support tool - the case of recycling versus incineration of paper.* Resources Conservation & Recycling, 1998. **24**(3-4): p. 235-256.
72. Edwards, C.A., J. Dominguez, and E.F. Neuhauser, *Growth and reproduction of perionyx excavatus (perr.) (megascolecidae) as factors in organic waste management.* Biology & Fertility of Soils, 1998. **27**(2): p. 155-161.
73. Dalemo, M., et al., *Effects of including nitrogen emissions from soil in environmental systems analysis of waste management strategies.* Resources Conservation & Recycling, 1998. **24**(3-4): p. 363-381.
74. Clift, R., *Engineering for the environment - the new model engineer and her role.* Process Safety & Environmental Protection, 1998. **76**(B2): p. 151-160.
75. Chubbs, S.T. and B.A. Steiner, *Life cycle assessment in the steel industry.* Environmental Progress, 1998. **17**(2): p. 92-95.

76. Ayres, R.U., L.W. Ayres, and K. Martinas, *Exergy, waste accounting, and life-cycle analysis.* Energy, 1998. **23**(5): p. 355-363.
77. Otoma, S., et al., *Estimation of energy recovery and reduction of co2 emissions in municipal solid waste power generation.* Resources Conservation & Recycling, 1997. **20**(2): p. 95-117.
78. Morselli, L. and E. Sbaffi, *Environmental control in municipal solid waste incineration - a survey of the plants operating in the emilia-romagna region.* Annali di Chimica, 1997. **87**(11-12): p. 721-731.
79. McLeod, C.A., M. Terazawa, and E. Yamamura, *Using geographical information systems to evaluate decentralized management of municipal food waste.* Compost Science & Utilization, 1997. **5**(1): p. 49-61.
80. Klopffer, W., *Life cycle assessment - from the beginning to the current state.* Environmental Science & Pollution Research, 1997. **4**(4): p. 223-228.
81. Zeininger, H., et al., *Eco-compass - the comprehensive life cycle assessment tool.* Siemens Review, 1996(Special Issue SI): p. 8-10.
82. Ryynanen, H. and P.J. Nelson, *Environmental life cycle assessment of some new methods for producing bleached pulps from australian eucalypt woods.* Appita Journal, 1996. **49**(3): p. 167-172.
83. Platzer, E., U. Hamm, and L. Gottsching, *Life cycle assessment - it is possible to allocate environmental burdens fairly to the paper chain.* Papier, 1996. **50**(10A Suppl S): p. V 63-V 70.
84. Kavanaugh, M.C., *An overview of the management of contaminated sites in the us - the conflict between technology and public policy.* Water Science & Technology, 1996. **34**(7-8): p. 275-283.
85. Edwards, D.W. and J. Schelling, *Municipal waste life cycle assessment .1. and aluminium case study.* Process Safety & Environmental Protection, 1996. **74**(B3): p. 205-222.
86. Denison, R.A., *Environmental life-cycle comparisons of recycling, landfilling, and incineration - a review of recent studies.* Annual Review of Energy & the Environment, 1996. **21**: p. 191-237.
87. Barton, J.R., D. Dalley, and V.S. Patel, *Life cycle assessment for waste management.* Waste Management, 1996. **16**(1-3): p. 35-50.
88. Bailey, P.E., *Valuing Potential Environmental Liabilities for Managerial Decision-Making: A Review of Available Techniques*. 1996, EPA. p. 122.
89. Hunt, R.G., *Lca considerations of solid waste management alternatives for paper and plastics.* Resources Conservation & Recycling, 1995. **14**(3-4): p. 225-231.
90. Heinen, J.T., *A review of, and research suggestions for, solid-waste management issues - the predicted role of incentives in promoting conservation behaviour.* Environmental Conservation, 1995. **22**(2): p. 157-166.
91. Ayres, R.U., *Life cycle analysis - a critique.* Resources Conservation & Recycling, 1995. **14**(3-4): p. 199-223.
92. Young, S.B. and W.H. Vanderburg, *Applying environmental life-cycle analysis to materials.* JOM-Journal of the Minerals Metals & Materials Society, 1994. **46**(4): p. 22-27.
93. Sundberg, J. and C.O. Wene, *Integrated modelling of material flows and energy systems (mimes).* International Journal of Energy Research, 1994. **18**(3): p. 359-381.
94. Karna, A., J. Engstrom, and T. Kutinlahti, *Recycling life cycle analysis of newsprint - a european view - it may be best to use onp for energy recovery.* Pulp & Paper-Canada, 1994. **95**(11): p. 38-45.

