Report

Alternative Technologies for Municipal Solid Waste

Project I.D.: 13R003-00

Prepared for
Ramsey Washington County Resource Recovery Project

July 2013

RAMSEY/WASHINGTON COUNTY
RESOURCE RECOVERY PROJECT
RAMSEY AND WASHINGTON COUNTIES, MINNESOTA

Foth

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July 15, 2013

Zack Hansen
Judy Hunter
Ramsey Washington County Resource Recovery Project
2785 White Bear Ave N
Maplewood, MN 55109

Dear Zack and Judy:

RE: Alternative Technologies for Municipal Solid Waste

Foth Infrastructure & Environment, LLC (Foth) is pleased to provide this Alternative Technologies for Municipal Solid Waste report for your consideration. Foth has completed up-to-date research on gasification, pyrolysis, plasma arc, mass burn, anaerobic digestion, mixed waste processing, and plastics to fuel to provide the current status of the technology and its likely applicability to the waste stream in Ramsey and Washington Counties.

We look forward to presenting this report at the Project Board meeting, as well as any follow up discussions.

Sincerely,

Foth Infrastructure & Environment, LLC

Warren Shuros
Client Director

Curt Hartog, P.E.
Technical Director

Ramsey Washington County Resource Recovery Project
Alternative Technologies for Municipal Solid Waste

Distribution

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Executive Summary

The Ramsey/Washington County Resource Recovery Project Board (Board) has a service agreement with Resource Recovery Technologies, LLC (RRT) to process solid waste from the two counties at the Newport Resource Recovery Facility (Facility). The Facility began processing solid waste into refuse-derived fuel (RDF) in 1987 under different ownership. The current service agreement extends until the end of 2015. The Solid Waste Master Plans for Ramsey and Washington Counties (R/W Counties) each include a processing policy for solid waste as follows:

> *"Consistent with the State hierarchy, Ramsey and Washington County affirms processing of waste, for the purpose of recovering energy and recyclables and other beneficially useful materials, as the preferred MSW and non-MSW management method over landfilling for waste that is not reduced, reused, or separately recycled or composted. This policy applies both to waste generated throughout the county and specifically to MSW generated by public entities including contracts for organized collection of solid waste. Pursuant to State law, public entities in Ramsey County will assure that MSW that they generate or contract for is processed rather than land disposed."*

As part of the preliminary planning process for waste management options after the end of the current processing agreement, the Board is conducting a number of evaluations of the existing Facility and alternative technologies. This report provides a review of the current status and application of the following technologies to R/W Counties:

- Gasification – A thermal process that converts solid waste to a synthetic gas (syngas), using limited amounts of air or oxygen.
- Pyrolysis – A thermal process that breaks down solid waste without air or oxygen and uses heat to produce syngas.
- Plasma arc – A process that uses very high temperatures (5,000 to 13,000 degrees Fahrenheit) to breakdown waste into elemental byproducts,
- Mass Burn Waste-To-Energy – A process that burns solid waste in a combustion chamber, without presorting of waste components, and recovers heat energy.
- Anaerobic Digestion – A process that decomposes the organic (carbon-based) portion of solid waste in the absence of oxygen, producing syngas or natural gas, and a digestate with a liquid and solid component.
- Mixed Waste Processing – MWP – Also known as "front-end separation," this is a process that removes recyclable materials from mixed solid waste; it can either be stand-alone or be part of a front-end process before another technology.
- Plastic to Fuel – A process that uses heat and distillation to convert various plastics into oil.

Waste Stream Analyis

The type and amount of mixed municipal solid waste available in the future needs to be considered when reviewing applicable technologies. Projecting waste volumes takes into consideration the changes likely to occur in the solid waste system, with increased levels of recycling and separate management of organic waste. Between 2012 and 2037 the amount of MSW that is not reduced, reused, recycled or managed as separate organic waste in the two counties is expected to grow from 391,000 tons, to close to 500,000 tons. The waste composition over that time period is expected to change somewhat, with reduced volumes of recyclable paper, glass, metal and organics. The type and amount of materials that are discarded in the Counties depends heavily on a number of factors, such as changes in population, the economy, consumer habits, and types of business development.

Comparison of Alternatives

Table ES-1 provides a summary of the technologies covered in this report according to basic criteria including:

- Whether the technology is proven in North America
- There is available documented cost data
- The relative ease of permitting
- Development time frame
- Flexibility/Compatibility – now and in the future
- Applicability to R/W Counties waste stream, and
- Viability for further consideration.

Technology Status

- Mass burn, RDF, and MWP are considered proven technologies for handling MSW, having been in commercial operation for many years
- Gasification is moving into commercial operation, with three gasification facilities scheduled to begin commercial operation in the next two years. If successful, this could start to prove the technology as capable of handling MSW on a large scale.
- Plasma arc systems, while used for certain special waste destruction, are still in the development phase in the U.S. for use in processing MSW, usually in the form of RDF. There may be one plant coming on line in the next year.
- Anaerobic digestion is receiving a great deal of interest and plant development activity targeting organic rich waste streams, primarily food wastes.
- Plastics to Fuel is drawing interest and there is a local commercial operating plant.
- Pyrolysis is not proven for MSW and there are no known plants being considered in the U.S.

Table ES-1
Summary Comparison of Alternatives

	Proven Technology for MSW in North America	Documented Cost Database	Ease of Permitting	Plant Development Period	Flexibility & Compatibility	Applicable to R/W MSW	Viability for Further Consideration
Mass Burn	Yes with several existing plants in Minnesota	Yes	Proven to be difficult	5 years+	Can handle all non-recyclable waste but size & economics typically need long term commitment	Yes	Yes
Refuse-Derived Fuel	Yes	Yes	Proven difficult	5 years+	Fits with gasification, plasma, AD, MWP	Yes, current system in place	Yes
Mixed Waste Processing	Yes	Yes	Occurring in Minnesota	1 to 2 years	Fits as front end processing to all	Yes for a Portion	Yes
Gasification	Three plants in development	No	Unknown	5 years+	Fits with RDF, AD, MWP	Maybe RDF from Newport	Maybe, pending new plants
Plastics To Fuel	One plant - maybe	No	Occurring in Minnesota	1 to 2 years	Fits with MWP ahead of all technologies	Yes for a Portion	Yes
Anaerobic Digestion	Yes for organic fraction	Yes for organic fraction	Occurring in Minnesota	1 to 2 years	Fits with gasification, plasma, RDF, MWP	Organic fraction	Yes
Plasma Arc	One plant in development	No	Unknown	5 years+	Possibly fits with RDF, AD, MWP	Maybe RDF from Newport	No
Pyrolysis	No	No	Unknown	5 years+	Unknown	None	No

Documented Cost Database

For the Technology Scan in this report, the only technologies that have reasonably available, actual capital and operating costs are mass burn, RDF, and mixed waste processing. Anaerobic digestion costs are likely close to those documented for other AD processes using organic waste streams, and can be projected. The experience with the other technologies of gasification, pyrolysis and plasma arc is not sufficient to accurately document or even estimate the cost per ton of MSW. Should estimates be needed as this work proceeds, further in-depth analysis could provide some cost estimates.

Ease of Permitting/Public Acceptance

Understanding that any new waste management facility typically faces difficulty with public acceptance, some technologies may be less difficult than others to permit. Minnesota law would require an Environmental Impact Statement (EIS) and a lengthy permitting process for a mass-burn facility, and possibly for other newly-sited technologies. The environmental review and permitting process may take five years or more. Based on historical experience, a new solid waste facility will have great difficulty receiving public acceptance. Any of the technologies are likely to be easier to permit at an existing waste management facility that is currently permitted. Permitting is currently being completed for anaerobic digestion of targeted organics, mixed waste processing facilities, and a plastics to fuel facility in Minnesota. Permitting processes for gasification, pyrolysis, and plasma arc are not yet clearly defined by the MPCA which may cause additional delay.

Development Period

This is an estimate of the time from a decision to pursue the technology until actual commercial operation. The time periods in Table ES-1 are for green fields sites. Siting at an existing solid waste facility typically reduces development time.

Flexibility/Compatibility

Future waste processing systems may be most effective if multiple technologies are used in a "systems" approach. This parameter addresses how the technology could fit in "concert" with a system. Gasification, RDF, AD, mixed waste processing, and plastics to fuel could all fit together in a comprehensive system with each technology focused on managing wastes most compatible with the process. Mass burn has an advantage in its capability to handle all non-recyclable wastes, but there may be some concern regarding the size and long term commitment to a single facility and approach.

Applicability to R/W Counties Waste Stream

Gasification requires the MSW to be pre-processed into an RDF type of material and could be quite applicable to the RDF produced at the Newport Facility. Pyrolysis and plasma arc might also use the RDF, but are an unproven technology and likely cost prohibitive. Mass burn technology could be applied to the entire R/W Counties waste stream currently available for processing. Organics such as food wastes and non-recyclable paper could be processed using anaerobic digestion. Mixed waste processing could potentially be used to handle primarily commercial wastes that still have recoverable materials and high amounts of organics or plastics. The Plastics to Fuel technology could be applied to the non-recyclable plastics.

One potential concept could be to use a combination of technologies such as the "front end processing" of a MWP facility that would sort out recyclables (for typical markets), organics (for anaerobic digestion), plastics (for plastics to fuel), with the remainder of the wastes shredded for either RDF for combustion or eventually for some type of gasification facility. This concept would be a "systems" approach. This would be similar to the City of Edmonton, Canada that has a waste management center to process various wastes using multiple technologies.

Viability for Further Consideration

Pyrolysis and plasma arc are not technically or economically viable to be considered further at this time. Mass burn is a proven, viable, and relatively cost effective technology, but has been demonstrated to be difficult for public acceptance and permitting and therefore could be very difficult to implement. Pending how the new gasification plants perform, the technology could hold promise in the future. The concept of the "systems" approach with mixed waste processing, anaerobic digestion, plastics to fuel, and production of RDF has potential for consideration. RDF combustion is a proven technology at the existing Xcel combustion plants at least until and if the gasification technology develops to technical and economic viability.

List of Abbreviations, Acronyms, and Symbols

AC	Alternating Current (Electric)
AD	Anaerobic Digestion
ADC	Alternative Daily Cover
ATR	Advanced Thermal Recycling
BACT	Best Available Control Technology
BETF	Break Even Tip Fee
Btu	British Thermal Unit
CAD	Computer Aided Drafting
CEM	Continuous Emissions Monitoring
CER	Certified Emission Reductions
CNG	Compressed Natural Gas
CT	Conversion Technology
DC	Direct Current (Electric)
EfW	Energy from Waste
EPA	United States Environmental Protection Agency
Foth	Foth Infrastructure and Environment, LLC
GHG	Green House Gas
HCl	Hydrochloric Acid
HHV	High Heating Value
HRSG	Heat Recovery Steam Generator
JV	Joint Venture
kW	Kilowatt
kWh	Kilowatt hour
lb	Pound
Lb/hr	Pound per hour
LHV	Low Heating Value
MM Btu	Million British Thermal Units
mmt	Million Metric Ton
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatt hour

MWP	Mixed Waste Processing
NEPA	National Environmental Quality Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PM	Particulate Matter
PSIG	Pounds Per Square Inch Gauge
QA	Quality Assurance
QC	Quality Control
RDF	Refuse Derived Fuel
RFP	Request for Proposal
RFQ	Request for Qualifications
RPS	Renewable Standards Portfolio
scf	Standard Cubic Feet
SCR	Selective catalytic reduction
SNCR	Selective non-catalytic reduction
SSOM	Source separated organic materials
SVSWA	Salinas Valley Solid Waste Authority
TPD	Tons Per Day
TPH	Tons Per Hour
TPY	Tons Per Year
voc	Volatile Organic Compound
WTE	Waste to Energy

Definitions

Anaerobic Digestion:	A series of processes in which microorganisms break down biodegradable material in the absence of oxygen.
Gasification:	A process that converts organic carbonaceous materials into carbon monoxide, hydrogen, and carbon dioxide, and a controlled amount of oxygen and/or steam.
Pyrolysis:	A thermochemical decomposition of organic material at temperatures > 200°C without oxygen that produce syngas, liquids, and char.
Plasma Arc:	A process where gasification is conducted that uses plasma as a thermal source to convert organic matter to a syngas at temperatures > 2000°C
Mass Burn:	The combustion of waste materials in a furnace to typically produce steam for electric energy. Mass burn processes produce heat, ash, and flare gases.
Mixed Waste Processing:	A process to identify and separate materials from the mixed waste stream that can be recycled or used for better purposes other than landfilling. Separation processes include both mechanical and manual sorting. MWP may sort a range of materials including cans, bottles, paper, fines, cardboard, and organics.
Plastics to Fuel:	A thermal conversion process that transforms waste plastics into petroleum products. Thermal conversion is similar to gasification and converts plastics to syngas which is converted to petroleum products but typically crude oil that can be refined.

1 Introduction

The following information provides a general overview of municipal solid waste (MSW) technologies and their potential application to the waste stream from the Ramsey and Washington Counties (R/W Counties) currently delivered to the Newport Resource Recovery Facility (Newport). The report is provided to the R/W Counties Resource Recovery Project Board. The report is assembled by providing an overview of:

- ♦ The technology.
- ♦ Technology performance at converting MSW.
- ♦ Project descriptions.
- ♦ Environmental performance in regards to emissions for thermal processes.
- ♦ Financial information.
- ♦ General analysis of outputs and performance.
- ♦ General advantages and disadvantages.

For this report, Foth is using published data sources, articles, and web site information. Therefore, the report is a scan of the technologies reviewed. Further refinement of select technologies may occur in subsequent reports.

This report examines the following technologies as they apply to MSW generated in R/W Counties:

- ♦ Gasification
- ♦ Pyrolysis
- ♦ Plasma Arc
- ♦ Mass Burn
- ♦ Anaerobic Digestion
- ♦ Mixed Waste Processing and Residual Management
- ♦ Plastics to Fuel

The report also addresses the potential advantages of combining processes (e.g., using a mixed waste processing system prior to making RDF for gasification).

1.1 Purpose

The purpose of this report is to provide a general overview using published information on the selected technologies. The data obtained is then used to extrapolate information on how the technology would perform on the MSW generated in R/W Counties that is currently not recycled (i.e. MSW delivered to Newport or to sanitary landfills).

1.2 Scope of Work

The scope of work for this report is to develop a general overview of emerging technologies; including the seven technologies previously presented.

For each technology, the report addresses:

- Process
- Performance
- Vendors
- Projects
- Environmental Considerations
- Application to Current Waste Stream
- Financial Performance

Since this report is a general overview, Foth examined and presents only published data sources with appropriate citation of sources. The overall goal of the report is to provide sufficient information to select one or more technologies for an in-depth analysis.

2 Waste Stream Analysis

The R/W Counties waste stream data was reviewed to understand the current throughput and future quantity of MSW for processing. The following tables include summaries of:

- R/W Counties waste quantity from an aggregate and fractional (Table 2-1) perspective,
- R/W Counties wastes potentially available for processing (Table 2-2),
- Actual waste compositions received at for processing in 2012 (Table 2-3), and
- Actual and projected waste quantities received available for processing (Table 2-4).

2.1 Quantity

Table 2-1 provides a 2012 snapshot of the R/W Counties waste streams including recycling, processing, landfilling, and other waste management. The total waste stream in 2012 was 791,437 tons. Of this total 303,375 tons was delivered to Newport and another 87,216 tons was delivered directly to a sanitary landfill without processing. The remaining waste is recycled or part of commercial industrial and institutional wastes. It was noted in 2002 that approximately 614,000 tons could have been processed. 2012 total waste that could have been processed is estimated to be 390,591 tons, down from previous years.

2.2 Waste Stream Projections Available for Processing

Table 2-2 provides waste stream growth projections based on data from average growth rates from the Metropolitan Council for population, households, and employment (1.0%). Using 390,591 tons that could have been processed at Newport from R/W Counties in 2012, Table 2-2 provides projections of the wastes that could be available to a processing facility in the future. It was estimated in 2002 that approximately 800,000 tons were projected to be available in 2017. However, these projections estimate that 410,000 tons will be available in 2017.

2.3 Waste Composition for Processing - Current and Projected

Table 2-3 shows a comparison of the aggregate waste composition percentage for nine groups of material categories for Newport. This data was collected during a solid waste composition study at Newport in 2012.

Table 2-4 provides actual and projected waste quantity based on 2012 waste composition and assumed growth as well as estimated composition adjustments for 2022. Composition adjustments included a reduction in paper due to higher recovery and reduced newspaper generation; glass use declines; a balance of increased plastics generation offset with increased plastics recovery; increased organics recovery; and increased other wastes due to increased composites and unknowns. Continued actual waste composition studies should be conducted during future facility design. The purpose of Table 2-4 is to provide preliminary quantities of MSW that may be suitable for the various alternative processing technologies in this report.

Table 2-1
2012[1] Management of Waste in R/W Counties

Waste	Ramsey	Washington	TOTAL
Recycling	**298,874**	**95,249**	**394,123**
Residential (curbside and drop-off)	50,234	30,417	80,651
Commercial/industrial/institutional	239,622	61,621	301,243
Separated at processing	9,018	3,211	12,229*
Land Disposal	**92,247**	**18,631**	**110,878**
Residual/non-processible at processing	17,282	6,380	23,662*
Unprocessed MSW to MN landfills	48,228	6,795	55,023*
Unprocessed MSW to non-MN landfills	26,737	5,456	32,193*
Other Waste Management [2]	**12,883**	**6,069**	**18,952**
RDF recovered [3]	**195,271**	**72,213**	**267,484***
TOTAL	**599,275**	**192,162**	**791,437**

1. Information provided in this table were from the 2012 County Certification/ Annual Report forms for MSW, related recycling, and management of certain problem materials (recycled portion included with recycling and the remainder under Other Waste Management). C&D and other separately managed waste streams, including yard waste, are excluded from the table above.
2. "Other Waste Management" refers to items neither recycled nor processed at a MSW facility; these include the un-recycled portion of several problem materials (major appliances, used motor oil, oil filters, tires, lead acid batteries) and may also include the un-recycled portion of household hazardous waste.
3. "RDF recovered" refers to the estimated quantity recovered. This was back calculated from the total waste and other fractions.

* Available tonnage for R/W Counties for processing

Table 2-2
Projected Available Waste for Processing

Year	Annual Growth[1] (%)	Cumulative Growth[2] (%)	Available Tonnage[3]
2012	1.0	0	391,000
2017	1.0	5.05	410,000
2022	1.0	10.10	430,000
2027	1.0	15.15	450,000
2032	1.0	20.2	470,000
2037	1.0	25.25	490,000

1 Annual growth assumed corollary to population of 1.0%
2 Cumulative growth estimates starting from the year 2012
3 Available Tonnage represents the availability of waste in R/W counties for processing.

Table 2-3
Actual Waste Fractions Processed[1]

Waste	Mean (%)	Lower Bound[2] (%)	Upper Bound[2] (%)
Paper	23.1	20.1	26.3
Plastic	17.1	15	19.4
Metals	5	3.7	6.5
Glass	2.6	1.9	3.4
Organic Materials	28.2	24.6	32
Problem Materials	3.6	2.1	5.5
C&D	3.9	1.5	7.4
HHW	0.1	0	0.2
Other Waste	16.3	12	21.1

1. Source: Solid Waste Composition Study – Newport Resource Recovery Facility, Letter Report to Xcel Energy dated September 17 2012, SAIC.
2. These represent the lower and upper bounds of the 90% Confidence Interval.