95. Hirsinger, F. and J. Knaut, *Life cycle analysis (lca) of renewable raw materials using palm oil as an example.* Fett Wissenschaft Technologie-Fat Science Technology, 1994. **96**(9): p. 333-340.
96. Bridges, J.S., *Us epas pollution prevention rd-and-d results - practical tools for the trade.* Water Science & Technology, 1994. **29**(8): p. 193-200.
97. Wrisberg, N., et al., *LCANET, European Network for Strategic Life-Cycle Assessment Research and Development*, Leiden University: Leiden, The Netherlands. p. 200.

CO_2 and other GHG References

1. Lima, A.L.C., T.I. Eglinton, and C.M. Reddy, *High-Resolution Record of Pyrogenic Polycyclic Aromatic Hydrocarbon Deposition during the 20th Century.* Environ. Sci. Technol., 2003. **37**(1): p. 53-61.
2. Miranda, M.L. and B.H. Hale, *A Taxing Environment: Evaluating the Multiple Objectives of Environmental Taxes.* Environ. Sci. Technol., 2002. **36**(24): p. 5289-5295.
3. Marrero, I.O., et al., *Second law analysis and optimization of a combined triple power cycle.* Energy Conversion and Management, 2002. **43**(4): p. 557-573.
4. Hoffert, M.I., et al., *Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet.* Science, 2002. **298**(5595): p. 981-987.
5. Heiskanen, E., *The institutional logic of life cycle thinking.* Journal of Cleaner Production, 2002. **10**(5): p. 427-437.
6. Metzger, R.A. and G. Benford, *Sequestering of Atmospheric Carbon through Permanent Disposal of Crop Residue.* Climatic Change, 2001. **49**(1-2): p. 11-19.
7. Marxsen, C.S., *Potential world garbage and waste carbon sequestration.* Environmental Science & Policy, 2001. **4**(6): p. 293-300.
8. Marland, G., K. Fruit, and R. Sedjo, *Accounting for sequestered carbon: the question of permanence.* Environmental Science & Policy, 2001. **4**(6): p. 259-268.
9. Kheshgi, H.S., R.C. Prince, and G. Marland, *The potential of biomass fuels in the context of global climate change: Focus on transportation fuels.* Annual Review of Energy & the Environment, 2000. **25**: p. 199-244.
10. Huber, P.W., *Hard Green: Saving the Environment from the Environmentalists: a Conservative Manifesto*. 1999, New York: Basic Books.
11. Andres, R.J., et al., *Carbon dioxide emissions from fossil-fuel use, 1751-1950.* Tellus Series B-Chemical & Physical Meteorology, 1999. **51**(4): p. 759-765.

Hydrogen References

1. Cortright, R.D., R.R. Davda, and J.A. Dumesic, *Hydrogen from catalytic reforming of biomass-derived hydrocarbons in liquid water*, in *Nature*. 2002. p. 964-967.
2. Chornet, E. and S. Czernik, *Renewable fuels: Harnessing hydrogen*, in *Nature*. 2002. p. 928-929.
3. Suppes, G.J., S. Roy, and J. Ruckman, *Impact of Common Salts on Oxidation of Alcohols and Chlorinated Hydrocarbons.* AIChE Journal, 2001. **47**(7): p. 1623-1631.
4. Norbeck, J.M. and K. Johnson, *Evaluation of a Process to Convert Biomass to Methanol Fuel*. 2000, CE-CERT: Riverside. p. 62.
5. *USDOE Hydrogen Program - Summary of analysis projects 1994-2000*. 2000, USDOE. p. 205.
6. Skolni, E.G., J.P. DiPietro, and Z.U. Haq, *Technical Assessment and Analysis of Hydrogen R & D Projects*. 1999. p. 17.
7. Padro, C.E.G. and V. Putsche, *Survey of the Economics of Hydrogen Technologies*. 1999, NREL. p. 57.
8. Dufaud, V. and J. Basset, *Catalytic Hydrogenolysis at Low Temperatureand Pressure of Polyethylene and Polypropylene to Diesels or Lower Alkanes by a Zirconium Hydride Supported on Silica-Alumina: A Step Toward Polyolefin Degradation by the Microscopic Reverse of Ziegler - Natta Polymerization.* Angew. Chem, Int. Ed., 1998. **37**(6): p. 806-810.
9. Dong, Y.J. and R.H. Borgwardt, *Biomass reactivity in gasification by the hynol process.* Energy & Fuels, 1998. **12**(3): p. 479-484.
10. Dong, Y.J. and M. Steinberg, *Hynol - an economical process for methanol production from biomass and natural gas with reduced co2 emission.* International Journal of Hydrogen Energy, 1997. **22**(10-11): p. 971-977.

Patent References

1. Winter, J.D. and G.N. Richter, *Gasification of Biosludge*. 2002, US Patent 6,436,157. Texaco Inc.: USA.
2. Ruegg, H., et al., *PROCESS FOR MELTING ASHES, SLAGS OR GLASS*. 2002, US Patent 6432162. Asea Brown Boveri AG.
3. Pope, L.B. and M.L. Murphy, *Biomass gasifier apparatus and method*. 2002, Patent Application No. 20020112403. Energy Products of Idaho: USA.
4. Pope, G.M., *ORGANIC WASTE GASIFICATION PROCESSING AND THE PRODUCTION OF ALTERNATIVE ENERGY SOURCES*. 2002, US Patent 6439135. International Environmental Technologies Inc.
5. *Patent Report.* Fuel Processing Technology, 2002. **80**(2): p. 195-205.
6. Womack, R.K., *Using the Centrifugal Method for the Plasma-Arc Vitrification of Waste.* Jom, 1999. **51**(10): p. 14-16.
7. . 1998, Patent No. 5746926.
8. Weston, R., *On-Site Thermal Desorption of PCP-And Dioxin-Contaminated Soil at The Coleman-Evans Wood Preserving Site, WhiteHouse, FL, USA*.

Appendix 5

Other thermochemical process definitions identified in literature

Other thermochemical process definitions

There is ongoing debate and misunderstanding or misuse of certain terms relating to waste conversion among members of the industry, government, environmental groups, and the general public. For example, the chaptered version of AB 2270 contains a definition of gasification that is unnecessarily limiting.

From the chaptered AB2770,

> `SECTION 1. Section 40117 is added to the Public Resources Code, to read:`
> `40117. "Gasification" means a technology that uses a noncombustion thermal process to convert solid waste to a clean burning fuel for the purpose of generating electricity, and that, at minimum, meets all of the following criteria:`
>
> `(a) The technology does not use air or oxygen in the conversion process, except ambient air to maintain temperature control.`
> `(b) The technology produces no discharges of air contaminants or emissions, including greenhouse gases, as defined in subdivision (g) of Section 42801.1 of the Health and Safety Code.`
> `(c) The technology produces no discharges to surface or groundwaters of the state.`
> `(d) The technology produces no hazardous waste.`

The subsection (a) referring to using no air or oxygen in the conversion process except to allow 'ambient' air for temperature control precludes virtually all actual gasification processes if strictly interpreted. It is unclear why ambient air is allowed, but heated air is not (heating the input oxidant stream from waste heat elsewhere in the process is a common method used to improve overall energy conversion efficiency). Also, this limits processes that utilize oxygen or other oxygen containing synthetic gases instead of air (which may be more efficient and economic because of reduced gas flow, reactor size, and perhaps NOx emissions from follow-on processes). Most gasifiers use air, steam or pure oxygen (or a combination) in the process of converting MSW and delivering the fuel gas to a suitable follow-on conversion system for power production. The State needs to examine whether regulation of technology using what appear to be mostly uninformed definitions is a preferred approach compared to setting performance-based standards without restricting technology development by class.

A brief review of the literature was done to find other views and descriptions of thermochemical conversion terms (specifically gasification, with some combustion or pyrolysis descriptions included). This is not an exhaustive search but serves to show a number of descriptions or definitions some of which are alike, and others which are quite specific because of the nature of the feedstock.

The definitions, descriptions, or viewpoints fall within one of three sections. The first two sections emphasize gasification and the third addresses the term 'incineration'.

I. General Gasification

In these general definitions of gasification, the descriptions are independent of feedstock (except that they are carbon containing), and have no limiting process conditions or oxidants.. All (non-mineral) components of the typical MSW stream would be able to be converted using processes that fall under these definitions.

II. Conditional /limiting Gasification

These are definitions derived from hazardous waste processing or the petrochemical and coal industries. Process conditions (pressure, temperature) are specified and many times the oxidant is limited (oxygen or steam only, for instance). These definitions would over-specify process conditions for converting MSW, and thus unnecessarily limit the number of acceptable processes.