Table 2-4
Actual and Projected Waste Fraction Quantities for Processing

Waste	Fraction[1] (%)	2012 Annual Tonnage[2]	2012 Daily Tonnage[3]	2022 Estimated (%)[4]	2022 Annual Tonnage[2]	2022 Daily Tonnage[3]
Paper	23.1	90,227	247	17.0	73,100	200
Plastic	17.1	66,791	183	17.1	73,530	201
Metals	5	19,530	54	5.0	21,500	59
Glass	2.6	10,155	28	2.0	8,600	24
Organic Materials	28.2	110,147	302	20.0	86,000	236
Problem Materials	3.6	14,061	39	3.6	15,480	42
C&D	3.9	15,233	42	3.9	16,770	46
HHW	0.1	391	1	0.1	430	1
Other Waste	16.4	64,057	175	31.3	134,590	369
Total	**100**	**390,591**	**1,070**	**100**	**430,000**	**1,178**

1. From Table 2-3, mean percent
2. Applied percentages to total waste to quantify waste fraction
3. Tonnage divided by 365 days per year
4. Adjusted composition.

3 Gasification

3.1 Process

Gasification is a thermal process that converts carbon based materials into a syngas. The process uses limited amounts of air or oxygen. Some gasification processes also inject steam to promote the production of carbon dioxide and hydrogen.[1] Gasification that uses air in the process typically produces a low Btu fuel that is nitrogen rich. Thermal gasification dissociates water from the waste into hydrogen and oxygen.[2] Gasification typically operates at temperatures ranging from 1450°F to 3000°F.

Production of energy from gasification using MSW has three major processes:[3]

1. MSW Handling and Processing
2. Conversion of MSW into Syngas
3. Power Conversion

MSW handling and processing is the first step in the gasification process. Receipt of MSW is typically completed in a building to control odor and windblown litter. The building is sized to handle the expected daily waste input and the waste storage area is typically large enough to store two to three days of waste to assure adequate waste input should interruption in the waste flow occur.

In order to remove recyclables and inert materials in the waste stream, the waste receiving area typically has a recycling facility and some method of shredding or grinding the MSW so it can be sent to the gasification chamber efficiently. Size reduction is often required for more efficient handling of materials.[4] Additionally, the size reduction process allows for further metals removal and drying of the waste before the gasification process. Some gasification processes use refuse-derived fuel (RDF) as a feedstock. Enerkem, which is discussed later, uses RDF as the feedstock for their RDF to fuels process that uses a gasification technology.

The gasification process that converts the MSW into syngas can be completed in either fixed or fluidized bed configurations. The reactions that occur in a gasification process are:

1. $C + O_2 \rightarrow CO_2$
2. $C + H_2O \rightarrow CO + H_2$
3. $C + CO_2 \rightarrow 2CO$
4. $C + 2H_2 \rightarrow CH_4$
5. $CO + H_2O \rightarrow CO_2 + H_2$
6. $CO + 3H_2 \rightarrow CH_4 + H_2O$

[1] Young, Gary C. Municipal Solid Waste to Energy Conversion Process. John Wiley & Sons, Inc. 2010. Page 3
[2] Alemeda Power & Telecom, Investigation into Municipal Solid Waste Gasification for Power Generation. May 27, 2004. Page 6
[3] Ibid.
[4] URS Corp "Evaluation of Alternative Solid Waste Processing Technologies", Sept 2005, Page 2-4

The reactions are all reversible and are dependent on the pressure, temperature, and oxygen in the reactor.[5]

Fixed bed gasifiers are designed with a grate to support the MSW in the reaction zone. The downside of fixed bed gasifiers is the syngas yield can be variable in composition and quality. Fixed bed gasifiers are easier to design and operate compared to fluidized beds, but are not well suited for large scale operations.[6] Two typical fixed bed gasifier designs include downdraft and updraft. Both feed MSW from the top of the gasifier. The advantage of the updraft gasifier is that no drying of the waste is required. Additionally, the syngas leaving the process is typically cooler than with a downdraft gasifier. [7]

The fluidized bed gasifiers typically use a solid material such as coarse sand or limestone as a bed for solid fuel. Waste is introduced into the reactor either on top of the bed or into the bed. Fluidized bed can be either bubbling fluidized bed or circulating fluidized bed reactors. Typically, fluidized bed reactors are used for larger capacity applications than fixed bed reactors[8]

There also exists a single or two chamber gasification process that does not require front end processing of MSW (to size reduce the MSW before gasification).[9] The syngas produced from this gasification process is used in a waste heat boiler to produce steam. Thus, the quality of syngas produced is not critical since it is essentially burned to power a boiler. The steam from the boiler is then used to turn a turbine to produce electricity. This is generally the simplest form of the gasification approaches and is offered by several vendors in the U.S.

3.2 Performance

Development of gasification facilities that produce a clean syngas from homogeneous solid waste materials began over 70 years ago, with gasification of MSW facilities starting over 40 years ago.[10] More than 20 gasification processes were developed in the 1970's. Thirteen of the gasification systems were operated at greater than 10 TPD and five were tested between 1 and 10 TPD.[11] Of all the gasification start-ups in the 1970's, there are no longer any operating facilities. The last plant in France was oriented towards hazardous waste, but filed bankruptcy in 2002.[12]

[5] Krigmont, H. (1999), "IBGCC Power Generation Concept: A Gateway for a Cleaner Future." Allied Environmental Technologies, white paper.www.alentecinc.com/papers/IGCC/ADVGASIFICATION.pdf
[6] Klien, A. (2002). Thesis. "Gasification: an Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes." Columbia University.
[7] Ibid.
[8] Ibid.
[9] HDR (2013), "Alternative Disposal Feasibility Final" prepared for Metro Waste Authority. Page ES-10
[10] Stoller, Paul J., and Niessen, Walter R. 2009. "Lessons Learned from the 1970's Experiments in Solid Waste Conversion Technologies." Presented at NAWTEC 17, Chantilly, Virginia May 18-20, 2009.
[11] Rensfelt, E and A Ostman. IEA Biomass Agreement. Subtask 6-Gasification of Waste, 1996. Pages 7-8.
[12] Notices of ADEME. No. 1. "Thermolysis and Pyrolysis." 2006. www.ademe.fr Accessed April 14, 2013

Failure of the early MSW gasification plants can be attributed to:[13]

1. Most of the processes intended to gasify the raw MSW, i.e., no separation was envisioned. In combination with the proposed techniques, this often led to a more or less endless number of mechanical problems and shut-downs.

2. The basic knowledge about waste and gasification/pyrolysis was poor. In several cases not even an acceptable analysis of the waste was available, and the heterogeneity of the raw material was underestimated. Both short-term (hours, day-to-day), and long-term (seasonal) variations have to be considered.

3. Scaling-up in the capacities of the units was too fast.

4. The fact that pyrolysis/gasification is a complex chemical conversion was seriously under-estimated. Several of the processes were "inventions" treating the process as a "thermal process".

5. Most of these process efforts included a fixed bed reactor, the ideas coming from coal gasification and old-time biomass gasification or metallurgical processes. The most common equipment is a shaft reactor with a bottom temperature of about 1800°F. The experience from fixed bed reactors found problems feeding waste to the reactor, difficulties in the reactor process and ash management challenges.

6. Most of the systems were pyrolysis/gasification producing tar or a mixture of tar and gas. Only a few of the processes included gas cleaning. The tar-rich gas caused problems on the gas side as well as condensation, clogging, etc. in the pipes to the combustor. The Garrett/Occidental process, with advanced recycling and thermal treatment on the other hand, probably was before its time, and included many new technologies.

During the 1980's and 1990's, several technological advances occurred which have addressed some of the challenges experienced in the 1970's. Additionally, fluidized bed reactors have become common, as has the production of RDF to allow for more advanced pretreatment of the waste to reduce reactor problems.

However, conclusions of recent consulting studies, presentations and state studies conclude the viability of gasification for MSW has not been proven on a commercial scale in the U.S.[14]

3.3 Vendors

Currently, there are nineteen gasification plants operating in the U.S. All plants are used in the petrochemical industry (not solid waste industry) to produce chemicals. The first plant was constructed in 1977 in Houston, Texas and is still in operation today.[15] The world gasification

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[13] Rensfelt, E and A Ostman. IEA Biomass Agreement. Subtask 6-Gasification of Waste, 1996. Pages 5-6.
[14] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011. Pg 13.
[15] www.gasification.org/pup/us-gasification-plants-tables.aspx Accessed April 15, 2013

database[16] indicates there are 11 gasification plants worldwide that use biomass/waste as a feedstock with primarily wood wastes being used in these gasifiers. The most common gasifier in Europe is the Foster Wheeler Atmospheric Circulating Fluidized Bed Gasifier. The Lurgi Circulating Fluidized Bed, Uhde Prenflo gasification technology and Synthesis Energy Systems gasification process are also used. Most of these gasifiers use some form of wood waste as the biomass in the gasifier.

There are some gasification plants operating worldwide that reportedly use MSW as a feedstock. Fifty-three percent (53%) of the gasification plants are owned by Nippon Steel. Most of the plants are located in Japan, with two in Germany, and one in the UK.[17]

In 2005, the County of Los Angeles sent an RFP to conversion technology providers[18]. The following gasification providers were sent the questionnaire regarding their gasification process and experience.

Table 3-1
Gasification Vendors

Supplier	Address
Ambient ECO	ON, Canada
Thermogenics, Inc.	Albuquerque, NM
Emery Energy Company	Salt Lake City, UT
Whitten Group International	Long View WA
Global Warming Prevention	ON, Canada
Ebara Corporation	Tokyo Japan
Technologies, Inc.	
Energy Products of Idaho	Coeur d'Alene, ID
Improved Converters, Inc.	Sacramento, CA
Enerkem Technologies, Inc.	Quebec, Canada
Innovative Logistics Solutions	Palm Desert, CA
Heuristic Engineering	Vancouver, Canada
Omnifuel Technologies, Inc.	Folsom, CA
United Recycling Technologies	LaCresenta, CA
Primenery, LLC	Tulsa, OK

Other gasification vendors that were not part of the County of Los Angeles process include Genahol, LLC, located in Ohio; Entech Renewable Energy Solutions, located in Australia; Full Circle Energy, located in Tulare, California; NTech Environmental, located in Poland; and Urbaser, SA, located in Spain.[19]

[16] Gasification Technologies Council Resource Center. www.gasification.org Accessed April 15, 2013
[17] Pytlar, Theodore S. Jr. "Waste Conversion Technologies: Emergence of a New Option or the Same Old Story?" Presented at the Federation of New York Solid Waste Association, Solid Waste and Recycling Conference. May 9, 2007.
[18] URS. Conversion Technology Evaluation Report – Appendices. August 18, 2005. Table A-1
[19] Calrecycle Conversion Technology Vendors. www.calrecycle.cca.gov Accessed April 18, 2013

Complete and experienced MSW gasification system vendors are very limited. Two North American vendors, Enerkem and INEOS Bio, are featured in Section 3.4 as potentially viable projects for gasification technology using MSW as feedstock.

Several municipalities in California have issued request for qualifications (RFQ) for conversion technologies. In 2007, the County of Los Angeles selected two gasification technologies to continue to be developed for eventual commercialization. These vendors included Interstate Waste Technologies and NTech Environmental.[20] These projects have not been built. The City and County of Santa Barbara and other cities have followed the lead provided by the County of Los Angeles and are evaluating implementation of gasification to manage MSW.

Additional potential gasification system vendors include Thermoselect, Ebara, Primenergy, Brightstar Environmental, Erergos, Taylor Biomass Energy, SilvaGas, Technip, Compact Power, PKA, and New Planet Energy.[21] While gasification system vendors appear to be plentiful, actual commerical plants are limited. The following section provides information on Enerkem, INEOS Bio, and other vendors that have commercial scale plants underway and other vendors that are of interest.

3.4 Projects

3.4.1 Edmonton Waste-to-Biofuels Project (Enerkem, Edmonton, Alberta, Canada)[22]

Enerkem, through its affiliate Enerkem Alberta Biofuels, has signed a 25-year agreement with the City of Edmonton to build and operate a plant that will produce and sell next-generation biofuels from non-recyclable and non-compostable municipal solid waste (MSW). It is expected to be the world's first major collaboration between a metropolitan center and a waste-to-biofuels producer to turn municipal waste into methanol and ethanol.

As part of the agreement, the City of Edmonton will supply 100,000 dry metric tons (110,231 tons) of sorted MSW per year. The sorted MSW to be used is the ultimate residue after recycling and composting, which is saved from being landfilled. The MSW will be gasified to produce methanol and ethanol. The plant is sized to produce 10 million gallons per year of methanol and ethanol.

The project was granted a permit, under the Environmental Protection and Enhancement Act of the Province of Alberta, to commence construction and operation of the commercial facility. Construction started during summer 2010. Operations are scheduled to start in 2013 or 2014.

Enerkem's project partners, the City of Edmonton and Alberta Innovates – Energy and Environment Solutions, contributed $20 million to the project. The project has been selected by Alberta Energy to receive $3.35 million in funding, as part of the Biorefining Commercialization and Market Development Program. This program is designed to stimulate investment in Alberta's

[20] Los Angeles County Conversion Technology Evaluation Report, Phase II Assessment. October 2007, ES-8.
[21] Metro Waste Authority Alternative Disposal Feasibility Final Report. HDR Engineering, Inc. 2013
[22] http://enerkem.com/en/facilities/plant/edmonton-alberta-canada.htlm

bio-energy sector. In addition, Waste Management and EB Investments are investing $15 million for a minority equity interest in the project.

This facility, which is part of a comprehensive municipal waste-to-biofuels initiative,[23] in partnership with the City of Edmonton and Alberta Innovates, will enable the City of Edmonton to increase its residential waste diversion rate to 90 percent.

3.4.1.1 **Technology and Process**[24]

The Edmonton Waste-to-Biofuels project integrates both the City of Edmonton's sorting and processing methodology and Enerkem's technology platform.

The sorting and processing operation has three distinct operations: a pre-processing operation, a waste transfer operation, and a refuse derived fuel (RDF) plant. The facility sorts waste and transfers it to the appropriate downstream plants like composting and biofuels plants.

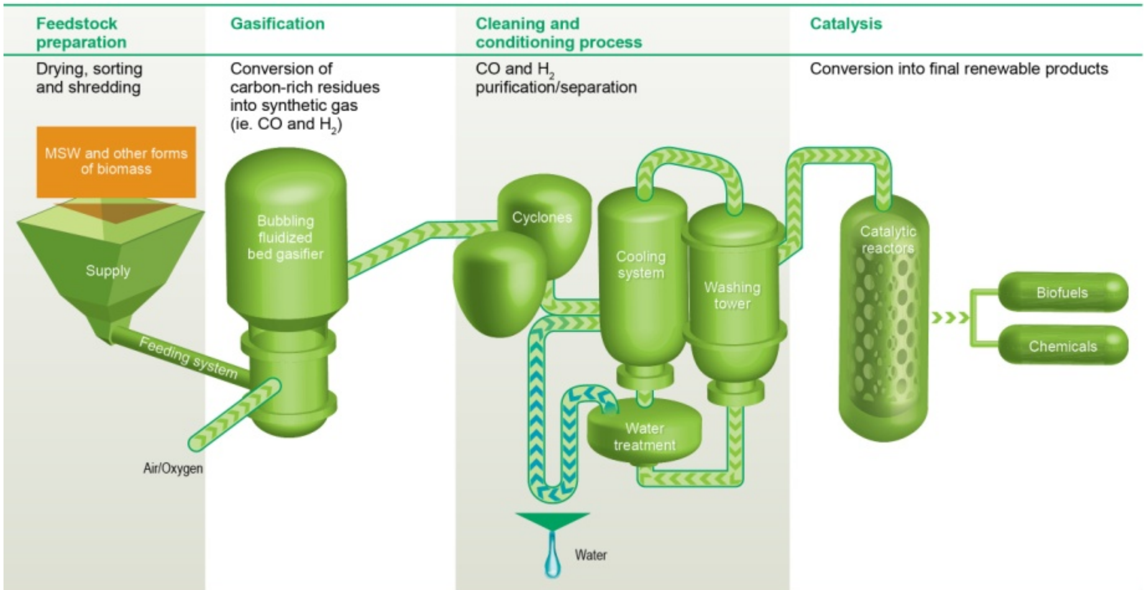
In the pre-processing operation, all Edmonton's residential waste and some commercial waste is sorted mechanically and manually into three streams:

- organic materials are conveyed to the Edmonton Composting Facility;
- cardboard and metals are diverted for recycling; and
- non-recyclable, non-compostable waste (including mixed textiles, plastics, contaminated fibers, wood) is shredded into RDF, to become feedstock for the Biofuels Facility.

At Enerkem's biofuel facility, RDF is placed in a process that involves heat, pressure, advanced chemistry and the use of cutting-edge catalysts. It has a positive energy balance, since gasification requires less energy than it produces. A significant portion of the water in the system is reused in a closed-loop. The process can be broken down into four steps as shown in Figure 3-1. The conversion process takes less than 4 minutes.

[23] www.edmontonbiofuels.ca
[24] http://www.edmontonbiofuels.ca/assets/files/Ressources/Edmonton-Waste-to-Biofuels-Project_Factsheet.pdf

Figure 3-1
Enerkem Biofuel Process Steps



Step 1 - Feedstock pre-treatment
The sorted MSW is shredded and then stored in a container that is connected to the gasifier via a front-end feeding system.

Step 2 - Gasification
The gasification process converts carbon-rich residues into a uniform synthetic gas (syngas). The heat and the pressure break apart the chemical bonds of the waste material into a syngas.

Step 3 - Cleaning and conditioning of the synthesis gas
The syngas is cleaned and conditioned in order to prepare it for catalytic conversion into methanol and/or ethanol. The cleaning process is accomplished through a sequential conditioning system, which includes cyclonic removal of inert matter, secondary carbon conversion, heat recovery units, and reinjection of inerts into the reactor. The syngas that is produced by this process is ready for conversion into liquid fuel.

Step 4 - Conversion into liquid fuel
Using a sequential catalytic conversion process, and commercially available catalysts, the syngas is converted into high-value, market ready fuels and chemicals. The catalysts rearrange the molecules in the gas into methanol and ethanol.

3.4.1.2 Pollution Control[25]

The Enerkem gasification process has many pollution controls that were required as part of permitting the facility.
Pollution controls include:

- Two cyclones for particulate removal located after gasification.
- A two stage wet scrubber system in the gas conditioning phase.
- A waste heat recovery unit.
- A baghouse system for particulate control.
- A low NO_x burner on the boilers.
- Tank vapor control system.

Additionally, the permit requires the following emission limits:

- Waste heat recovery; NO_x 10kg/hr; SO_2 1.3 kg/hr
- Boiler stack; NO_2 0.9 kg/hr
- Baghouse and dust collectors; 0.20 g/kg

3.4.2 Indian River BioEnergy Center (INEOS Bio, Vero Beach, Florida)[26]

INEOS New Planet BioEnergy has started production from a first-of-its-kind advanced bio-energy facility in Vero Beach in Florida. The new plant, named the Indian River BioEnergy Center, was built with an investment of more than $130 million. It is the first commercial scale plant to produce third generation bioethanol.

The project broke ground in February 2011. Construction was completed in June 2012 and the plant began production in September 2012. INEOS also plans to expand the facility in 2015. The plant was constructed on a site which was earlier an agricultural processing facility.

The Vero Beach plant will produce 8 million gallons of bioethanol annually, which is expected to generate $19 million of annual revenue. It will also produce six megawatts of renewable power for its needs. Excess power generated at the plant will be supplied to the local Floridian market and will be enough to power 1,400 households.

The INEOS Bio plant is a fully integrated gas fermentation technology that converts waste into a syngas that goes into a bioreactor and comes out as a mixture of ethanol and water that is distilled and dried, or can be further purified and used as a pharmaceutical grade alcohol as well. To produce bioethanol, the plant uses 150,000 tons of renewable biomass.