III. ‘Incineration’

Two entries that deal with the word incineration are included.

The citations appear at the end of this appendix.

Section I. General Gasification Definitions

From(Bridgwater 1984)[57],

Gasification

-Energy is provided internally by exothermic reaction of part of the feed

Oxygen supplies the oxidizing environment, thus

Air **gasification** – air burns part of the feed to generate heat to gasify/pyrolyze the rest. The product contains up to 60% nitrogen. Suitable for fuel gas or ammonia synthesis, but requires complex processing to remove nitrogen for production of a carbon based chemical.

Oxygen **gasification** – air separation plant required to remove nitrogen from oxidizer (yields essentially nitrogen free product). Higher temperatures are encountered requiring better control, and higher safety standards with pure oxygen. Product is more suitable for carbon based chemical or fuels such as methanol.

Steam **gasification** – Sometimes considered as a distinct category with energy supplied by a steam reforming reaction which is only exothermic at high pressures, typically above 7 bar. Common to add steam as a thermal moderator and/or reagent in oxygen gasification.

-Relatively high temperatures can be produced

-Usually all the carbon is converted to gaseous form leaving only an inert residue.

Pyrolysis

-Energy is provided externally

-Relatively low temperatures are produced

-relatively low gas yields are obtained with high liquid yields and carbonaceous residues

Liquefaction

-energy is provided externally

-Relatively low temperatures but high pressures are used

-Relatively high yields of liquids are obtained

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[57] Bridgwater is a long time and well respected researcher in thermochemical conversion of biomass. He runs the European based Gasnet and Pyne (gasification and pyrolysis interest networks). Aston University, UK.

From a paper by (Jaeger and Mayer 2000) on the Noell gasifier and conversion process utilizing sewage sludge is this straightforward definition (which, however, is not generally thermodynamically realizable),

> *The term "**gasification**" is understood in theory as the conversion of every carbon atom in the fuel to CO. In contrast, with incineration processes theoretically every carbon atom is converted to CO2. Some basic chemical reactions for the gasification of carbon are as follows:*
>
> *C+O2=CO2 Combustion Reaction (1)*
> *C+CO2=2 CO Boudouard Reaction (2)*
> *C+H2O=CO2+2 H2 heterogeneous Water Gas Reaction (3)*

From a US DOE report by (Ciferno and Marano 2002),

> *Biomass **gasification** is the conversion of an organically derived, carbonaceous feedstock by partial oxidation into a gaseous product, synthesis gas or "syngas," consisting primarily of hydrogen (H_2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO_2), water (H_2O), methane (CH_4), higher hydrocarbons (C_2+), and nitrogen (N_2). The reactions are carried out at elevated temperatures, 500-1400°C, and atmospheric or elevated pressures up to 33 bar (480 psia). The oxidant used can be air, pure oxygen, steam or a mixture of these gases. Air-based gasifiers typically produce a product gas containing a relatively high concentration of nitrogen with a low heating value between 4 and 6 MJ/m^3 (107-161 Btu/ft^3). Oxygen and steam-based gasifiers produce a product gas containing a relatively high concentration of hydrogen and CO with a heating value between 10 and 20 MJ/m^3 (268-537 Btu/ft^3).*

This is a general definition with no restriction on operating temperature or pressure or type of oxidant used for heat generation by partial oxidation.

The National Renewable Energy Laboratory (NREL) makes a reference to gasification[58],

> ***Gasification** is the thermal conversion of solid organic material to a mixture of gases (CO, H2, CO2, CH4), organic vapors, water vapor, and residual solids. Gasification of biomass takes place at elevated temperature, 700-850℃, in an atmosphere of steam or air (or both).*

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[58] http://www.nrel.gov/chemistry_bioenergy/bgcc.html

From the USDOE Energy Efficiency and Renewable Energy Glossary,[59]

> ***Gasification*** *- The process in which a solid fuel is converted into a gas; also known as pyrolitic distillation or pyrolysis.*
>
> ***Pyrolysis*** *- The transformation on a compound or material into one or more substances by heat alone (without oxidation). Often called destructive distillation. Pyrolysis of biomass is the thermal degradation of the material in the absence of reacting gases, and occurs prior to or simultaneously with gasification reactions in a gasifier. Pyrolysis products consist of gases, liquids, and char generally. The liquid fraction of pyrolisized biomass consists of an insoluble viscous tar, and pyroligneous acids (acetic acid, methanol, acetone, esters, aldehydes, and furfural). The distribution of pyrolysis products varies depending on the feedstock composition, heating rate, temperature, and pressure.*