The process consists of four stages, which include gasification, fermentation, purification and power generation. In the first step, the biomass is fed into a gasification chamber which results in

[25] Excerpts from Air Permit http://www.edmontonbiofuels.ca/assets/files/Ressources/Environmental-Permit-Approval-April-2009.pdf
[26] http://www.chemicals-technology.com/projects/ineosbioenergyfacili/

the production of syngas. This step results in negligible by-products, such as ash, which are sent to a nearby landfill to be used as daily cover.

The most important step of the process is the anaerobic fermentation of the gases produced during gasification. In this step, naturally occurring bacteria transform the gases into ethanol. Purification of the ethanol is then carried out by distillation. The purified ethanol is sold as fuel for transportation. The final step includes collection of waste heat and off-gas recovery. These gases are fed into a steam turbine to produce renewable power.

INEOS New Planet BioEnergy is a joint venture (JV) between INEOS Bio and New Planet Energy. The JV received a $50 million grant from the DOE in December 2009 for building the facility. The project also received a $2.5 million grant from the State of Florida.

In January 2011, the project received a conditional commitment for a $75 million loan from the US Department of Agriculture under the 9003 Biorefinery Assistance Programme.[27]

3.4.2.1 Process and Technology[28]

The primary feedstock for the facility is vegetative yard waste and land clearing debris collected by the Solid Waste Disposal District (SWDD) curbside collection program, delivered to the county's collection centers, or delivered directly to the facility by the public. On an annual average, yard waste is anticipated to make up approximately 90 percent of the feedstock. The remainder of the biomass feedstock may consist of clean woody C&D debris and municipal solid waste (MSW).

The INEOS Bio ethanol technology process will gasify the biomass feedstock. The organic material will not be directly combusted; instead, oxygen will be supplied to the gasifier which converts the feed material into a synthetic gas (syngas) consisting of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and other hydrocarbons.

This syngas will not be directly combusted. It will be cleaned and cooled and then fed into a fermentation system where proprietary bacterial metabolic action converts the syngas into ethanol. The ethanol will then be distilled, dehydrated, denatured, stored and loaded into dedicated ethanol tanker trucks. Off gases from the fermentation process will be routed to a boiler for combustion. Steam from the fermentation vent gas boiler-as well as steam from waste heat recovery at the gasifiers-will be routed to a turbine to generate electricity. Vent gas boiler emissions will be controlled through sorbent injection and fabric filtration.

The process used by INEOS has three major steps: material handling; drying, gasification, fermentation and distillation.   These steps are discussed in detail in the following section.

[27] http://www.chemicals-technology.com/projects/ineosbioenergyfacili/
[28] Permit Mod App Review 9/2011. http://arm-permit2k.dep.state.fl.us/psd/0610096/00006402.pdf

Materials Handling Area

Trucks deliver vegetative waste and clean woody construction debris to the tipping floor of the materials handling area. The materials handling area includes equipment for storage, handling, grinding and screening of the feedstock.

To help control fugitive particulate matter (PM) emissions, biomass (vegetative matter, yard waste and untreated wood) that exceeds the storage capacity of the tipping floor will be stored outdoors on hard packed gravel. The associated conveyer equipment will be unenclosed.

Trucks delivering the feedstock are accepted on a twelve hours per day, seven days per week basis, excluding some holidays; similar to present landfill operation hours. Trucks removing ash will operate on the same schedule. Feedstock deliveries are approximately 100 to 200 trips per day with much of this traffic being diverted from its current destination, the landfill just beyond the plant site entrance. Front-end loaders are used to maneuver the materials from the truck tipping floor to the storage and processing areas.

The materials handling area includes a feedstock grinder so that the facility can accept vegetative waste, C&D material and MSW that has not yet been shredded. The grinder is powered by a Caterpillar C 18 ACERT industrial diesel engine rated for 765 brake horsepower at 2100 revolutions per minute and will be controlled by limiting the annual fuel.

Feedstock Dryers No. 1 and No. 2

The two feedstock dryers receive shredded feedstock from the storage piles and use low-pressure steam, provided by the boiler and heat recovery systems, to reduce the feedstock moisture to around 15 percent. Flue gas from the dryers is vented to the atmosphere through a dust control system. The dried feedstock is then sent to the gasifiers by way of a covered conveyor system. Particulate emissions from the dryer exhaust are controlled with a baghouse.

Gasification, Fermentation and Distillation Systems

Two gasifiers convert the shredded input feedstock to syngas through a two-stage process. First, a dedicated ram feeder pushes dried feedstock into the lower gasification zone. During startup, natural gas will be introduced into the lower zone burner to bring the system up to speed, but once steady operation is achieved, only additional oxygen will need to be supplied. There will be no vent from the gasifier, other than emergency pressure relief through diversion to the gasifier flare.

Following gasification, the syngas is cleaned and cooled through several steps. First, two heat recovery systems cool the syngas while preheating the boiler feed water. The two streams of cooled syngas combine before passing through dry gas clean-up, where lime and activated carbon injection remove halogens, metals, tars and ammonia. A fabric filter recovers the spent lime and carbon, and the exhaust from the fabric filter is routed to a quench tower for additional cooling. The cool, dry, clean syngas is then ready for introduction to the fermentation system.

In the fermentation system, proprietary bacteria act to convert the syngas to ethanol. The fermentation system includes nutrient feed tanks and alkali for pH control. Liquid ethanol is sent to the distillation system, and vent gas from the fermenter is routed to a vent gas scrubber.

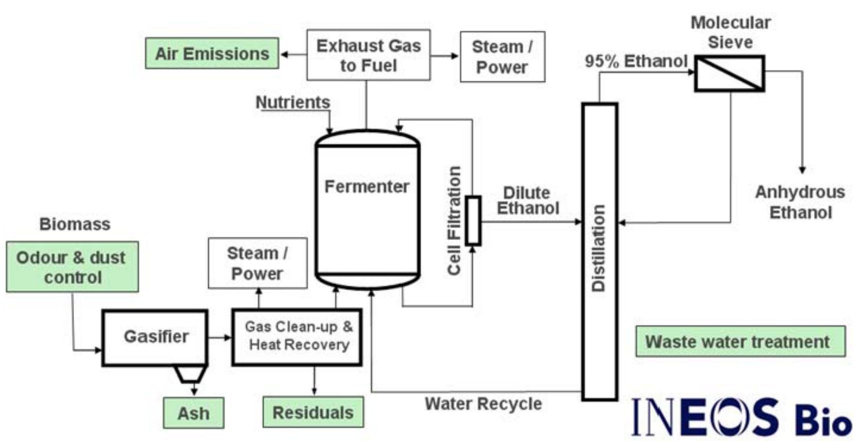
The distillation system accepts the filtered fermentation broth as well as the vent gas scrubber bottoms. The distillation tower receives the broth (a mixture of water, ethanol, acetic acid and heavy alcohols) from the distillation feed tank, and overhead vapor leaving the distillation tower will be collected in a reflux drum and pumped back into the tower. There is off-gas from the feed tank and the reflux drum. Off-gas from both is routed to the vent gas boiler with some fugitive emissions from the distillation system.

The fermentation system vent gas scrubber recovers ethanol from the vent gas before routing it to the desulfurization unit. It then uses an iron chelate solution to remove hydrogen sulfide from the vent gas prior to combustion in the vent gas boiler. The spent iron chelate solution is routed to an oxidation tank where air sparging recharges it.

The site also contains back up flare facilities to capture and destroy ethanol vapors and for emergency back up during system malfunction.

A process flow diagram is provided in Figure 3-2

Figure 3-2[29]
INEOS Process Flow Diagram



[29] Guell, Berta Matas; Bugge, Mette; kempegowda, Rajesh S.; George, Anthe and Paap, Scott. Report Benchmark of Conversion and Production Technologies for Synthetic Biofuels for Aucation. SINTEF Energy Research. November 6, 2011. Page 14. www.avinor.no

3.4.2.2 Pollution Controls

Pollution controls at the facility meet state and federal air pollution control requirements. Table 3-2 shows total emissions from the plant from all sources

Table 3-2[30]
Emission - INEOS Bio Facility

Pollutant	Plant Emissions (ton/year)
NO_x	99.8
CO	50.5
SO_x	97.0
VOC	74.4
PM-10	18.7
PM-2.5	16.2
LEAD	0.07
HAPs	18.7

The pollution controls implemented at the plant keep emissions below major threshold limits (100 tpy). A majority of the emissions come from feedstock dryers.

3.4.3 Other Enerkem Facilities[31]

3.4.3.1 Innovation Center, Sherbrooke, Quebec

Enerkem has been operating its pilot plant in Sherbrooke, Quebec since 2003. This pilot plant produces small quantities of syngas, methanol, acetates and second-generation ethanol. It is equipped with various sampling ports for data collection. It is well instrumented and automated for testing and reporting.

It can feed solid materials, slurries, and liquids. To date, over 25 different types of feedstocks have been used to test and validate the technology, and for engineering design purposes. These feedstocks include municipal solid waste, wood chips, treated wood, sludge, petcoke, spent plastics and wheat straw. Enerkem works in close relationship with the University of Sherbrooke.

3.4.3.2 Advanced Energy Research Facility, Edmonton, Alberta

The Advanced Energy Research Facility in Edmonton is a collaborative effort between the City of Edmonton, the government of Alberta, via Alberta Innovates – Energy and Environment Solutions, and Enerkem. It is being developed by the City of Edmonton, and is using Enerkem's proprietary technology. It focuses on the conversion of various waste into biochemicals and advanced biofuels.

[30] Permit Mod App Review 9/2011 http://arm-permit2k.dep.state.fl.us/psd/0610096/00006402.pdf
[31] http://enerkem.com/en/facilities/overview.html

The research facility includes laboratory equipment and a well-instrumented pilot plant, attracting top researchers from the country. Enerkem will conduct some of its advanced research at the facility, led by Dr. Esteban Chornet, Enerkem's Chief Technology Officer.

3.4.3.3 Commercial Plant, Pontotoc, Mississippi

Enerkem plans to build and operate a waste-to-biofuels plant in Pontotoc, Mississippi, under its U.S. affiliate, Enerkem Mississippi Biofuels LLC.

The company has signed an agreement with the Three Rivers Solid Waste Management Authority of Mississippi (TRSWMA) for the supply of MSW. The facility will be located on the Three Rivers' landfill site. A portion of the waste will be recycled and the other portion will be converted into ethanol.

The project has been selected to receive an award of up to $50 million from the U.S. Department of Energy (DOE). It has also received strong support from local politicians and partners. This landmark project obtained a conditional commitment in January of 2011 for an $80 million loan guarantee by the U.S. Department of Agriculture (USDA).

The plant under development has successfully met the federal environmental assessment requirements and is now finalizing the process to obtain other permits required to build and operate the facility.[32] Plant construction is expected to begin in the third or fourth quarter of 2013. Construction is anticipated to take approximately 18 months.

3.4.4 Sierra BioFuels Plant (Fulcrum BioEnergy), McCarran, Nevada[33]

Fulcrum BioEnergy has completed permitting, front-end engineering and site preparation activities for their first MSW to fuels plant, the Sierra BioFuels Plant, located in the Tahoe-Reno Industrial Center, in the City of McCarran, Storey County, Nevada. The Sierra BioFuels Plant intends to produce approximately 10 million gallons of low-carbon, renewable fuel per year.

Fulcrum BioEnergy has also entered into long-term, zero-cost MSW feedstock agreements with Waste Management and Waste Connections, two of the largest waste service companies in North America, and a fuel off-take agreement with Tenaska BioFuels. They expect to begin production by the end of 2015, making the Sierra BioFuels Plant one of the United States' first fully operational, commercial-scale MSW-to-biofuels production plants.

Fulcrum's process that converts MSW into low-carbon renewable transportation fuels including jet fuel, diesel and ethanol begins with the gasification of the organic material in post-recycled MSW to a synthesis gas. This synthesis gas is purified and processed through a Fischer-Tropsch process to produce jet fuel and/or diesel or through Fulcrum's proprietary alcohol synthesis process to produce ethanol.

[32] http://enerkem.com/en/facilities/overview.html
[33] http://fulcrum-bioenergy.com/facilities.html

3.5 Environmental Considerations

Gasification as a process can produce emissions below regulated limits. However, the Integrated Waste Technology plant in Karlsruhe, Germany did have operational challenges that did cause environmental damage.[34] However; good engineering, construction, and operations can mitigate most, if not all, environmental concerns.

The primary environmental issue for gasification is air emissions. Air emissions controls and processing systems are required for a gasification plant.

Air emissions controls may include:

- When syngas is combusted in a boiler, reciprocating engine, or gas turbine, automated combustion controls and furnace geometry (for boilers) designed to optimize residence time, temperature, and turbulence to ensure combustion.
- For combustion of syngas in a boiler, low-NO_x burners and/or a Selective Non-Catalytic Reduction (SNCR) system for reduction of NO_x emissions. Selective Catalytic Reduction (SCR) is typical for exhaust gases from reciprocating engines and gas turbine.
- Baghouse (fabric filter) for removal of particulate matter from flue gases.
- Activated carbon injection (followed by a baghouse) for removal of trace metals (such as mercury).
- Wet scrubber for removal of chlorides/HCl (may produce salable HCl).
- Wet, dry, or semi-dry scrubber for SO_2 (may produce salable gypsum).
- Final baghouse for removal of fine particulate matter after dry or semi-dry scrubbers.

Air emission control equipment to accomplish this syngas and/or flue gas clean-up is commercially available and is able to reduce air emissions to levels well below regulatory limits.[35]

There is little published air emission data on gasification plants operating on MSW or RDF. The Greve in Chianti, Italy, plant had limited air emissions data, but indicated emissions below regulated limits. Emissions from gasification may cause fuel burned nitrogen to form ammonia or hydrogen cyanide which could require catalytic cracking to treat the syngas.[36] However, the INEOS and Enerkem plants appear to meet air emission requirements.

Gasification does have the potential to form dioxins. However, the production of dioxins is relative to the oxygen concentration of the syngas. Since gasification requires limited amounts of oxygen

[34] "Thermoselect Reality Check." http://www.greenaction.org/incinerators/documents/factsheet_ThermoselectRealityCheck.pdf" viewed December 4, 2011

[35] "Evaluation of Alternative Solid Waste Technologies." Prepared for the City of Los Angeles by URS Corporation, September 2005. Page 2-14 and 2-15.

[36] "Thermal Methods of Municipal Waste Treatment." L-Tech Innovation LTD. 2003. Page 40.

for the process, dioxin formation is unlikely. In two gasification plants in Europe, dioxin levels were below the detection levels.[37]

Other environmental considerations include water and residual disposal. The liquid used for syngas cooling can be cleaned up to surface water discharge standards using conventional equipment and processes. Additionally, the liquid is usually recycled in the plant which further reduces discharge. Residuals disposal from gasification of MSW is expected to be similar to ash disposal for MSW combustion. Ash disposal for MSW combustion is well regulated to protect human health and the environment.

Gasification technologies claim two important advantages over traditional WTE systems with respect to environmental impacts:

- Reduced Air Emissions – Since the syngas is cleaned prior to combustion, gasification technology vendors claim significant reductions in air emissions.
- Vitrification of Ash – Gasification technologies melt and then cool ash residues to form a vitrified ash by-product, which effectively immobilizes heavy metals.
- Air emissions from MSW gasification facilities are controlled as follows:
  - Particulates and Metals – Fabric Filters.
  - Mercury and Dioxins – Carbon Packed Bed.
  - Acid Gases – Dry Scrubbers.

3.6 Application of Current Waste Stream

3.6.1 Outputs

Outputs from a gasification process are typically electricity and/or chemicals. Current plants appear to be focused on chemical production from gasification processes. Primarily, ethanol and methanol are being or are proposed to be produced at MSW gasification plants. This is likely a result of the higher margins available from producing chemicals and fuel versus electricity.

The following sections discuss the three major component outputs from a gasification process. Further investigation and selection of a specific process and a vendor would be needed to provide a specific mass balance for a gasification process. This could be completed in a subsequent report if gasification is a selected process for further study by R/W Counties.

3.6.1.1 Recovered Gas

The syngas from gasification consists primarily of carbon monoxide, hydrogen, nitrogen and carbon dioxide. The amount of each gas depends on the amount and quality of air, oxygen or steam used in the gasification process. More air or oxygen brought into the system tends to increase the carbon monoxide and carbon dioxide amounts and can produce acid gases. Increases in steam tend to increase hydrogen quantities. The gas composition is usually dictated by the end user of the gas;

[37] Ibid.

however, most commercial products tend to try to balance gas output at 30% to 35% each for carbon monoxide and hydrogen, with the remainder being carbon dioxide and some trace gases. [38]

3.6.1.2 Recovered Liquid

Liquids from a gasification process tend to be in the form of tars. The amount and composition of tars is dependent on the operating condition of the gasifier. Elliot[39] classified tars into three primary categories. The category of tar that forms during the gasification process depends on the temperature of the process. Table 3-3[40] provides the categories of tars formed.

Table 3-3
Categories of Tars

Category	Formation Temperature	Constituents
Primary	750-1100°F	Mixed Oxygenates, Phenolic Ethers
Secondary	1100-1500°F	Alkyl Phenolics, Heterocyclic Ethers
Tertiary	1500-1800°F	Polynucleic Aromatic Hydrocarbons

3.6.1.3 Recovered Ash

With a gasification process and the introduction of oxygen into the process, some materials will burn and ash is formed. The amount of ash and its composition is dependent on feedstock, oxygen availability and temperature of the process. Primarily the ash contains heavy metals remaining from the gasification process. The ash is estimated to be 8% to 15%[41] of the original volume of material. Constituents of concern in the ash would be lead, cadmium and mercury. The ash from gasification would need to be managed in the same manner as the ash from incineration of MSW.

3.7 Financial Performance

Economic studies for gasification plants in North America have not been published. Most of the plants in North America in the pilot stage have limited data available. The economics of a pilot plant may not be relevant to a full scale plant. Recently published information on gasification economics indicates a tipping fee of $100-$300 per ton with capital costs in the range of $275,000 per ton per day of waste capacity (a 250 TPD plant capital costs would be $68.75 million).[42]

Economic analysis of an MSW fueled gasification plant in Greve in Chianti, Italy reports capital costs were $20 million with an additional $13 million upgrade for a 200 tons per day RDF gasifier ($165,000 per ton per day). No operating costs for this plant were available.[43]

[38] Klein, Alexander. "Gasification as an Alternative Process for Energy Recovery and Disposal of Municipal Solid Waste." Masters Thesis. Columbia University. May 2002.
[39] Elliott, D.C. "Relation of Reaction Time and Temperature to Chemical Composition of Pyrolysis Oils," ACS Symposium Series 376, *Pyrolysis Oils from Biomass*.
[40] Evans, R.J., Milne, T.A. "Chemistry of Tar Formation and Maturation in the Thermochemical Conversion of Biomass," Developments in Thermochemical Biomass Conversion, Vol. 2, 1999.
[41] "Waste Gasification Impacts on the Environment and Public Health," A Blue Ridge Environmental Defense League Report, April 1, 2002.
[42] O'Brien, Jeremy K. "Waste Conversion Technologies." MSW Management. January/February 2012 Page 13-18
[43] "Case Study on Waste-Fuelled Gasification Project, Greve in Chianti, Italy." IEA Bioenergy Agreement – Task 36. D.L. Granutstein. June 2003, Page 11

TPS Termiska gasification plant published a capital cost of $171 million ($1996) for a 1,200 tons per day plant ($142,500 per ton per day). Annual gross operation and maintenance costs were $35.6 million ($1996) with electrical revenues of $16.2 million annually. The net cost for the process was estimated to be $38.91 (1996$) per ton of MSW.[44]

Various other economic studies were completed at small pilot plants and attempts were made to estimate "scaled up" plant costs.[45] However, the gasifiers were based on coal or wood pellets and are not applicable to this study.

The nine local government procurements involving waste conversion technologies have, to date, not resulted in actual contracted construction cost or tipping fee data for MSW gasification facilities. In the City of Los Angeles procurement, the Thermoselect proposal indicated a tipping fee of $185 per ton while the Ebara proposal was $289 per ton.

In addition, the Thermoselect tipping fee for a 312-TPD facility was $131 per ton, and the construction cost for the facility was $276,000 per daily ton of capacity. Since these numbers are associated with proposals rather than negotiated contracts, they should be used with caution. Japanese facilities represent the best source of actual cost data. Estimated tipping fees for MSW gasification facilities in Japan are in the $200 to $300 per ton range.[46]

3.8 Summary

Gasification appears to be a promising technology that could be effective in converting waste materials into fuels and chemicals. The key developments for this technology are the plants in Edmonton, Alberta and Vero Beach, Florida. If these plants can be shown to be effective at a reasonable tipping fee, further plants may be developed.

At this time, these plants are in the early stages of operating and are expected to go through a significant commissioning process. After the commissioning process, if a sustainable plant is the outcome, gasification technologies applied to MSW should expand.

Gasification faces several challenges in expanding technology beyond the two plants mentioned. These challenges include:

- **Cost.** Given the current plants appear to create fuels; cost volatility may be a challenge for investment into a waste gasification to fuels process. Additionally, waste jurisdictions that have low tipping fees (<$100/ton) may find this technology not economically viable. More study of commercial scale plants is needed to better understand costs for gasification.

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[44] Rensfelt, E. "Swedish Biomass Gasification Activities." TPS Termiska Processor AD. March 2011.
[45] Granatstein, D.L. "Fluidized Bed Gasification as a Means of Converting Waste to Energy." Natural Resources, Canada, Ontario, CA. 2004
[46] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.

- **Scale Up.** Many vendors of gasification systems point to pilot scale plants as demonstration of the technology. However, scale up of pilot plants creates significant challenges. Typically, scale ups greater than three (3) are considered risky.

- **Permitting.** Most states do not have an appropriate regulatory framework to permit gasification facilities using waste as a feedstock. While air permitting for a gasification facility is relatively straight forward, permitting facilities to accept and convert waste to products, like ethanol and methanol, can be challenging. Oregon is moving toward comprehensive conversion technology rules that may be a template for other states to consider.[47]

Table 3-4 shows the advantages and disadvantages for an MSW gasification system.

Table 3-4
Potential Advantages and Disadvantages of Gasification

Advantages	Disadvantages
♦ Not incineration ♦ Efficient energy production through combustion of gases ♦ High temperatures can make the process flexible to other waste streams ♦ Recycling can be enhanced by up-front separation ♦ Fuels production may be economically superior to electrical generation.	♦ Most systems require MSW pre-treatment to remove non-organic waste and homogenize the material (similar to RDF production) ♦ Unproven on a commercial scale for MSW in the United States ♦ Permitting – no clear path. ♦ System can be sensitive to non-organic feedstock

If the Enerkem, Alberta, the future plant in Pontonac, Mississippi and the Fulcrum plant in Nevada succeed, it may be a considerable turning point for the gasification of MSW. Successful conversion of the MSW to biofuels would be considered a "game changer" to MSW management. However, the application of the gasification technology to any specific location in the U.S. may face considerable challenges.

The Enerkem Waste-to-Biofuels Project in Edmonton, Canada may be a worthwhile facility to tour when it becomes fully operational.

[47] http://www.deq.state.or.us/lg/sw/conversiontechnology.htm

4 Pyrolysis

4.1 Process

Pyrolysis is a thermal breakdown process of carbon based materials in an oxygen-deficient atmosphere using heat to produce syngas. The process does not allow air or oxygen to enter the process so there is no direct burning of the waste material.[48] Based on descriptions of several United States based projects, most at the pilot level, managing MSW through pyrolysis appears to require several process steps:

- Pre-processing, this typically includes a bag opener, a sorting or screening system to separate non-organic recyclables, and a shredding or size reduction process.
- Drying, this involves evaporation of moisture from the waste feedstock. This typically occurs through heating the feedstock before it enters the pyrolysis system.
- Recovery and refinement of oils, gases, and solids from the pyrolysis process.
- Power generation or gas combustion, typically to support on-site processes.

Pilot and demonstration projects also note the need to clean the output gases, possibly through an electrostatic precipitator (ESP) or wet scrubbing process.

The result of these processes is intended to be the transformation of MSW into pre-separated recyclable materials and three process components; gas, liquid, and solid (sometimes referred to as "char.").

The composition of the pyrolytic product is determined by the temperature, speed of process, and rate of heat transfer. Lower pyrolysis temperatures usually produce more liquid products, and higher temperatures produce more gases. Slow pyrolysis can be used to maximize the yield of solid char and is commonly used to make charcoal from wood feedstock. Fast or "flash" pyrolysis is a process that uses a shorter exposure time at temperatures of approximately 930°F. Typical exposure times for fast pyrolysis are less than one second. Rapid quenching of pyrolytic decomposition products is used to "freeze" the decomposition products and condense the liquids before they become low molecular weight gaseous products. This process results in a product that is up to 80 percent liquid by weight. Gases produced during the pyrolysis reaction can be utilized in a separate reaction chamber to produce thermal energy. The thermal energy can be used to produce steam for electricity production. It can also be used to heat the pyrolytic reaction chamber or dry the feedstock entering the reaction chamber. If pyrolytic gases are combusted to produce electricity, emission control equipment is needed to meet regulatory standards.[49]

4.2 Performance

Pyrolysis processes as applied to MSW began in North America in the 1970's. Two particular projects were the San Diego Flash Pyrolysis Facility and the Andco-Torrax Pyrolysis system. A

[48] Young, Gary C. Municipal Solid Waste to Energy Conversion Process. John Wiley & Sons, Inc. 2010. Page 3
[49] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.

summary of both projects is provided. Since there are no operational pyrolysis plants using MSW in North America, these two plants are the best available data on performance of pyrolysis plants.

4.2.1 San Diego Pyrolysis Facility, Occidental Research Corporation[50]

A full-scale MSW pyrolysis facility, the 200 TPD San Diego Flash Pyrolysis Facility was constructed in the United States. The San Diego facility was intended to be operated as a demonstration project only prior to development of a much larger 1,000 to 2,000 TPD facility. The facility was constructed and operated by the Occidental Research Corporation (Occidental) under a turnkey contract with San Diego County and some financial support ($4.2 million) from the EPA.

Construction on the facility began in February 1976. Following a seven-month shakedown period by a third party, a one-year testing and evaluation phase began in August 1977. The facility was closed in July 1978.

The facility was intended to run waste receiving and pre-processing operations eight hours per day, six days per week (2,496 hours per year) with all other operations intended to run 24 hours per day, six days per week (7,488 hours per year). Despite this planned schedule, during the eleven months between the start of the third party evaluation and facility closure, the pyrolysis system operated only 140 hours. The facility was never able to complete EPA's requirement for 72 hours of consecutive operation.

The limited amount of operating time was "attributed to excessive mechanical problems and breakdowns experienced throughout the plant, especially in the pyrolysis system." Operating problems were reported to occur at all stages of the processing, including an inability to dry feedstock to design specifications, an inability to replace outside heating fuel sources with internally produced pyrolytic gas, and problems separating solids and gases that led to blockages in a variety of waste handling and material delivery systems. Taken as a whole, the problems led to the production of a pyrofuel, the intended facility output, that did not meet market specifications for moisture content and thus, heating values.

4.2.2 Andco-Torrax Pyrolysis System[51]

The Andco-Torrax Pyrolysis (Andco) System was intended to convert MSW into a usable gas, which could be burned to produce heat and generate steam. It was demonstrated in Eric County, New York, beginning in 1972. Additional commercial (full-scale applications) facilities were reported as under construction in Europe in 1977 and 1978.

The Andco system report provided design and operating assumptions and cost projections for facilities at three sizes; 331 TPD, 992 TPD, and 1,653 TPD. At the 992 TPD design through put level, a facility was assumed to have a utilization factor of 85 to 90 percent per year and some system redundancy (i.e., back-up systems) necessary for production reliability. Site requirements were estimated at eight (8) acres for staging, buildings, load-out, and traffic flow.

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[50] Stoller, Paul J. and Walter, R. Niessen. "Lessons Learned from the 1970s Experiments in Solid waste Conversion Technologies." 17th Annual NAWTEC. May 18-20, 2009. Chantilly, Virginia.

[51] USEPA. Engineering and Economic Analysis of Waste to Energy Systems, EPA – 600/7-38-086. May 1978, Pages 135-166.

The 992 TPD facility was projected to produce 2,449 TPD of steam at 493 pounds per square inch (psia) and 234 TPD of potentially reusable slag. Emissions include hydrochloric acids, sulfur oxides, nitrous oxides, carbon oxides, and hydrocarbons. Use of an electrostatic precipitator for cleaning air emissions was recommended as a means to meet federal air quality standards for CO_2 existing at the time.

The study concluded that the system was likely to be competitive with oil-based steam generators where tipping fees of approximately $10 per ton (approximately $46.00 in 2013 dollars) were charged on incoming MSW. Neither the San Diego or Andco Torrax systems are operational today.

4.3 Vendors

Pyrolysis processes are in commercial use by the metals industry for fracking contaminated non-ferrous scrap. Additionally, pyrolysis processes are used to convert polymers back to petrochemicals.[52] There are several pyrolysis systems in Japan and other countries that use MSW as a feedstock. MSW is typically used in combination with other wastes such as industrial waste, petcoke, auto shedder residue, and medical waste. Pyrolysis plants operating using MSW as a feedstock are in Japan, Europe, Australia, and Indonesia.[53] There are no known commercial MSW pyrolysis plants in North America.

Some examples of vendors that offer the pyrolysis technology include: Brightstar Environmental, Mitsui, Compact Power, PKA, Thide Environmental, WasteGen UK, International Environmental Solutions (IES), SMUDA Technologies (plastics only), Utah Valley Energy, WasteGen Ltd. /Tech Trade, and Taylor Recycling Facility LLC/FERCO.[54]

4.4 Projects

Pyrolysis systems have had some success with wood waste feedstocks. Several attempts to commercialize large-scale MSW processing systems in the U.S. in the 1980's failed, but there are several pilot projects at various stages of development. There has been some commercial-scale pyrolysis facilities in operation in Europe (e.g. Germany) on select waste streams. Vendors claim that the activated carbon byproduct from the pyrolysis is marketable, but this has not been demonstrated.[55]

The use of pyrolysis systems to process MSW has occurred mostly in Japan, where landfill space and resources are limited. In examining the three largest suppliers in Japan, the capacities of their plants represent more than two million tons of material each year, with additional plants being planned. Much of this capacity has been installed in the past five (5) years. Japan is currently the leader in the use of pyrolysis systems for MSW.

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52 "Thermal Methods of Municipal Waste Treatment." Biffaward Prograrn on Sustainable Resource Use. 2003 Page 28.
53 "Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid Waste and Business." U.C. Riverside. June 21, 2009 Page 38-41
54 Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.
55 Metro Waste Authority Alternative Disposal Feasibility Final Report. HDR Engineering, Inc., 2013.

Table 4-1 lists 12 commercially-active pyrolysis facilities that use MSW.[56]

Table 4-1
Commercially-Active Pyrolysis Facilities Using MSW[57]

Location	Company	Began Operation	MSW Capacity
Toyohashi City, Japan Aichi Prefecture	Mitsui Babcock	2002	♦ 2 x 220 TPD ♦ 77 TPD bulky waste facility
Hamm, Germany	Techtrade	2002	♦ 353 TPD
Koga Seibu, Japan Fukuoka Prefecture	Mitsui Babcock	2003	♦ 2 x 143 TPD ♦ No bulky waste facility
Yame Seibu, Japan Fukuoka Prefecture	Mitsui Babcock	2000	♦ 2 x 121 TPD ♦ 55 TPD bulky waste facility
Izumo, Japan	Thidde/Hitachi	2003	♦ 70,000 TPY
Nishi Iburi, Japan Hokkaido Prefecture	Mitsui Babcock	2003	♦ 2 x 115 TPD ♦ 63 TPD bulky waste facility
Kokubu, Japan	Takuma	2003	♦ 2 x 89 TPD
Kyouhoku, Japan Prefecture	Mitsui Babcock	2003	♦ 2 x 88 TPD ♦ No bulky waste facility
Ebetsu City, Japan Hokkaido Prefecture	Mitsui Babcock	2002	♦ 2 x 77 TPD ♦ 38 TPD bulky waste facility
Oshima, Hokkaido Is., Japan	Takuma		♦ 2 x 66 TPD
Burgau, Germany	Technip/Waste Gen	1987	♦ 40,000 TPY
Itoigawa, Japan	Thidde/Hitachi	2002	♦ 25,000 TPY

In the United States, there was a 50-TPD MSW pyrolysis demonstration facility in Romoland, California, which is owned and operated by International Environmental Solutions (IES). This facility consisted of a waste pre-processing system, a pyrolytic gasifier, a thermal oxidizer for combustion of the syngas, a waste heat recovery unit, a steam turbine, and associated air pollution control equipment.

The facility (which has recently been dismantled and moved to another site for commercial operations) intermittently processed residuals from a material recovery facility (MRF) since 2004

[56] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.
[57] Ibid

for demonstration purposes. The MRF residuals are sized reduced to a two-inch particle size and then dried to 20 percent moisture before being fed to the pyrolysis chamber. [58]

A 91-TPD MSW pyrolysis demonstration facility was constructed in 2001 by Brightstar Environmental in Wollongong, New South Wales, Australia. At this facility, the waste is first dried in an autoclave, after which the organic fraction is washed to remove sand and glass and then dried before being converted in a pyrolysis vessel. Six months following start-up, the plant was still not fully operational and was processing well below its permitted capacity.   The plant was closed in 2004.[59]

As shown in Table 4-2, MSW pyrolysis technologies have been approved for implementation or further consideration in four of the nine procurements [of recent waste conversion technologies in the United States].[60]

Table 4-2
Recent Procurement Conclusions Regarding the Technical Viability of MSW Pyrolysis

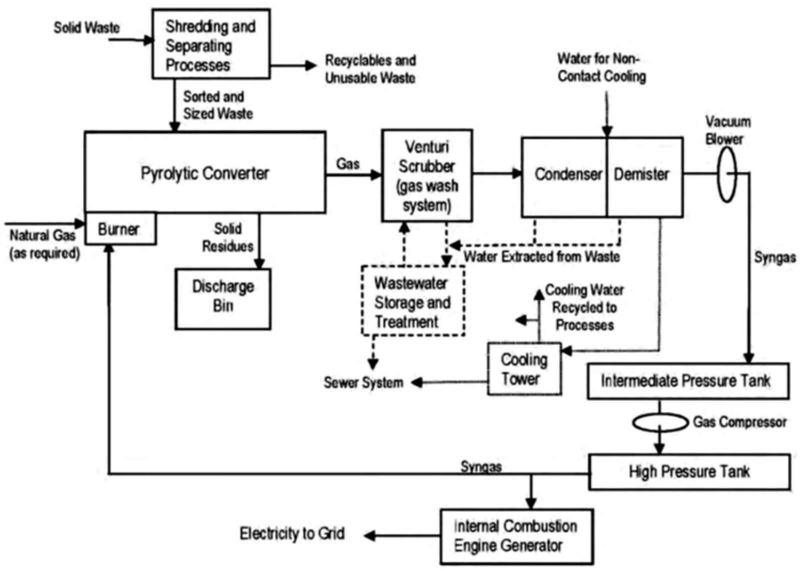
Year	Agency	Type of Procurement	Approved Pyrolysis
2007	City of Los Angeles, CA	RFP – Commercial and Emerging Technologies	WasteGen Ltd.
2012	New York City, NY	RFP	GEM America
2004	Los Angeles County, CA	RFI – Demonstration	IES
2008	Santa Barbara County, CA	RFP	IES

The Oneida Seven Generations Corporation and the City of Green Bay, WI were considering a pyrolysis plant for MSW in 2012. Called the Oneida Energy Recovery Project (project), it was to include shredding, sorting, and pyrolysis chambers to convert the waste into syngas. The syngas was proposed to be used in engines to convert the syngas to electricity.

Figure 4-1 is a simplified schematic of the primary process elements that would make up the Oneida Energy Recovery Project. The main process flow is shown in the figure with solid lines and arrows, the dashed lines represent the water that would be extracted from the waste, and the dotted lines represent the fresh water that would be used in the process to provide non-contact cooling of various process elements.

[58] Ibid
[59] Presentation by Melville Nickerson, Environmental Law and Policy Center. Illinois Counties Solid Waste Management Association, 2010 Annual Conference. September 28, 2010
[60] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.

Figure 4-1
Simplified Schematic
of Oneida Energy Recovery System Process Elements[61]



<u>Shredding and Separating Processes</u>

MSW brought to the facility would run through multiple shredding and separation steps to get to an appropriate size (2 inches or less) and to remove items such as metal, glass, and dirt that are not appropriate for the pyrolysis process. An initial shredder would break down the waste material into pieces of 8-inches or smaller. A ballistic separator would then mechanically separate the waste into one of three types of material:

1. Items with distinct width, length, and depth (three dimensions) such as cans, bottles, and similar materials. These items would be conveyed directly to further separation actions including hand picking and magnets to remove recyclable materials [including aluminum, steel, and polyethylene terephthalate (PET) and high-density polyethylene (HDPE) plastics] and waste inappropriate for the pyrolysis units (including materials with no energy value such as sheet rock, concrete blocks, and glass tiles).
2. Flat items such as paper, cardboard, and light films, which would be conveyed directly to the next shredder.
3. Small, fine material (fines) including broken glass, dust, and dirt, which would be conveyed directly to a waste bin for eventual removal from the facility.

A final shredder would then break down the material further so that no pieces would be greater than 2 inches in size. The shredded material would be conveyed to a storage silo before going to the pyrolysis process. The shredded waste would move through an enclosed tube conveyor from the silo to the pyrolysis units. Waste deliveries would occur five days a week; however, the

[61] Draft Environmental Assessment for the Oneida Seven Generation Corporation: Energy Recovery Project, Green Bay, Wisconsin, U.S. Department of Energy. August 2011. Page 12.

waste would have to be of sufficient quantity to supply the shredding processes and pyrolysis units for a full seven days of operations. Therefore, the up-front waste receipt, or tipping area would require storage for up to a three-day supply of waste. The waste would be staged to allow for the waste that had been in the facility the longest to be used first (first in, first out).

Pyrolytic Converter

From the shredding and separating processes (and the associated storage silo) the waste would move via screw auger through a pair of air lock valves and into the pyrolytic converter (or pyrolysis unit). The air locks are necessary to keep air out because the objective of pyrolysis is to decompose organic material at an elevated temperature with no, or minimal, oxygen. The outlet of the converter is similarly equipped with two air lock valves. The waste material, continually moved by the screw auger from the inlet to the outlet, would stay in the converter for 60 to 75 minutes, where it would be subjected to temperatures ranging from 850° to 1,400°F. Gases formed during decomposition of the organic material would be pulled out of the converter with a blower, while solid residues were dropped into a discharge bin as they moved out of the converter. The facility would have three of these pyrolysis units.

Venturi Scrubber

Gases pulled from the pyrolytic converter would first go through a venturi scrubber or separator. This step washes out carbon particles that may have traveled with the gas from the converter and removes some of the condensable gases. It also begins bringing the temperature of the gas down. At steady-state conditions, water used in the scrubber would be that extracted from the waste as it heated in the pyrolysis units. For start-up conditions, the scrubber would use fresh water from the city's drinking water system.