Energy Information Administration (EIA)[60]

> ***Gasification:*** *A method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels.*
>
> ***Pyrolysis:*** *The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.*

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[59] http://www.eere.energy.gov/consumerinfo/glossary.html

[60] http://www.eia.doe.gov/glossary/glossary_g.htm

Section II Conditional /limiting Gasification Definitions

The EPA on regulation of hazardous waste from petroleum refineries is proposing a change in regulations[61] which includes a definition of gasification for purposes of this rule and certain hazardous feedstocks;

```
[Federal Register: March 25, 2002 (Volume 67, Number 57)]
[Proposed Rules]
[Page 13683-13700]
From the Federal Register Online via GPO Access [wais.access.gpo.gov]
[DOCID:fr25mr02-21]

-----------------------------------------------------------------------

        ENVIRONMENTAL PROTECTION AGENCY
        40 CFR Parts 260 and 261
        [FRL-7162-8]
        RIN 2050-AE78

        Regulation of Hazardous Oil-Bearing Secondary Materials From the
        Petroleum Refining Industry and Other Hazardous Secondary Materials
        Processed in a Gasification System To Produce Synthesis Gas

        AGENCY: Environmental Protection Agency (EPA).
        ACTION: Proposed rule.
```

> **Gasification** system means an enclosed thermal device and associated gas cleaning system or systems that does not meet the definition of an incinerator or industrial furnace (found at Secs. 260.10), and that: (1) Limits oxygen concentrations in the enclosed thermal device to prevent the full oxidization of thermally disassociated gaseous compounds; (2) utilizes a gas cleanup system or systems designed to remove contaminants from the partially oxidized gas that do not contribute to its fuel value; (3) slags inorganic feed materials at temperatures above 2000; deg. F; (4) produces a synthesis gas; and (5) is equipped with monitoring devices that ensure the quality of the synthesis gas produced by the gasification system.

The EPA rule is driven by the desire of petroleum refineries to be able to process oil bearing secondary (or waste) materials by gasification. Impediments now are due to classification of these feedstocks as hazardous wastes from the initial refinery processes which require special handling and processing requirements. By submitting petroleum refinery and other hazardous wastes to the restrictive gasification process described in the proposed rule, it is claimed that the materials should be considered non-hazardous and regulated as such. The EPA definition of gasification system requires that it operate above 2000 ºF in order to melt (slag) the inorganic, or ash, portion of the feedstock. This is a highly restrictive and specific definition that should be limited to hazardous waste material destruction or conversion and not allowed to define general solids or liquid conversion to a gas.

The DOE/NETL (National Energy Technology Laboratory) is a national laboratory funded and operated by the Department of Energy. Other DOE national laboratories are operated by contractors (University of California, Lockheed Martin, Batelle, Midwest Reserch Institute, Bechtel, Iowa State, etc.). NETL's primary mission is "to assure that **U.S. fossil energy** resources can meet increasing

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[61] http://www.epa.gov/fedrgstr/EPA-WASTE/2002/March/Day-25/f7097.htm

demand for affordable energy without compromising the quality of life for future generations of Americans".

The Gasification Technologies section of NETL is in the Coal Energy branch. The description of the gasification process used by NETL[62] is essentially the same as that found on the Gasification Technologies Council (GTC) website[63] both of which appear below:

NETL definition:

> ***Gasifiers*** *convert carbonaceous feedstock into gaseous products at high temperature and elevated pressure in the presence of oxygen and steam. Partial oxidation of the feedstock provides the heat. At operating conditions, chemical reactions occur that produce synthesis gas or "syngas," a mixture of predominantly CO and* H_2.

The Gasification Technologies Council definition:

> ***Gasification*** *technologies differ in many aspects but share certain general production characteristics. Typical raw materials used in* ***gasification*** *are coal, petroleum based materials (crude oil, high sulfur fuel oil, petroleum coke, and other refinery residuals), gases, or materials that would otherwise be disposed of as waste. The feedstock reacts in the* ***gasifier*** *with steam and oxygen at high temperature and pressure in a reducing (oxygen starved) atmosphere. This produces the synthesis gas, or syngas, made up primarily of carbon monoxide and hydrogen (more than 85% by volume) and smaller quantities of carbon dioxide and methane.*
>
> *The high temperature in the* ***gasifier*** *converts the inorganic materials in the feedstock (such as ash and metals) into a vitrified material resembling coarse sand. With some feedstocks, valuable metals are concentrated and recovered for reuse. The vitrified material, generally referred to as slag, is inert and has a variety of uses in the construction and building industries.*

This description/definition includes high pressure as a condition and temperature high enough to slag and vitrify the inorganic material. The typical feedstocks mentioned are coal and petroleum refinery wastes which are more specific than the general carbon containing feedstock. Also, it is implied that (added) steam is a necessary reactant which is not true for a general description/definition of gasification. The NETL/GTC gasification definition is very specific and would be inappropriate for use as a general gasification description for use in MSW conversion regulations.