Condenser and Demister

From the venturi scrubber, the gas would go through a condenser to remove the rest of the condensable gases, which consist primarily of steam/water, but which could also include some hydrocarbons. The non-condensable gas then would go through a demister to ensure no liquid remained in the stream. Fresh water would be used in the process to provide non-contact cooling of various process components (greatly simplified in Figure 4-1). That is, the fresh water would be enclosed in pipes or radiator-like components that would allow heat to be exchanged but would keep the fresh water from contacting either gas flows or the water extracted from the waste).

Storage Tanks

From the demister, the blower would move the syngas into a storage tank with an intermediate pressure level, and a compressor would be used to move the gas into a high-pressure storage tank. Gas in the storage tanks can be used to supply the burner in the pyrolytic converter or sent to an internal combustion engine generator. Oneida expects to use a single 10,000-gallon tank for the intermediate pressure syngas and two 33,000-gallon tanks located outside the building for storage of the high-pressure syngas. The smaller vessel would operate at 10 to 15 pounds per square inch of gauge pressure (psig) and would be rated for 50 psig. The two larger vessels would operate at 50 psig and would be rated for 75 psig.

Internal Combustion Engine Generator

The internal combustion engine generator, specified as the Cummins C1540N6C, is a four-cycle, water-cooled engine, specifically designed to run on low-British thermal unit (Btu) gas, such as that which would be produced through the pyrolysis of solid waste. The engine and its electric generator have the capacity to generate 1.54 megawatts of electricity. The facility would have three of these generator sets, with a combined capacity of approximately 4.6 megawatts of electricity. Electricity from the generator would be sent to the regional grid.

Other system components include water cooling and recycling wastewater management systems and a solids discharge bin.

The specific pyrolysis system proposed for the project is the International Environmental Solutions (IES) system. IES has demonstrated their system in their Romoland, California facility. The Romoland facility is used as a pilot facility with a capacity of 30 tons per day of various feedstocks. IES was also selected by the Los Angeles County Department of Public Works to develop a 184 ton per day pyrolysis demonstration plant. However, this plant faced significant challenges and currently IES and the County of Los Angeles are exploring other options.[62] IES was also selected by Santa Barbara County, California; but since has abandoned pyrolysis for anaerobic digestion with an upfront materials recovery facility in 2012.[63]

4.5 Environmental Considerations

Environmental considerations for pyrolysis processes with MSW feedstock include air emissions and the remaining char. While pyrolysis processes also can produce a liquid, the liquid can be refined at a typical refinery. If the pyrolysis process produces a non-refinable liquid, then reverse osmosis and/or carbon absorption may be needed to cleanse the liquid component prior to refining the liquid.

Air emissions from pyrolysis processes were evaluated from the International Environmental Solutions (IES) pyrolysis plant in Romoland, California (a small test facility) and from a pyrolysis and gasification plant in Nagasaki, Japan using Thermoselect process. [64]

The IES process utilized an air pollution control system consisting of a selective non-catalytic reduction unit for NO_x control, a baghouse to capture particulate matter (PM) and a scrubber to control acid gases and volatile metals.

Emissions from the IES system from the compliance test report are shown in Table 4-3.[65]

[62] County of Los Angeles Department of Public Works, April 20, 2010. Item 44. http://file.lacounty.gov/bc/q2_2011/cms1_159240.pdf

[63] Presentation to Multi-Jurisdictional Solid Waste Task Group Conversion Technology Subgroup Meeting. December 12, 2011. http://conversiontechnologystudy.com

[64] "Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid Waste and Business." U.C. Riverside. June 21, 2009 Page 16

[65] South Coast Air Quality Management District Memorandum, "Evaluation of Source Test Report – International Environment Solutions, Romoland, California." April 18, 2007.

Table 4-3
IES Air Emissions, Romoland, California (2006)

30 Tons per day MSW		
Emissions ($mg/N\text{-}M^3@7\%O_2$)	**Measured**	**US EPA Standard**
PM	5.75	20
HCL	---	40.6
Nox	129	308
Sox	0.44	85.7
Hg	---	50
Dioxins/furans ($mg/N\text{-}M^3$)	0.000581	13

The Thermoselect process is a pyrolysis and gasification process to increase the quantity of syngas produced from MSW. The Thermoselect process is used in Japan to process MSW, MSW and industrial waste, and a new plant (2007) that processes wood chips.[66]

Emissions from the Thermoselect Nagasaki plant for 2006 are provided in Table 4-4.[67]

Table 4-4
Thermoselect Air Emissions, Nagasaki, Japan (2006)

300 Tons per Day Pyrolysis and Gasification			
Emissions ($mg/N\text{-}M^3@7\%O_2$)	**Measured**	**Japanese Standard**	**US EPA Standard**
PM	<4.7	15.4	20
HCL	11.6	126	40.6
Nox	---	320	308
Sox	---	225	85.7
Hg	---	---	50
Dioxins/furans ($mg/N\text{-}M^3$)	0.025	0.14	13

4.6 Application of Current Waste Stream

4.6.1 Outputs

Outputs from a pyrolysis process are likely to be electrical generation and oils that can be refined. However, since pyrolysis is an unproven technology as applied to MSW, the quantity and quality of outputs are unknown. However, the three outputs from a pyrolysis process include: syngas, liquid and char.

[66] "Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid waste and Business." U.C. Riverside. June 21, 2009 Page 17
[67] Kenou-Kennen, Kankyou-Kumiai. "Emissions Data of JFE Nagasaki Plant." Compliance Source Test report, April-June 2006.

4.6.1.1 Syngas

The syngas produced in a pyrolysis process contains hydrogen, methane, carbon dioxide, carbon monoxide, ethylene and ethane. The percentage of each compound in the syngas varies with the temperature of the pyrolysis process as shown in Table 4-5.[68]

Table 4-5
Percentages of Components in Syngas from Pyrolysis of MSW

	% by Volume			
Gas	**900°F**	**1200°F**	**1500°F**	**1700°F**
Hydrogen	5.56	16.58	28.55	32.48
Methane	12.43	15.91	13.73	10.45
Carbon Dioxide	33.50	30.49	34.12	35.25
Carbon Monoxide	44.77	31.78	20.59	18.31
Ethylene	0.45	2.18	2.24	2.43
Ethane	3.03	3.06	0.77	1.07

Typical syngas composition from the Purox pyrolysis process (2700°F) is shown in Table 4-6.[69]

Table 4-6
Syngas Composition from Purox Pyrolysis Process

Gas	Percent (%), Dry Basis
Hydrogen	24
Carbon Dioxide	40
Carbon Monoxide	24
Methane	5
Acetylene	0.7
Ethylene	2.1
Ethane	0.3
Other Hydrocarbons	2.35
Nitrogen	1
Argon	0.5
Hydrogen Sulfide	0.05

4.6.1.2 Liquids

Liquids provided from pyrolysis processes contain tars and oils composed of acetic acid, acetone, methanol, and other hydrocarbons. Liquid production is somewhat influenced by the pyrolysis temperature but only a few pounds of difference in liquid production was observed when pyrolysis

[68] Tchobanaglous, George, Hilary Theisen and Samuel Vigil. Integrated Solid Waste Management: Engineering Principles and Management Issues. Page 628
[69] Farberow, Carrie, and Kevin Bailey. "Green is Seen in Fertilizers. A New Approach to Municipal Solid Waste Management." University of Oklahoma. May 1, 2007. Page 8.

temperatures ranged from 900°F to 1700°F. Higher temperatures produce less liquid.[70] Liquids from a pyrolysis process are referred to as tars. Liquids can be refined and further processed to make fuel.

4.6.1.3 Char

The final product of the pyrolysis process is a solid, called char, which consists of pure carbon and inert materials from the MSW feedstock. According to a Regional Director of a pyrolysis system vendor, char is typically a non-toxic, non-hazardous product with a heating value of 7,000 to 8,000 Btus per pound. It may have value as a fuel source or potential soil additive.[71]

4.6.1.4 Mass Balance

The mass balance for pyrolysis systems has not been well studied. Studies on the Purox Pyrolysis system yielded the following mass balance:[72]

Input	Output
100 tons of MSW	8.93 tons metals
20.62 tons of oxygen	66.15 tons syngas
	20.63 tons slag
	20.67 tons water

In a study of pyrolysis of RDF in Japan, at 932°F with a residence of 30 minutes, outputs were 28% by weight liquids, 30% by weight gases and 42% by weight solids.[73]

Mass balance from the San Diego Flash Pyrolysis facility is provided in Table 4-7[74]

Table 4-7
Pyrolysis Mass Balance for Flash Pyrolysis (lbs.)

Temp (°F)	Refuse [1]	Gases	Pyroligneous Acids and Tars[2]	Char	Mass Accounted For
900	100	12.33	61.08	24.71	98.12
1200	100	18.64	18.64	59.18	99.62
1500	100	23.69	59.67	17.24	100.59
1700	100	24.36	58.70	19.67	100.73

1 On an as-received basis, except that metals and glass have been removed.
2. This column includes all condensable and the figures cited include 70 to 80 percent water.

[70] Tchobanaglous, George, Hilary Theisen and Samuel Vigil. Integrated Solid Waste Management: Engineering Principles and Management Issues. Page 628
[71] Doble, Bill. "Pyrolysis for Low Cost Waste Disposal and Generation of Electricity. http://eco-web.com/editorial/03280.html
[72] Farberow, Carrie, and Kevin Bailey. "Green is Seen in Fertilizers. A New Approach to Municipal Solid Waste Management." University of Oklahoma. May 1, 2007. Page 8.
[73] Kuen-Sung Lin, et. al. "Pyrolysis Kinetics of Refuse Derived Fuel." Fuel Processing Technology 60 (1989). Page 103-110.
[74] Drobny, N.L., et. al. "Recovery and Utilization of Municipal Solid Waste (SW-10c) U.S. EPA 1971 Page 77.

4.6.1.5 Likely Outputs for Newport

If pyrolysis is implemented at Newport, likely outputs would be similar to the outputs from RDF experienced in Taiwan, Japan. In that study, RDF, ranging in size from 1" to 4", was subjected to pyrolysis at a temperature of 932° F for 30 minutes and produced 28% oils, 30% gases, and 42% solids (by weight). Using current (2012) waste stream at Newport consisting of 329,656 tons RDF, an output from pyrolysis process could be expected as 92,304 tons oils, 98,897 tons gases and 138,455 tons of solids (char).

4.7 Financial Performance

With the lack of plants in North America, no published economic studies are known. Recent published information on pyrolysis plants with MSW feedstock indicated tipping fees for new facilities would be in the range of $100-$300 per ton with capital costs approximated as $275,000 per design ton per day.[75] Since most plants that have operated in the past experienced significant problems, the cost for a pyrolysis plant could be excessive.

4.8 Summary

There are no pyrolysis facilities in commercial operation in the U.S. with minimal current development activities. The most recent plant proposed in Green Bay, Wisconsin is no longer being pursued. Much of the data on pyrolysis plants is over 30 years old and should not be relied upon as representative of current technology. The majority of pyrolysis plants are located in Japan and little is known about feedstock, emissions and cost. Extensive, in-depth investigation is required if pyrolysis is going to be pursued as an alternative MSW technology.

No potential advantages and disadvantages are noted due to the limited documented information with the technology handling MSW. There are no operating plants to tour in North America.

[75] O'Brien, Jeremy K. "Waste Conversion Technologies." MSW Management. January/February 2012 Page 14-15

5 Plasma Arc

5.1 Process

The plasma arc technology is a heating method that can be used in both pyrolysis and gasification systems. This technology was developed for the metals industry in the late nineteenth century. Plasma arc technology uses very high temperatures to break down the feedstock into elemental byproducts. Plasma arc technology uses carbon electrodes to produce a very-high-temperature arc ranging between 5,000 to 13,000 degrees Fahrenheit that "vaporizes" the feedstock. The high-energy electric arc that is struck between the two carbon electrodes creates a high temperature ionized gas (or "plasma"). The intense heat of the plasma breaks the MSW and the other organic materials fed to the reaction chamber into basic elemental compounds[76].

The inorganic fractions (glass, metals, etc.) of the MSW stream are melted to form a liquid slag material which when cooled and hardened encapsulates toxic metals. The ash material forms an inert glass-like slag material that may be marketable as a construction aggregate. Metals can be recovered from both feedstock pre-processing and from the post-processing slag material.

Similar to gasification and pyrolysis processes, the MSW feedstock is pre-processed to remove bulky waste and other undesirable materials, as well as for size reduction. Plasma technology also produces a low Btu syngas; this fuel can be combusted and the heat recovered in a heat recovery steam generator (HRSG), or the syngas can be cleaned and combusted directly in an internal combustion engine or theoretically a gas turbine. Electricity and/or thermal energy (i.e. steam, hot water) can be produced by this technology[77].

Plasma torches used in the device can be one of two types: the transferred torch and the nontransferred torch. The transferred torch creates an electric field between an electrode (the tip of the torch) and the reactor wall or conducting slag bath. The non-transferred torch creates the electric arc internal to the torch and sends a process gas (such as air or nitrogen) through the arc, where it is heated, and then leaves the torch as a hot gas.

For applications in which MSW is processed, the intense heat actually breaks down the molecular structure of the organic material to produce simpler gaseous molecules such as carbon monoxide (CO), hydrogen (H_2), and carbon dioxide (CO_2). The inorganic material is vitrified to form a glassy residue. The glassy residue (called "slag") may have a market as aggregate.

A significant requirement for the MSW plasma arc gasification process is that the MSW must be preprocessed before being fed into the plasma arc gasifier. As an example, for the Plasco Energy process, the waste must be shredded to a two-inch or less particle size. In addition, the process, in some applications, appears to require the use of supplemental fuels to moderate and control the gasification process.[78]

[76] Metro Waste Authority Alternative Disposal Feasibility Final Report by HDR Engineering, Inc., 2013.
[77] Ibid
[78] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.

5.2 Performance

Vendors of this technology claim efficiencies that are comparable to conventional mass burn technologies (550-650+ kWh/ton (net)). Some vendors are claiming even higher efficiencies (800-1,100 kWh/ton (net)). These higher efficiencies may be feasible if a combined cycle power system is proposed. However, the electricity required to generate the plasma arc, as well as the other auxiliary systems required, brings into question whether more electrical power or other energy products can be produced than what is consumed in the process. Plasma arc gasification syngas may also be used as a chemical feedstock[79].

Performance data of actual plants is limited. The MSW cited plant performance data is from the Utashinai Plasma Facility in Japan. However, the plant does not take traditional MSW as a feedstock[80] and has had a low availability record (74% run time).[81]

Based on a review of commercial facility operating data, as well as recent studies and technology procurements, there appears to be three areas of concern regarding the technical viability of MSW plasma arc gasification in North America.

- **Ability to Process North American MSW** – The sole commercially operating MSW plasma arc gasification facility in Japan does not process traditional MSW but shredded paper and plastics from the Japanese MSW stream. A key technical concern is how processing North American MSW will impact the performance and costs of plasma arc gasification technologies in North America.
- **Preprocessing Requirements and Costs** – The Plasco Energy process requires wastes to be shredded to a nominal two inches in size. This can increase costs for operations of a plasma system.
- **Scale Up and Demonstration on a Commercial Basis** –Scale up from the currently existing 200 TPD plasma facility to a larger facility (such as 800 TPD) can cause significant problems in the process. Typically, scale up facilities are incremental in nature versus large scale ups to identify and address problems.

MSW plasma arc gasification facilities produce 400 to 1,250 kWh/ton including supplemental fuel. However, a substantial portion of the generated electricity is used in the plasma arc and other plant processes (conveyors, shredders, etc.). As a result, the net power output available for sale is likely to be comparable to or lower than the amount of power generated from comparable WTE facilities.[82]

[79] Metro Waste Authority Alternative Disposal Feasibility Final Report by HDR Engineering, Inc. 2013
[80] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.
[81] Ibid
[82] Ibid

5.3 Vendors

There are a number of plasma arc technology vendors, including Startech, Geoplasma, PyroGenesis Canada, Inc., Westinghouse, Alter NRG, Plasco Energy, Integrated Environmental Technologies and Coronal. Recent procurement activities for plasma systems are included in Table 5-1.

Table 5-1
Recent Procurement Conclusions Regarding the Technical Viability of MSW Plasma Gasification[83]

Year	Agency	Type of Procurement	Approved Plasma Arc Gasification Technologies
2004	New York City, NY	Pre-Procurement Study	♦ Rigel Resource Recovery and Conversion (Westinghouse)
2006	St. Lucie County, FL	RFP	♦ Geoplasma
2007	Tallahassee, FL	RFP	♦ Green Power Systems
2008	SVSWA, CA	RFP	♦ Plasco Energy
2008	Santa Barbara County, CA	RFP Prequalification	♦ Plasco Energy ♦ AdaptiveNRG
2008	Honolulu, HI	RFP	♦ Geoplasma

It is important to note that none of the projects in Table 5-1 has proceeded to an operational plant.

5.4 Projects

Plasma technology has received considerable attention. There are some large-scale projects being planned in North America (e.g. Koochaching County, Minnesota; and Atlantic County, New Jersey). In addition, there are a number of commercial-scale demonstration facilities in North America, including the Plasco Energy Facility in Ottawa (Figure 5-1), Ontario and the Alter NRG demonstration facility in Madison, Pennsylvania. PyroGenesis Canada, Inc., based out of Montreal, Quebec, also has a demonstration unit (approximately 10 tpd) located on Hulburt Air Force Base in Florida that has been in various stages of start-up since 2010.[84]

There are currently plasma gasification plants operating in Japan, Canada and India. For example, a facility in Utashinai, Japan has been in commercial operation since 2001, gasifying municipal solid waste and auto shredder waste to produce electricity. However, plasma plants in the U.S. have struggled. The Geoplasma plant in St. Lucie, Florida was not constructed due to various reasons despite having the permits. Other vendors have faced financial and technical problems that have delayed projects or outright cancelled development. Many of the projects have faced financial challenges, making project development impossible. A list of known projects using plasma technologies is provided in Table 5-2.[85]

[83] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.
[84] Metro Waste Authority Alternative Disposal Feasibility Final Report by HDR Engineering, Inc., 2013.
[85] http://www.gasification.org/page_1.asp?a=84&b=85

5.4.1 Plasco Energy

Plasco Energy is a plasma arc system vendor based in Ottawa, Canada. Plasco uses plasma arc technology in a gasification system for MSW. Plasco's Trail Road facility was awarded a 20 year contract for the City of Ottawa to supply 100,000 tons per year of MSW to the plant. Plant construction is expected to begin in late 2013 and be fully operational in 2015. Expected tipping fee at the facility is $84.58 per ton.[86]

Figure 5-1
Plasco Energy Demonstration plant, Ottawa, Canada

Plasco was also selected to move ahead in the permit process at the Salinas Valley Solid Waste Authority (SVSWA) in California. The Plasco system proposed for that project consists of two or three Plasco units to process 87,000-123,000 tons per year at an estimated tip fee of $70-$77 per ton.[87]

However, in 2012, the Renewable Portfolio Standard Certification of Plasco's technology was removed from the project. This made the project environmentally unviable and Plasco notified SVSWA that they were withdrawing from the project.[88]

[86] Plasco Press Release dated December 17, 2012. http://www.plascoenergygroup.com
[87] Salinas Valley Solid Waste Authority Conversion Technology Commission. August 13, 2009 meeting minutes. http://swswa.org/pdf/ct/ct%20history/2011_01_05.pdf
[88] 2012 Monterey County Civil Grand Jury, Interim Report No. 5, Salinas Valley Solid Waste Authority. http:/www.monterey.courts.ca.gov

Table 5-2
Plasma Arc MSW Gasification Facilities [89]

Location	Owner	Technology Supplier	Start of Operation	Feedstock	Through-put (TPD)
Yoshii, Japan	Hitachi Metals Ltd.	Westinghouse Plasma Corp.	1999 (Pilot Plant)	MSW	25
Utashinai City, Japan	Hitachi Metals Ltd.	Westinghouse Plasma Corp.	2003	MSW (shredded paper/plastics) – 66%, auto shredder waste – 34%, coke50	200
Mihami-Mikata, Japan	Hitachi Metals Ltd.	Westinghouse Plasma Corp.	2002 (Pilot Plant)	MSW (sorted) – 78% Sewage sludge – 22%	22
Ottawa, Canada	Plasco Energy	Plasco Energy	2007 (Pilot Plant)	Shredded MSW (2 inches); High Carbon Feed (shredded plastics – 2 to 5% of feedstock)	94

5.4.2 Westinghouse Plasma Corporation

Westinghouse Plasma Corporation (WPC) has spent over 30 years developing plasma technology for industrial applications. Over the last 10 years, WPC has researched plasma technology application to MSW and industrial wastes. WPC's main test center is located near Madison, Pennsylvania and has been used to evaluate plasma technology using various feedstock. Testing at the facility was conducted on MSW, RDF, C&D Waste, hazardous wastes including PCBs, wastewater sludge, tires, auto shredder residue, incinerator ash, and heavy oil. WPC primarily is focused on plasma technology in a gasification system.[90]

5.4.3 Hitachi, Ltd

Hitachi, Ltd. also has three projects that utilize plasma technology on waste materials. The plant in Yoshii, Japan uses plasma technology to convert 25 tons per day of MSW to steam for industrial use. The Hitachi plant in Utashinai, Japan uses plasma gasification technology to convert auto shredder residue to syngas to produce steam for industrial use and to generate electricity. The third Hitachi plant in Mihama and Mikdata, Japan treats 24 tons per day of MSW and 4 tons per day of sewage sludge to generate electricity that is used in a waste water treatment plant.[91]

5.4.4 Air Products

Air Products has started construction on their Tess Valley Renewable Energy Facility in England. Westinghouse Plasma Corporation supplied the plasma gasification unit and commissioning of the plant is anticipated in 2014. The facility is expected to receive 1,000 tons per day of pre-sorted MSW that will be treated in the plasma gasification unit to convert the MSW to syngas. The syngas

[89] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.
[90] http://www.westinghouse-plasma.com/projects/
[91] http://www.net1.doe.gov/technologies/coalpower/gasification/gasification/4-gasifiers/4-1-4-1a_westinghouse.html

will be sent to a power island which consists of a combined recovery steam generator and a steam turbine.[92]

5.4.5 Phoenix Solutions Company[93]

Phoenix Solutions Company was founded 56 years ago as FluiDyne Engineering Corporation. In 1993, FluiDyne Engineering Corporation reformed in Phoenix Solutions Company with a focus on plasma heating systems.

The Phoenix Solutions Company plasma heating system consists of plasma arc torches, process furnace, current controlled DC power supply, control system, water/gas manifold, starting system and a torch manipulation system. The heating system can be used for ash melting, processing nuclear and biomedical waste and as PCB waste material.

Phoenix Solutions Company has a test facility is Hutchinson, Minnesota. The facility is used to evaluate systems prior to shipping and installations. Additionally, the facility has a plasma heating system for material testing at the pilot scale.

Phoenix Solutions Company plasma heating system was utilized by Plasco Energy Group in their plasma gasification process. GE also uses the plasma heating furnace for R&D activities.

Phoenix Solutions Company is a supplier to plasma gasification project developers like Plasco, Ebaram and Nippon Steel Corporation. The company focus is on smaller scale application (they have five (5) plasma systems in Japan converting 270 tons/day of waste materials). The test facility in Hutchinson does offer an opportunity to understand plasma gasification on RDF from Newport and could serve as a pilot test facility for plasma technology.

5.5 Environmental Considerations

Plasma arc gasification technologies, like traditional MSW gasification, can claim two important advantages over traditional WTE systems with respect to environmental impacts:

- **Reduced Air Emissions** – Since the syngas is cleaned prior to combustion, gasification technology vendors claim significant reductions in air emissions. Air emissions from MSW plasma arc gasification facilities are controlled as follows:
  - Particulates and Metals – Fabric Filters.
  - Mercury and Dioxins – Carbon Packed Bed.
  - Acid Gases – Dry Scrubbers.[94]

- **Vitrification of Ash** – Gasification technologies melt and then cool ash residues to form a vitrified ash by-product, which effectively immobilizes heavy metals.

[92] http://www.westinghouse-plasma.com/projects
[93] www.phoenixsolutionsco.com
[94] Solid Waste Association of North America (SWANA) Applied Research Foundation. Waste Conversion Technologies. 2011.

5.6 Application of Current Waste Stream

Potentially, plasma arc technology could be applied to the entire available R/W Counties waste stream. However, not enough documented information is available to make an estimate as to the specific application of plasma arc technology to the Newport RDF waste stream. A good first step may be utilizing the Phoenix Solutions Company Hutchinson, Minnesota test facility. Actual testing of Newport RDF using plasma arc technology would provide valuable information on applicability of the technology on Newport RDF.

5.7 Outputs

Outputs from plasma arc process are syngas and slag. Syngas can be converted to electricity using an engine/generator set and/or converted to chemicals like methanol and ethanol. The slag that is formed could potentially have value as an aggregate. Plasma arc processes using MSW in North America are not developed so the specific value of outputs is not known.

5.7.1 Recovered Gas

Gas from plasma based processes typically includes carbon monoxide (CO), hydrogen (H_2) and carbon dioxide (CO_2). Other gases may also form (SO_x, HCL, and HF) but are usually neutralized in a gas scrubber. The gas has a typical heat value of 300 Btu/scf, similar to coal gas.

5.7.2 Vitrified Residue

The inorganic fraction of the waste stream is converted to a silicate based slag. The slag is formed from the glass, soil, minerals and metals in the MSW. In a plasma pyrolysis process, the lack of oxygen causes metal, halogen and sulfur atoms to bond with the silicate. This atomic bonding makes leaching of the materials difficult. Any waste processing facility generating an ash or slag is required by the United States Environmental Protection Agency (USEPA) to subject the ash to a Toxicity Characteristic Leaching Procedure (TCLP) test. The TCLP test is designed to measure the amount of eight elements that leach from the material being tested. Data from existing facilities, even those processing highly hazardous materials or medical waste, show results that are well below regulatory limits.

5.8 Financial Performance

The geoplasma St. Lucie County, Florida project had a reported capital cost of $120 million. However, the plant was not constructed and the reported capital costs did not include waste pre-processing costs that can be significant.[95] The Tees Valley Renewable Energy Facility is reported to cost $500 million in capital costs for a plant that accepts 345,000 tons per year.[96] The lack of operational plasma arc plants that utilize MSW or RDF as a feedstock limit available financial information. However, capital costs for the Plasco facilities are estimated to be $86/ton of waste per day.[97] The costs do not include typical O&M costs. For reference, O&M costs for WTE

[95] SWANA Applied Research Foundation. Waste Conversion Technologies. 2011.
[96] http://www.nepic.co.uk/presentation/IntL_bio_conf_2012/lisa.jordan.pdf
[97] EPA. State of Practice for Emergency Waste Conversion Technologies. EPA 600/R-12/705. October 2012. Page 42

facilities are reported to be \$28/ton[98] to \$65/ton.[99] This would translate to a tip fee in the range of \$114 to \$151 per ton.

5.9 Summary

At this time, it is difficult to obtain data on the plasma process. The major plasma facilities are in Japan and limited cost and performance data is available to determine the applicability of plasma arc to the R/W Counties. As potential new facilities are completed better information should become available to determine if the plasma arc process is viable. Table 5-3 provides a summary of plasma arc advantages and disadvantages.

Table 5-3
Potential Advantages and Disadvantages of Plasma Arc Systems

Advantages	Disadvantages
♦ Superior thermal destruction	♦ High initial investment
♦ Limited pollution	♦ High power requirements
♦ Beneficial use possibilities for gas and ash produced from plasma destruction	♦ Unknown Performance
♦ Potential to expand waste stream to include other non-MSW streams	♦ May require waste pre-shredding to fit into plasma reactor
	♦ Not a proven technology handling U.S. MSW

The Plasco Energy facility in Ottawa, Canada may provide a touring opportunity sometime in 2015 when it is projected to be fully operational.

[98] SWANA. Waste to Energy Facilities Provide Significant Economic Benefits White Paper. http://swana.org/portals/press_releases/economic_benefits_WTE_WP.PDF

[99] Joint Institute for Strategic Analysis (JISEA). Waste Not, Want Not: Analyzing the Economic and Environmental Viability of Waste to Energy (WTE) Technology for Site Specific Optimization of Renewable Energy Options. NREL/TP-6A50-52829. February 2013. Page 20

6 Mass Burn/Waste to Energy (WTE)

The modern WTE industry (also known in Europe as Energy from Waste or EfW) emerged in the United States in the 1970's, taking advantage of existing European technologies. At that time, energy prices were rising and the lack of stability of petroleum imports from the nations that comprised the Organization of Petroleum Exporting Countries (OPEC) raised strategic and economic concerns in the United States. Landfills were becoming more difficult to site as communities became aware of their leverage under the National Environmental Policy Act (NEPA) and landfills became increasingly regulated as a result of the Resource Conservation and Recovery Act (RCRA).

The European EfW technologies, especially German technologies, were seen as viable alternatives to simultaneously dispose of waste and produce energy. WTE use grew in the 1980's; by the early 1990's more than 15% of all MSW in the United States was combusted[100]. The EPA reports that the WTE facilities that combust MSW have the capacity to produce 2,720 megawatts of power per year (4% of the national demand) by processing more than 28 million tons of waste per year.

There are two basic types of WTE facilities; refuse derived fuel (RDF) and mass burn. Hybrids of these two types are also in existence. RDF facilities typically presort recyclables-rich loads, shredding the non-recyclable and highly mixed wastes which are then combusted in on or off-site incineration facilities.

Mass burn facilities are fed directly from the tipping floor or stockpile, through a feed chute or conveyor into the combustion chamber without pre-sorting or processing. Of the mass burn facilities, there are two types: mass burn waterwall, and modular mass burn. Mass burn waterwall facilities, which are more common, incinerate MSW in a single chamber under non-pressurized conditions of excess turbulent air. Modular facilities are smaller, have two chambers, and can be developed as modules for expandability.

There are seven RDF facilities in the U.S.[101], of which three are privately owned facilities and four are publicly owned facilities. All but two of these facilities process MSW. Two facilities, Great River Energy Elk River Processing Facility and Newport Resource Recovery Facility are in Minnesota. The published MSW tipping fees, nationally, are $50 - $ 84 per ton; the two Minnesota facilities' published tipping fees are $68 and $84 per ton, respectively.

There are 99 mass burn WTE facilities in the nation[102]. Of these, fifty six (56) are publicly owned facilities and forty three (43) are privately owned facilities. Nineteen of the facilities burn only MSW, thirteen burn no MSW, and the remainder burn MSW in conjunction with scrap metals, wood, tires, dry industrial material, recyclables, asbestos, sludge or other combustibles.

Nationally published tipping fees for MSW range from $35 to $240 per ton. Six of the mass burn facilities are in Minnesota:

[100] http://www.epa.gov/osw/nonhaz/municipal/wte/basic.htm
[101] Waste Business Journal's Directory of Waste Processing & Disposal Sites 2012
[102] Waste Business Journal's Directory of Waste Processing & Disposal Sites 2012

Facility	Published MSW Tipping Fee[103]
Polk County Resource Recovery Plant	$ 70
Red Wing Integrated Solid Waste Management Campus	$ 72
Pope-Douglas Resource Recovery Facility	$ 82
Perham Renewable Resource Facility	$100
Olmsted Waste to Energy Facility (OWEF)	$ 83
Covanta Hennepin Energy Resource Company (HERC)	$ 60

It should be noted that "published Tipping Fees" are not necessarily the actual costs or rates paid. The contract rate at HERC is currently $47 per ton. The actual cost at OWEF in Rochester is $106 per ton plus debt service.

6.1 Process

6.1.1 RDF Facilities

6.1.1.1 Waste Preparation

Refuse-derived fuel combustors burn MSW that has been processed to increase its fuel value and increase the homogeneity of the fuel. Processing MSW to RDF improves the heating value of the waste because many of the noncombustible items are removed. MSW is brought to the RDF facility by truck, roll-off or transfer trailer and dumped on the tipping floor where processing to fuel occurs. The simplest processing involves removal of bulky and noncombustible items followed by shredding. The fuel product is processed into pellets, fluff, or other transportable forms. Extensive processing is used to produce a finely divided fuel suitable for co-firing in pulverized coal-fired boilers or dedicated RDF combustors. It is common for the fuel product to be transported to another location for combustion.

6.1.1.2 Waste Feed

A set of standards for classifying RDF types has been established by the American Society for Testing and Materials. The type of RDF used is dependent on the boiler design. Boilers that are designed to burn RDF as the primary fuel usually utilize spreader stokers and fire fluff RDF in a semi-suspension mode. Pulverized coal (PC)-fired boilers can co-fire fluff RDF or powdered RDF. In a PC-fired boiler that co-fires fluff with pulverized coal, the RDF is introduced into the combustor by air transport injectors that are located above or even with the coal nozzles. Due to its high moisture content and large particle size, RDF requires a longer burnout time than coal. RDF can also be co-fired with coal in stoker-fired boilers.

6.1.1.3 Combustion

In a Fluidized Bed Combustor (FBC), fluff or pelletized RDF is combusted on a turbulent bed of noncombustible material such as limestone, sand, or silica. In its simplest form, an FBC consists of a combustor vessel equipped with a gas distribution plate and underfire air windbox at the bottom. The combustion bed is suspended or "fluidized" through the introduction of underfire air at a high

[103] Waste Business Journal. Directory of Waste Processing and Disposal Sites. 2012. Pages 646-647.

flow rate. Other wastes and supplemental fuel may be blended with the RDF outside the combustor or added into the combustor through separate openings. The Xcel French Island Facilities in Lacrosse, Wisconsin uses the FBC technology.

There are 2 basic types of FBC systems: bubbling bed and circulating bed. Bubbling bed combustors use relatively low air fluidization velocities. This helps reduce the entrainment of solids from the bed into the flue gas, minimizing recirculation or reinjection of bed particles. In contrast, circulating bed combustors operate at relatively high air injection velocities to promote carryover of solids into the upper section of the combustor. Combustion occurs in both the bed and upper section of the combustor in circulating bed combustors. By design, a fraction of the bed material is entrained in the combustion gas and enters a cyclone separator which recycles unburned waste and inert particles to the lower bed. Some of the ash is removed from the cyclone with the solids from the bed.

Because the RDF is homogenous and finely shredded, and to protect the bed material, FBCs operate at around 815^{o}C (1,500^{o}F), a lower excess air and temperature level than conventional combustion systems.

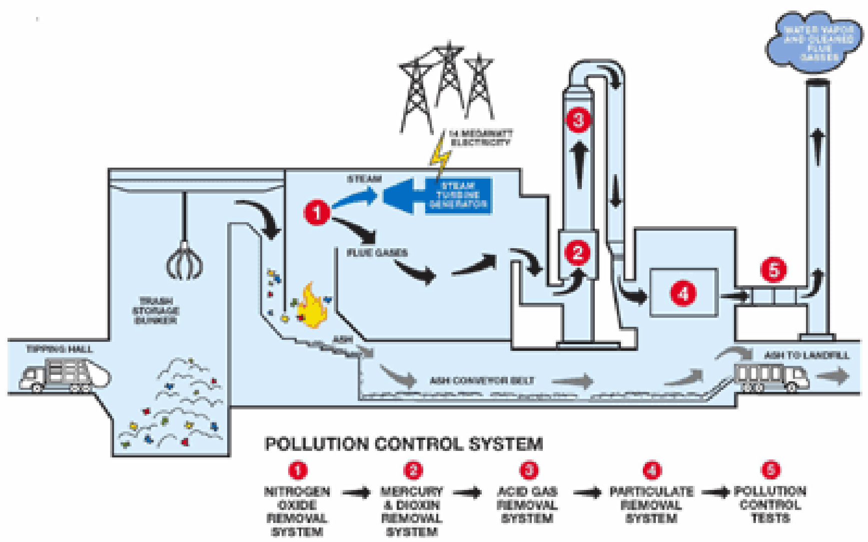
6.1.2 Mass Burn

6.1.2.1 Waste Feed

Figure 6-1 depicts a typical mass burn water wall facility. MSW is brought to the facility by truck, roll-off or transfer trailer and dumped on the tipping floor. The waste is pushed into the pit, where the crane operator mixes waste through the pit and removes unprocessible material. Consistent waste composition results from mixing the waste to avoid slugs of very wet or very high Btu material in the combustion chamber that would decrease the efficiency of the operation.

Waste may not be suitable for burning if it is too large (e.g. mattresses, furniture), is not combustible (e.g. concrete blocks) or would result in air quality problems not treatable with the facility's air quality systems (e.g. televisions, computers). The rejected waste is landfilled, or recycled if possible. The crane operator grabs an amount of the mixed waste and loads it from the pit to the feed hopper. Waste travels through the feed hopper to the gravity-feed or hydraulic ram-feed systems that deliver material at a controlled rate to the combustion chamber.

Figure 6-1
Waste to Energy Plant Diagram



6.1.2.2 Combustion

The walls of the combustion chamber are either of the waterwall or refractory type. Waterwall chambers are lined with tubes that contain circulating water which recovers the heat generated by combustion. In the actively burning region of the combustion chamber, where corrosive conditions may exist, the walls are generally lined with castable refractory. Heat is also recovered in the convective sections (i. e., superheater, economizer) of the combustor. Most waterwall WTE designs use inclined reciprocating grates or roller grates to move the waste through the combustion chamber.

The grates typically include 3 sections. The first grate section, referred to as the drying grate, reduces the moisture content of the waste prior to ignition. The second grate section, the burning grate, is where the majority of active burning takes place. The third grate section, the burnout or finishing grate, is where remaining combustibles in the waste are burned. The majority of the waterwall combustors supply underfire air to the individual grate sections through multiple pressurized inlets, or plenums, which improve the control of burning rate and heat release from the grates. Overfire air is injected through rows of high-pressure nozzles located in the side walls of the combustor to oxidize fuel-rich gases put off from the grates, to complete the combustion process for organic compounds in the flue gasses. Waterwall combustion units operate at relatively high temperatures, in the range of 1800^{o}F to 2200^{o}F. As the gasses pass out of the combustion chamber, they pass through additional heat recovery units, and air pollution control devices.

Refractory lined combustion units were built in the 1970's and 80's primarily to incinerate waste; energy recovery was generally not incorporated in their design. It is not expected that additional plants of this design will be built in the United States[104].

[104] AP42, Fifth Edition, Volume I, Chapter 2: Solid Waste Disposal. Section 2.1 Refuse Combustion. October 1996.

Bottom ash is discharged from the finishing grate into a water-filled ash quench pit or ram discharger. From there, the moist ash is discharged to a conveyor system and transported to an ash load-out or storage area prior to disposal. Many facilities have retrofitted metals recovery equipment to the ash conveyor system to recycle metals and reduce ash tonnage.

6.2 Air Delivery

The amount of air for combustion in the combustion chambers is controlled by draft fans. These fans deliver air through vents both above and below the waste (overfire and underfire vents). The amount of air delivered is continuously regulated to ensure complete combustion of waste, achieve maximum efficiency and minimize air pollutant emissions.

Air and waste delivery rates synergistically determine combustion chamber temperatures. A properly operating facility maintains combustion temperatures between 1,500^{o} F and 2,000^{o} F. When too much air is introduced into the combustion chamber, temperatures fall and carbon monoxide emissions may occur. Excessive waste flow also decreases temperature, and results in incomplete combustion of the waste. Continuous emissions monitoring (CEM) equipment in the control room of the facility is used to regulate waste delivery rates and air flow to the combustion chamber to optimize facility performance.