From a report by SAIC for the US DOE/NETL (Ratafia-Brown, et al. 2002), which discusses environmental aspects of gasification-based power generation is this description of a gasifier,

> *The* ***gasifier*** *converts carbonaceous feedstock into gaseous products at high temperature and (usually) elevated pressure in the presence of oxygen and steam. Partial oxidation of the*

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[62] http://www.netl.doe.gov/coalpower/gasification/description/gasifiers.html
[63] http://www.gasification.org/

> *feedstock in a reducing (oxygen starved) atmosphere provides the heat. A syngas is produced composed primarily of CO and* H_2

This report was sponsored by the Gasification Technologies Program at NETL and the Gasification Technologies Council. It is nearly identical to the description by NETL.

Section III Incineration

The term 'incineration' in the US is commonly used to mean 'burning of waste' (combustion of waste). The dictionary defines it as "causing to burn to ashes, to burn completely." (American Heritage Dictionary, 2000). Were this definition to strictly apply, there would be less controversy associated with the use of incineration, as complete burning would produce fewer emissions of concern.

The European Community lumps all thermal conversion technologies that utilize MSW and certain classes of other wastes under the heading of incineration (thermal treatment of wastes). EC Directive 2000/76/EC[64] contains this paragraph;

> *Article 3, paragraph. 4*
> *'incineration plant' means any stationary or mobile technical unit and equipment dedicated to the thermal treatment of wastes with or without recovery of the combustion heat generated. This includes the incineration by oxidation of waste as well as other thermal treatment processes such as pyrolysis, gasification or plasma processes in so far as the substances resulting from the treatment are subsequently incinerated.*

The Directive is technology neutral and instead sets detailed limits and allowable characterizations of the emissions and residues from thermal treatment or conversion plants.

From Global Anti-Incinerator Alliance (GAIA) recent publication, (Tangri 2003)

> *This report defines the term "incinerator" broadly. By our definition, an incinerator is any machine or device built or used for the purpose of burning waste. ... Our discussion of incineration will cover municipal, medical and hazardous waste burners, as well as cement kilns that burn hazardous waste, pyrolysis and gasification devices, and related technologies.*

GAIA is a group opposed to thermal conversion of MSW and promotes 'zero waste' and biochemical conversion.

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[64] Available at http://europa.eu.int/comm/environment/wasteinc/newdir/2000-76_en.pdf

References for Appendix 5

(2000). The American Heritage Dictionary of the English Laguage, Fourth Edition, Houghton Mifflin Company

Bridgwater, A. V. (1984). The Thermochemical Processing System. Thermochemical Processing of Biomass. A. V. Bridgwater. London, Butterworths**:** 35-52.

Ciferno, J. P. and J. J. Marano (2002). Benchmarking Biomass Gasification Technologies for Fuels, Chemicals and Hydrogen Production, DOE- NETL**:** 65.

DIRECTIVE 2000/76/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (4 December 2000) on the incineration of waste. Official Journal of the European Communities http://europa.eu.int/comm/environment/wasteinc/newdir/2000-76_en.pdf

Jaeger, M. and M. Mayer (2000). "The Noell Conversion Process – a gasification process for the pollutant-free disposal of sewage sludge and the recovery of energy and materials." Water Science & Technology **41**(8): 37-44.

Ratafia-Brown, J., L. Manfredo, et al. (2002). Major Environmental Aspects of Gasification-Based Power Generation Technologies - Final Report, DOE/NETL, SAIC**:** 270.

Tangri, N. (2003). Waste Incineration: A dying technology. Berkeley, CA, Global Anti-Incinerator Alliance**:** 107.

Appendix 6 Database Printout

The database is available through the internet at

http://cbc1.engr.ucdavis.edu/conv/home.htm

and can be accessed and viewed interactively or downloaded as Microsoft Excel® or Microsoft Access® files.