The large amounts of air necessary to combust waste creates a negative air differential in the boiler; the air pressure in the boiler is lower than the ambient air pressure. This negative air pressure ensures that fumes and exhausts do not exit the boiler, except through the stack and air emissions control equipment. Most WTE facilities draw the combustion air from outside across the enclosed tipping floor and then through the boiler, creating one-way air flow only into the facility, providing the side benefit of odor minimization to surrounding properties.

6.3 Energy Recovery

In either mass burn or RDF incineration facilities, energy from combustion is captured to heat water in contained vessels to produce superheated steam. Steam temperatures can exceed 900^{o}F and pressures can exceed 900 pounds per square inch gauge (PSIG). The steam can be used to power a turbine to generate electricity, to heat or cool buildings in a local "energy district" or to supply energy for industrial processes. WTE facilities that generate electricity and sell steam for other purposes are term co-generation (co-gen) facilities, because of the dual use of the recovered energy. Typically the higher temperature/pressure steam is used for electrical generation, and the remaining temperature/pressure is used for other purposes.

Expansion of WTE-produced electricity could significantly contribute to a lowering of Minnesota's Carbon Footprint. As shown in the Table 6-1, electric power generation from coal is the second greatest contributor to carbon dioxide emissions in Minnesota[105]. WTE, conversely, is capable of "negative" carbon emissions, or generation of Carbon Offset credits, when appropriate emission technology is employed. (See Section 6.12)

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[105] http://www.eia.gov/environment/emissions/state/state_emissions.cfm

Table 6-1
Minnesota Carbon Dioxide Emissions from Fossil Fuel Consumption

(Million Metric Tons of CO_2)

Sector	Year	Year
Residential Sector	2009	2010
Coal	0.0	0.0
Petroleum Products	1.7	1.7
Natural Gas	7.3	6.6
Total	**9.0**	**8.3**
Commercial Sector		
Coal	0.1	0.1
Petroleum Products	1.0	0.9
Natural Gas	5.3	4.8
Total	**15.4**	**17.3**
Industrial Sector		
Coal	2.1	2.3
Petroleum Products	6.3	6.5
Natural Gas	7.0	8.5
Total	**15.4**	**17.3**
Transportation Sector		
Coal	0.0	0.0
Petroleum Products	31.5	31.9
Natural Gas	0.7	0.8
Total	**32.1**	**32.7**
Electric Power Sector		
Coal	28.8	27.4
Petroleum Products	0.1	0.0
Natural Gas	1.3	1.9
Total	**30.2**	**29.3**
GRAND TOTAL	93.1	93.4

6.4 Pollution Control

Air pollution control equipment for WTE facilities have been greatly improved since the original facilities in the 1980's. The 1990 Clean Air Act, with the 1995 Maximum Achievable Control Technology (MACT) standards have resulted in WTE facilities that are cleaner in operation than coal or oil-fired electrical generating facilities, and rival emissions of natural gas combustion plants. Table 6-2 lists pre-1990 and 2005 emissions for WTE facilities.

Table 6-2
Pre-1990 And 2005 Emissions For WTE Facilities[106]

Pollutants	1990 Emissions (tons per year)	2005 Emissions (tons per year)	Recent Reduction
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
Hydrogen Chloride	57,400	3,200	94%
Sulfur Dioxide	38,300	4,600	88%
Nitrogen Oxides	64,900	49,500	24%

The data indicates that the performance of the MACT retrofits (to existing facilities) significantly reduced air pollution. Of particular interest, dioxin/furan emissions were reduced by more than 99% and mercury emissions were reduced by more than 96%.

6.5 Ash Use

WTE bottom ash is a mixed material that may contain varying proportions of glass, ceramics, metals, brick and concrete in addition to clinker and ash. The ash from MSW incineration has been used for at least twenty years in Europe as a substitute for valuable primary aggregate resources in the construction of roads and embankments. Germany, France, Denmark and the Netherlands use more than 60 % of the bottom ash generated by their WTE facilities in road base, highway sound barriers, embankments, parking lots, bicycle paths and concrete and asphalt products[107]. In some countries, such as the Netherlands, virtually all incinerator residues are reused. In the UK, an increasing supply of high quality bottom ash has led to it becoming accepted as a secondary aggregate with both environmental and cost benefits[108]. Bottom ash for Cory's Riverside Resource Recovery (EfW) facility in Belvedere, London was used to widen the M25, replacing primary and secondary aggregates.[109]

In the U.S., of the 7 million tons of ash produced in WTE facilities, only 7% is used, with the remaining 93% landfilled[110]. Four states have approved WTE Ash for beneficial use either on a case-by-case or pre-approved basis: Florida, Massachusetts, New York, and Pennsylvania[111]. Three states (New Hampshire, New York and Pennsylvania) have approved WTE ash for beneficial use as construction material either on a case-by-case or pre-approved basis[112]. Several states (Florida, Hawaii, Maryland, Massachusetts, Mississippi and New York) have approved WTE ash for various beneficial landfill uses, such as daily cover. Florida, in particular, has certified that bottom ash from Tampa's McKay Bay Refuse to Energy facility is a suitable material for road construction, not subject to regulations for waste materials, and the state has approved a soil cement substitute made

106 http://www.epa.gov/wastes/nonhaz/municipal/wte/airem.htm#5
107 http://waste360.com/mag/waste_ash_rise-united
108 http://infohouse.p2ric.org/ref/14/13989.pdf
109 http://www.edie.net/news/5/\Recycled-incinerator-bottom-ash-paves-way-for-M25-expansion
110 http://waste360.com/mag/waste_ash_rise-united
111 http://www.envcap.org/statetools/brsl/brust4.cfm?c1=314
112 http://www.envcap.org/statetools/brsl/brust4.cfm?c1=315

from ash from the Hillsborough County WTE facility[113]. The Connecticut Office of Legal Research reported in 2009 that Florida and Massachusetts had approved the use of WTE ash in manufacture of asphalt[114]. Project economics for ash recovery and reuse are more favorable in areas that do not have local aggregate sources, or for WTE facilities that must pay offsite landfill costs.

In Minnesota, Polk County has performed six waste combustor ash utilization projects. Three projects used the ash as an amendment to the asphalt mix. Three used the ash as a substitute for the clay binder of Class 5 aggregate used to construct the road base. In total, 33,500 tons of screened ash has been used for road construction projects with a majority being used in the Class 5 aggregate. The beneficial use determination allows for 25% substitution rate to use ash instead of clay in Class 5 aggregate. All the ash used on the road projects were totally encapsulated so leaching of metal from ash was not a concern.[115] Cost savings for using the ash in the Class 5 aggregate are estimated to be $0.37 per ton.[116]

Metals recovery from WTE ash is common for ferrous metals. Precious metals have been documented as present in bottom ash in levels of 10 ppm of silver and 0.4 ppm of gold in European facilities, thought to derive mainly from incineration of electrical and electronic equipment for smaller particle sizes and from jewelry for the larger particle sizes[117]. In the Netherlands, aluminum, copper, silver and other metals worth $67.3 million per year have been documented as lost through WTE incineration[118]. Historically, recovery of metals from small-particle-size ash (< 12 mm) has not been economically viable. The Confederation of European Waste to Energy Plants (CEWEP) and the Packaging Group of the European Aluminum Association (EAA) held a joint conference in 2011 to seek to maximize removal of aluminum from ash, contributing to a more resource efficient Europe. Commerce, CA has used ash from its WTE facility for 5 years. [119] More than 100,000 tons of ash has been used for road base at the landfill, and more than 8,000 tons of ferrous metal has been recovered, resulting in no in-landfill disposal of ash between 1995 and 1997[120].

The Delft University of Technology recently developed a dry recycling process for particles to 1 mm, and joined with a private investor to form a company, Inashco (Incineration Ash Company), to further develop the technology. Inashco North America signed its first U.S. contract in November, 2012, with 1st Response Rail Services, Inc., of Bishopville, S.C. The joint venture expected to begin operations in March, 2012, and eventually process 400,000 tpy of WTE ash[121]. To date, the operations have not yet started. In announcing the U.S. project, John Joyner, President of Inashco North America stated that, "this first U.S. installation will be followed by additional facilities that will significantly improve the economics of WTE projects" "We are finally able to recover the high-value, fine non-ferrous metal fraction while producing a better mineral fraction for eventual re-use..." The Inashco process train is:

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113 http://waste360.com/mag/waste_ash_rise-united
114 www.cga.ct.gov/2009/rpt/2009-R-0321.htm
115 http://www.mnresourcerecovery.com/index.php/faqs/
116 Wilson, Willard (Bill). "Waste Combustor Ash Utilization." Proceedings 17th Annual NAWTEC. May 18-20, 2009, Chantilly, Virgina. Page 9.
117 http://link.springer.com/article/10.1007%2Fs11267-008-9191-9
118 www.waste-managment-world.com/articles/print/volume-10/issue-6/features
119 www.alurecycling.eu/cewep_eaa_seminar
120 http://waste360.com/mag/waste_ash_rise-united
121 http://www.inashco.com/en/news

- Moist bottom ash screened to between 12 – 20 mm; steel and non-ferrous metals recovered from this fraction
- Inashco "concentrator" separates very fine metal contaminants (- 1 mm) and mineral particles (-2 mm) from bottom ash in a physical classification step.
- Inashco "upgrading facility" further separates and cleans non-ferrous metal concentrate into pure secondary metal products (copper, zinc, brass, lead gold, silver)
- Clean mineral aggregates may be sold to replace 20% of aggregates presently used in concrete, or for other aggregate uses.

An alternate technology using bottom ash to produce hydrogen gas has been reported by Sweden's Lund University. The new method is presented in a thesis, *Unsaturated Phase Environmental Processes in MSW Incinerator Bottom Ash*, and is claimed to have the potential to produce up to 20 billion liters of hydrogen gas a year, or 56 GWh – enough to meet the annual needs of around 11,000 detached houses.

According to Lund University the technique involves placing the ash in an oxygen-free environment, where when dampened with water it forms hydrogen gas. The gas is sucked up through pipes and stored in tanks. "The ash can be used as a resource through recovery of hydrogen gas instead of being allowed to be released into the air as at present.", commented Aamir Ilyas - a Doctor of Water Resources Engineering at Lund University and the developer of the technique[122].

6.6 Vendors

The WTE industry in the U.S. has seen significant consolidation since the early 1980's. In 1985 about 60 incinerator vendors operated in the United States; now only significant companies remain, of which only Babcock and Wilcox is currently building new facilities.

6.6.1 Covanta Energy

Covanta Energy, in its various business structures, is an owner and /or operator of forty four WTE facilities in North America, of which 41 are in the United States. Covanta Energy is a subsidiary of Covanta Holding Corporation, a publicly traded company (NYSE:CVA); and was formerly Ogden Martin Systems.

Covanta-operated facilities convert 20 million tons of trash annually into 9 million megawatt-hours energy and more than 9 billion pounds of steam sold to a variety of industries. Covanta produces almost eight percent of U.S. renewable energy (excluding hydro). Covanta is seeking to expand the 800,000 tpy Niagara Falls, NY, WTE facility, to accept 300,000 tpy of rail-hauled MSW from New York City. Currently 60% of the Niagara facility's waste is imported from Canada; steam from the facility is contracted to a nearby paper mill. In Minnesota, Covanta Hennepin Energy Resources, Inc. is the operator of the Hennepin County WTE facility.[123]

[122] Waste Management World, 8 April 2013
[123] http://www.covantaenergy.com/

6.6.2 Wheelabrator Technologies

Wheelabrator Technologies, a wholly owned subsidiary of Waste Management Company, designed, built and operated the first commercially successful U.S. WTE facility in Saugus, Massachusetts, in 1975.

Wheelabrator's U.S. waste-to-energy operations currently total 17 facilities with a combined processing capacity of more than 23,000 tons per day of municipal solid waste and an electric generating capacity of 669 megawatts. Wheelabrator has developed and patented an ash stabilization process, which it advertises as the most widely-used in the nation[124]. There are no Wheelabrator facilities in Minnesota[125].

6.6.3 Babcock and Wilcox Corporation

Babcock and Wilcox Corporation provide operations & maintenance (O&M) services to a variety of customers in the power generation business across the United States. Babcock & Wilcox Vorlund is especially active in Europe, with a new plant for the incineration of around 85,000 tons of waste per year for Peterborough City in the UK recently announced.

The Palm Beach Resource Recovery Facility was built by a joint venture of Babcock & Wilcox and Bechtel Civil, Inc., and is operated by Babcock & Wilcox under a 20-year contract. The NCRRF opened in 1989 and currently processes in excess of 850,000 tons of municipal solid waste per year, with an energy capacity of 62 MW[126]. A new facility for the Palm Beach County Solid Waste authority is mentioned later.

6.6.4 Veolia Environmental Services

Veolia Environmental Services, once a significant operator of WTE facilities, sold most of its WTE holdings to Covanta Holding Corp in 2009. The last Veolia WTE operating contract, for the Pinellas County incinerator in St. Petersburg, FL, has been taken over by Green Conversion Systems, LLC of Rye, NY. The Pinellas County facility can process 3,150 tpd of waste, generating 75MW of electricity.

6.6.5 Green Conversion Systems

Green Conversion Systems was founded in 2008 for the purpose of pursuing Waste-to-Energy ("WTE") projects throughout the Americas. Its mission is “to provide the cleanest, safest, and best available technology to divert the portion of our household waste that would otherwise be landfilled and turn it into energy and other materials that close the sustainable cycle getting to zero waste.” The company has not built WTE capacity, but cites its reference facility in Hamburg Germany as the cleanest energy-from-waste facility in the world which is singularly credited by the German Green Party as THE model for waste processing. The company’s proprietary system is based on

[124] http://waste360.com/mag/waste_ash_rise-united
[125] http://wheelabratortechnologies.com/
[126] http://www.babcock.com/?wwparam=1319803585

solid waste combustion; boiler and combustion control systems, and air pollution control equipment supplied by Fisia Babcock Environment GmbH (FBE)[127, 128]

6.6.6 Casella Waste Systems, Inc.

Casella Waste Systems, Inc. is an integrated regional solid waste services company that provides collection, transfer, disposal, recycling and resource management services to residential, industrial and commercial customers, primarily throughout the eastern United States. In late 1999, Casella acquired KTI, an integrated provider of waste processing services; Casella is the owner and KTI the operator of the Maine Energy Recovery Corporation facility, a 600 tpd facility capable of generating 22 MW[129].

6.6.7 Energy Recovery Operations, Inc.

Energy Recovery Operations, Inc., in partnership with the Northeast Maryland Waste Disposal Authority, operates a 360 TPD facility that has a steam generation capability of 100,000 lbs/hr. Energy Recovery Operations concentrates on comprehensive waste destruction and document destruction services in Consutech thermal destruction units[130].

6.6.8 Riley Power Inc.

Riley Power Inc. designs and manufactures steam generators and fuel firing equipment for all types of fossil fired and waste fuel fired plants. Riley Power Inc. and Babcock Power Environmental Inc. (together referred to as Babcock Power) provide fully integrated environmental solutions for utility power plants and waste-to-energy facilities. The Riley facility in Lisbon, CT, has a capacity of 500 tpd and generation capacity of 15 MW. There are no Riley Power facilities in Minnesota[131].

6.6.9 EnGen, LLC

EnGen, LLC is the operator of the Bay County Waste to Energy Facility. The facility is a 500 tpd Waste to Energy facility located in Bay County (just north of Panama City, Florida). The facility produces about 13 MWh of electricity that is utilized throughout the state of Florida[132].

6.6.10 Foster Wheeler

Foster Wheeler is known for circulating fluidized bed (CFB) WTE technology, beginning with small-scale utility applications in 1987. Foster Wheeler built a medium utility scale facility in 2001, the paired 300 MW units for the Jacksonville Energy Authority, and has a very large scale facility, the 1500 MWe Turów project in Poland. Foster Wheeler remains active in WfE in Europe, but has no current U.S. WTE operations[133].

[127] www.fisia-babcock.com
[128] http://www.gcsusa.com/index.html
[129] http://www.casella.com/
[130] http://energyrecoveryonline.com/default.aspx
[131] http://www.babcockpower.com/products/environmental/riley-power
[132] http://engenllc.com/index.html
[133] http://www.fwc.com/index.cfm

6.6.11 Minnesota WTE Plants

Minnesota has the following WTE Plants:

- Covanta Hennepin Energy Resource Co., Minneapolis, MN
- Great River Energy - Elk River Station, Elk River, MN
- Olmsted Waste-to-Energy Facility, Rochester, MN
- Perham Resource Recovery Facility, Perham, MN
- Polk County Solid Waste Resource Recovery Plant, Fosston, MN
- Pope/Douglas Solid Waste Management, Alexandria, MN
- Red Wing Resource Recovery Facility, Red Wing, MN
- Xcel Energy - Red Wing Steam Plant, Red Wing, MN
- Xcel Energy-Wilmarth Plant, Mankato, MN

The capacities of the plants vary from 84 tons/day at Polk County to 933 tons/day at Covanta Hennepin. Tipping fees are also varied. The lowest published tipping fee is Covanta Hennepin with $60 per ton. Perham had the highest tipping fee of $100/ton.

6.7 Projects

Pike Research notes that there are more than 900 thermal WTE plants operating, world-wide, treating an estimated 200 million tons of MSW and generating approximately 130 terra-watt hours of electricity. Pike considers energy from waste as a strong contributor to energy security and diversification to meet the growing demand for renewable energy in a carbon constrained world.[134] Bloomberg New Energy Finance predicts that the annual value of renewable energy capacity installed world-wide will double in real terms, rising from $195 billion in 2010 to $395 billion in 2020 and to $460 billion in 2030[135]. China will lead the world by 2014,with an annual spend slightly less than $50 billion Europe is predicted to remain one of the biggest markets in order to meet the EU 2020 renewable energy target. The U.S. and Canada, combined are predicted to spend $50 billion by 2020. Rapid growth will be seen in developing countries of India, the Middle East, Africa and Latin America. Of this world-wide investment, the bioenergy sector is predicted by Bloomberg to increase, such that investment in biofuels, biomass and WTE is projected to increase from $14 billion in 2010 to $80 billion in 2020, remaining level over the next decade.

The value of the global waste incineration market is set to hit $16.8 billion by 2022, according to a new report by industrial markets research company, SBI Reports. The report found that while global growth in incineration faltered in the wake of the global economic turndown, markets are well-poised for continued recovery and consistent growth. The analysts said that since 2008 the global market for incinerators has resurged from $7.9 billion to $9.2 billion in 2012 (at a compound annual growth rate (CAGR) of 3.9%). The researchers also forecast a CAGR of 6.2% for the years between 2012 and 2022 to take the total value to some $16.8 billion[136].

[134] http://finance.paidcontent.org/paidcontent/news/read?GUID=18644413
[135] http://bnef.com/PressReleases/view/173
[136] Waste Management World 5 April 2013

The Palm Beach County Solid Waste Authority[137] has a design-build-operate mass-burn facility under construction. The contractor is Babcock and Wilcox. The facility was approved by the Authority on April 13, 2011; ground was broken in April, 2012 and the facility is 40 % complete (2/1/2013). The facility is a Babcock and Wilcox design, with three, 1,000 tpd boilers and Volund grates. The projected commercial operations date is May 24, 2015. The project is primarily financed by tax-exempt bonds. This is the only WTE facility currently under construction in the U.S.

Covanta Energy Corp. has a planned expansion of its 800,000 tpy WTE facility in Niagara Falls, NY. The current facility receives 480,000 tpy from Canada; for the expansion Covanta plans to ship 300,000 tpy from New York City to the Niagara Falls facility by rail. The expansion is projected to cost $30 million, including a steam pipeline, natural gas boiler, rail transfer station and handling facility. Covanta has a 12 year contract for steam with a nearby paper mill, and is seeking $8 million in tax savings over 15 years as part of the finance package for the expansion.

Maui County, Hawaii received 20 bids from potential developers to build and operate a waste-to-energy plant that is proposed for a 10-acre site next to the landfill in Puunene. Interviews with the top bidders occurred in March or April with the winning bidder, Anaergia, Inc. announced in May. The proposed facility involves production of RDF, as well as liquefied natural gas. Feedstocks include MSW, green waste, sewage sludge, oil and grease. The plant could be operational by 2017. All of the bids were from off-island entities. Bidders were required to have established technologies that have been proved on a commercial scale at two facilities each operating commercially for at least three years[138].

The next generation of mass burn facilities is the Energy Tower, in Roskilde, Denmark (see Figures 6-2 and 6-3). The design of the facility is focused on maximum utilization of the energy resources in the waste, such that it may be harnessed with practically no losses. The grate and boiler for the plant have been supplied by German waste to energy technology specialist, MARTIN while the flue gas treatment system was supplied by LAB – a subsidiary of CNIM – and the turbine by and MAN Diesel & Turbo. The plant’s waste treatment process produces heat in the boiler room which is used for the production of steam in the boiler. Through this process some 85% - 90% of the energy content of the waste is transformed into steam, and the steam is subsequently converted to electricity as well as district heating. Increased focus on energy efficiency at the Energy Tower has resulted in the installation of flue gas condensation in order to increase the production of district heating. With flue gas condensation the temperature of the district heating water returning from the city is raised, and heat production is further increased by approximately 10%. In the recovery processes a certain amount of electricity is required to operate pumps and fans etc. However, at the Energy Tower the plant’s consumption of electricity is reduced by establishing a component cooling system driven by district heating.

The component cooling system is a necessary installation in any modern process plant, and hence also a necessity in the Energy Tower. However, instead of cooling away the heat with a traditional electrically powered cooling compressor, KARA/NOVEREN has established an absorption cooler

137 http://www.swa.org/site/about_swa.htm
138 http://www.mauinews.com/page/content.detail/id/569588.html

driven by district heating water. With the high utilization of energy resource, the total energy efficiency rate of the Energy Tower is almost 100%. On the basis of 200,000 tons of waste being processed at the plant each year, KARA/NOVEREN will produce electricity corresponding to the consumption of some 44,000 households, while the production of district heating will correspond to the consumption of around 26,000 households. As such, the Energy Tower will be one of the most modern and efficient waste to energy facilities in Europe, with the energy recovery increased by 35% compared to the facility's old units.

Figure 6-2
Energy Tower in Roskilde, Denmark

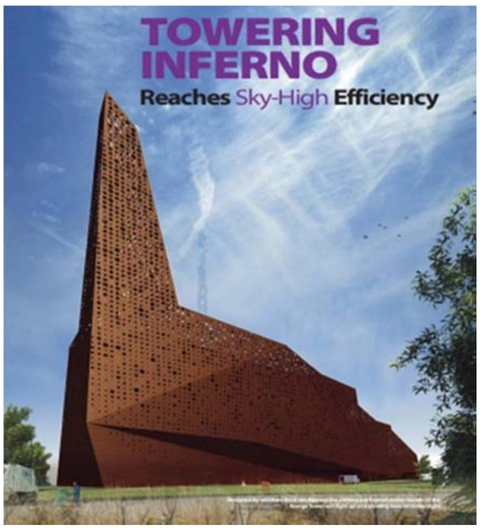
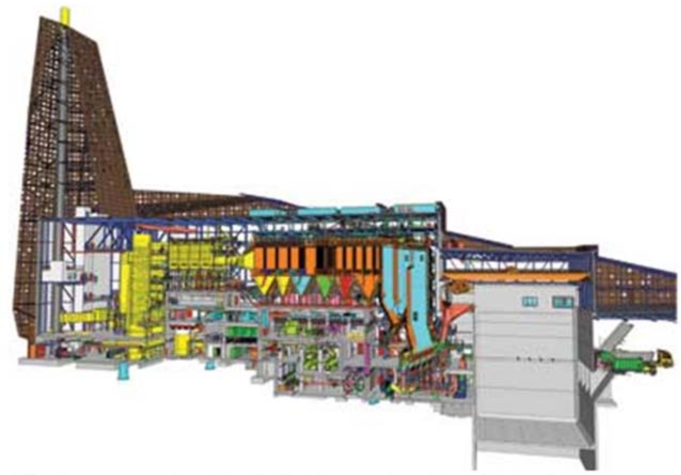


Figure 6-3
Energy Tower Interior Cross Section



With flue gas condensation technology and an absorption cooler driven by district heating water, efficiency approaches 100%

At night the backlighting of the perforated façade will transform the spire to an illusion of a glowing beacon, symbolizing the energy production inside the facility.

The facility designers predict the waste to energy facilities of the future will most likely be equipped with heat pumps coupled to flue gas condensation. This will increase the energy efficiency even further and enable flue gas condensation in systems with relatively high flue gas temperatures[139].

6.7.1 Minnesota Projects

In Minnesota, Olmsted County recently completed the expansion of the Olmsted Waste to Energy Facility (OWEF) by adding a third municipal solid waste combustor. The addition of the unit doubled the capacity of OWEF from 200 tons/day to 400 tons/day. The new combustion unit also included an additional steam turbine rated at 5 megawatts, as well as additional air pollution controls. Construction of the new combustor/turbine was completed in 2010 and has operated since that time.

[139] Waste Management World, March, 2013.

The Pope/Douglas facility also added a third combustor to the facility. Like Olmsted County, the expansion at Pope/Douglas will double the plant capacity from 120 ton/day to 240 tons/day. The expansion also included adding an additional steam turbine to generate 1.5 MWh of electricity. Upgraded air pollution controls were added for the new unit. The expansion was completed in the summer of 2011.

The Perham Renewable Resource Corporation has begun an upgrade to the WTE plant in Perham. Ownership of the plant has been transferred to Prairie Lakes Municipal Solid Waste Authority (a joint powers partnership including Becker, Otter Tail, Todd and Wadena Counties.) The expansion includes addition of a materials recovery facility and a waste to energy expansion, along with other facility improvements. The project is adding a second waste heat boiler to supply steam to a local business and a material recovery facility to increase recycling and provide a better fuel for the system. Upgrades are underway and are expected to be complete in December 2014.

6.8 Environmental Considerations

Environmental considerations surrounding WTE technology have been centered on air emissions, ash handling and the lack of commitment to waste activities higher in the waste hierarchy when WTE is employed. Combustion in an incinerator is not always perfect and there have been concerns about pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as dioxins, furans, and PAHs. Significant improvements to combustion systems and pollution control equipment and removal of certain items from the waste stream (e.g. TV's, computers, other electronic devices) have greatly reduced the stack emissions of WTE facilities.

6.8.1 General Air Quality

In 1990, EPA developed Maximum Achievable Control Technology (MACT) standards under the Clean Air Act for MSW combustion. The allowable emissions decreased by a factor of 20 after the MACT controls were put in place. Emissions from MSW combustion facilities declined significantly between 1990 and 2005; in the cases of mercury and cadmium, for example, more than 95 %[140].

Clean Air Act regulations require that all WTE facilities have the latest technology in air pollution equipment. Performance data is available for all 87 WTE facilities in the U.S., and the data show that actual air emissions for WTE facilities are less than the regulatory requirements[141]. The Kaplan study compared lifecycle emission factors per unit of electricity for landfill gas to energy (LFGTE) and WTE, finding lower greenhouse gas emissions from WTE facilities, and lower particulate matter and NO_x emissions from WTE facilities. SO_x emission comparisons between the two types of facilities depended on the specific configurations of each type of facility (efficiency, waste composition's, etc.).

[140] http://www/epa.gov/wastes/nonhaz/municipal/wte/airem.htm
[141] Kaplan, Ozge, Decarolis, J and Thornelo, S, "Is it Better to Burn or Bury Waste for Clean Electricity Generation?" Environ. Sci.Technolo.2009, 43,1711 – 1717

6.8.2 Greenhouse Gas Emissions

Waste is the seventh-largest contributor to greenhouse gas emissions, according to the latest statistics released by the U.S. Environmental Protection Agency[142]. The amount of waste incinerated in the U.S. has dropped from 30.6 million tons in 1990 to 23.7 million tons in 2011; however the amount of CO_2 equivalent emissions produced by waste to energy facilities rose from 8 million tons in 1990 to 12 million tons in 2011[143].

Municipal solid waste landfills, industrial waste landfills, industrial wastewater treatment systems and facilities that operate combustors or incinerators for the disposal of non-hazardous solid waste accounted for 103 million metric tons of carbon dioxide equivalents in 2011.

Nationally, the largest direct emitters of CO_2 are power plants with 2,221 million metric tons, followed by petroleum and natural gas systems at 225 million metric tons, refineries at 182 metric tons, the chemical sector at 180 tons, a combined category of "other" at 126 tons, metals at 115 tons, followed by waste emissions. Within the waste total, MSW landfills emitted 81 million metric tons (mmt), followed by solid waste combustion at 10 mmt, industrial landfills at 8.5mmt, and wastewater treatment at 3.7mmt. Energy recovery from MSW, although an emitter of CO_2, has a positive carbon balance. EPA's models for calculating GHG emissions show that between 0.5 and 1.0 tons of carbon equivalents are avoided for every ton of MSW burned in a WTE facility with energy and metals recovery capabilities.[144]

6.8.3 Nanoparticles

Nanoparticles are defined as small objects that each behave as a whole unit with respect to its transport and properties. Nanoparticles were used by artisans as far back as the 9th century in Mesopotamia for generating a glittering effect on the surface of pots, and Michael Faraday described the optical properties of nanometer-scale metals in an 1857 paper. The use of nanoparticles is growing, as they are designed to be insoluble and to increase stability of consumer goods, however, this stability can cause problems at end-of-product-life since nanoparticles may reside in the environment for a long time. Nanoparticles present possible dangers, both medically and environmentally due to their high surface to volume ratio, which can make the particles very reactive or catalytic. They are also able to pass through cell membranes in organisms, and their interactions with biological systems are relatively unknown. Concern has also been raised over the health effects of respirable nanoparticles from certain combustion processes.

A recent study conducted on behalf of the European Commission's Environment Directorate-General (DG) has shown that nanoparticles can pass though the waste incineration process into fly ash and slag. Researchers added nano-cerium oxide, which is used in ceramics and glass manufacture, to waste going to an incinerator. Samples were taken from the flue gas, fly ash, slag and slag water. The filter systems of the incinerator were effective in removing nearly 100% of the nano-cerium from the facility emissions. Nano-cerium remained present in the solid residues, such that precaution was recommended in residue management.[145]

[142] Waste and Recycling News, Feb 6, 2013
[143] EPA 430-R-13-001. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011. April 12, 2013
[144] http://www.waste-management-world,com/articles/print/volume-12/issue-5/features/is-was
[145] http://www.waste-management-world.com/index/display/article-display/_printArticle/article

6.8.4 Electrical Generation through WTE, Environmental Considerations

The EPA in 2009 estimated that the use of MSW to generate electricity, either through landfill-gas-to-energy or through WTE represents approximately 14% of the U.S. non-hydro renewable energy generation. When carbon dioxide equivalents of emissions from various methods of electrical generation are compared, WTE is significantly lower in CO_2 emissions than the use of LFGTE, coal or oil, and is only slightly higher than the use of natural gas to generate electricity[146]. WTE is capable of producing an order of magnitude more electricity from the same mass of waste than LFGTE, with significantly lower emissions from the same mass of waste.

The Kaplan article stated that, "if all MSW (excluding the recycled and composted portions) is utilized for electricity generation, the WTE alternative could have a generation capacity of 14,000MW, which could potentially replace approximately 4.5% of the 313,000MW of current coal-fired generation capacity. The article further stated that U.S. policy makers appear hesitant to support new WTE through inclusion in renewable energy policies; 30 states have renewable energy portfolio standards but only 19 include WTE as a renewable energy alternative.

6.9 Application of Current Waste Stream

Currently, most of the available MSW is delivered to the Newport facility and processed into RDF. A mass burn facility could also handle all of the available R/W Counties MSW.

6.10 Outputs

6.10.1 Typical Markets[147]

WTE facilities can market steam, electricity, or both. Although steam is more efficient and economical, it is more difficult to find convenient steam markets. Electricity is more flexible and easier to market.

6.10.1.1 Steam Markets

Steam and hot water markets may consist of industrial manufacturing firms, industrial development parks, district heating and cooling systems, institutions, and commercial firms. The potential revenues to the WTE facility are generally based on the costs that the steam customer can defer by not producing the steam in-house.

The most advantageous steam customers would have the following characteristics:

- Require steam use on a 24-hour-per-day, 365 day-per-year schedule;

[146] Kaplan, Ozge, Decarolis, J and Thornelo, S, "Is it Better to Burn or Bury Waste for Clean Electricity Generation?" Environ. Sci.Technolo.2009, 43,1711 – 1717
[147] Berenyi, E.B., 1997.

- A low pressure steam market may allow for cogeneration (producing electricity and steam for sale), maximizing two revenue sources;
- Expresses a "positive" interest in purchasing energy generated from a WTE facility;
- History of stability in its business or service at the specific location and a long-term Business Plan to continue operation
- Willing to enter into a long-term agreement for the purchase of steam;
- Current cost to produce steam is high, increasing the market's interest in alternative steam sources as well as increasing the rate paid (steam prices are typically negotiated on a case-by-case basis);
- Located in an industrially zoned area or within one mile of an area zoned industrial to accommodate the location of the WTE facility (or close enough for a steam line connection).

Steam potentially provides greater revenue than electricity per ton of waste. Based on the average waste processed (320,700 tpy), the average steam production (278,547 pounds per hour) and the average market price of steam ($5.78 per 1,000 lbs.), steam generates a revenue of $44 per ton of waste[148].

Only 20 percent of the WTE facilities are dedicated steam producers, and 18 percent are cogen facilities. In contrast, 63 percent are dedicated electricity producers. Approximately 70 percent of mass burn and RDF facilities are dedicated electricity producers. Approximately 56 percent of modular facilities are dedicated steam producers. Modular facilities tend to favor steam sales, because they usually cannot generate the superheated steam necessary to power electric turbines efficiently or they were more convenient to site next to the potential steam market.

While there may be advantages to having a steam customer, there are also some disadvantages. The WTE facility must be located reasonably close to the steam customer in order to pipe the steam without too much energy loss. Relying solely on a steam customer provides a greater element of risk over the long term should the steam customers' needs change or the business go out of operation. The WTE facility will also need to consider how "firm" a supply of steam the WTE facility can provide. Would back-up natural gas fired boilers be required? Can or should the WTE facility guarantee steam availability and provide for liquidated damages if unable to supply all the steam contracted? Does the steam customer need to keep its boilers in operation to provide backup? All these potential issues come into play in the steam supply contract and pricing arrangement.

As noted, the price paid for steam by the steam customer is typically tied to the cost of alternatives for the steam customer. This is determined by the efficiency of their boiler operation and the price of the alternate fuel—most often natural gas. Prices for natural gas may be changing that may impact the steam markets.

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[148] Berenyi, E.B., 1997.

6.10.1.2 Electrical Markets

A WTE facility's electric turbine generators are connected to a utility sub-station. From there, the local utility manages the electricity. Electricity generated from waste is sold based on an avoided cost value. This is the cost that the utility company saves by using electricity from the WTE plants. Based on the national average, plants sell their electricity for 5.09 cents per kWh and have an average net electricity production of 512 kWh per ton of MSW. This is equal to a revenue of $26 per ton of waste. The actual market values vary widely from site to site, and are changing due to deregulation of the electric industry. Electricity prices are generally lower in the Midwest than the East Coast, and rates received in Minnesota are therefore lower.

Legislation could be instituted to provide the WTE industry with a better price for its electricity. There are state and federal goals being set to promote the generation of electricity from renewable resources. The inclusion of WTE within the definition of renewable resources is not clearly agreed upon. In 2003, the State of Minnesota included WTE in the renewable fuels as part of biomass. Unfortunately, price incentives were not included in the Minnesota legislation. The Department of Energy (DOE), Public Utilities Regulatory Policy Act (PURPA), Federal Power Act Amendment (FPAA), and Clean Air Act (CAA) amendments all have different definitions for renewable resources. The definitions typically include biomass, wind, solar, and geothermal. WTE plants have been arguably classified as using renewable resources, since they burn MSW, which is typically 80 percent by mass composed of organic material, or biomass.[149]

RDF generates an average net output of 597 kWh per ton, followed by mass burn at 512 kWh and modular at 335 kWh. Although RDF plants produce more electricity per ton of waste incinerated than mass burn plants, the numbers are subject to interpretation. This increased efficiency is due partly to the fact that non-combustible materials such as metals are included in mass burn facilities. The non-combustibles are included in the kWh per ton output of a mass burn facility, but not in the kWh per ton in an RDF facility. Furthermore, the energy costs of processing RDF are not included in the comparisons.

6.10.1.3 Residual Materials

The primary residuals to a mass burn facility are bottom ash and fly ash. On average, the wet ash residue from mass burn and modular facilities comprises approximately 25 percent of the weight of the incoming waste. Because the ash is very dense, the ash volume is typically about 10 percent of the original volume. Ash residue from RDF facilities is generally less, averaging 12 percent by mass of the incoming waste. RDF also has the heavy fraction, which is separated in the process. This residue accounts for another 10 to 15 percent of the incoming waste.

The ferrous and non-ferrous metal markets fluctuate. It is not always profitable to recover metals. However, metal recovery has proven to be a dependable and preferred method for managing metals. Although most ash is landfilled, if ash is ever to be marketed as a resource, ferrous and non-ferrous metal recovery will be necessary.

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[149]Integrated Waste Services Association (IWSA), Waste-To-Energy: A Renewable Energy Source Fact Sheet

In 1994, a lawsuit, *Chicago vs. Environmental Defense Fund*, the Supreme Court decided that ash generated by WTE plants is subject to hazardous waste regulations. Consequently, WTE ash is tested according to toxicity characteristic leaching procedures (TCLP). The classification of ash as a hazardous waste added liability to reusing it. Currently, approximately 93 percent of ash is landfilled.

Approximately 7 million tons of ash was produced in the U.S. [150] Most facilities combine the bottom and fly ash. Landfilling ash is a significant cost in the WTE plant operating cost. For a 1,500 tpd facility, at 85 percent availability, 25 percent by mass ash residual, and transport and disposal fees at $25 per ton, it would cost approximately $3 million per year to landfill the ash. Unlike the United States, many European countries use over half of their ash for road aggregate, concrete, asphalt products, and sound barriers[151].

Since 1994, TCLP testing of the ash has proven it to be non-hazardous. Special ash handling processes have been developed. Lime or phosphorous is added to stabilize the ash. Ash is being used on closely monitored projects for road aggregate and cement manufacturing. A road test project in Polk County, Minnesota was conducted using bottom and fly ash mixed from a starved air incinerator. Conclusions from the final report[152] include:

- The use of municipal solid waste combustor (MWC) ash as a partial replacement for aggregate in the production and use of bituminous paving materials is viable;
- The potential for impact to the environment, with a 10 percent replacement rate, is very low (many of the environmental tests that were performed at much higher ash replacement rates also support this conclusion);
- The cost to produce bituminous with 10 percent MWC ash was approximately $3 per ton of bituminous, or an increase of about 13 percent. However, this cost would likely be reduced significantly by process modifications and by improved bituminous performance;
- There is a very distinct possibility that the use of MWC ash results in improved stability, flow and freeze/thaw characteristics;
- While ash-amended bituminous was not used in the wear course of the Polk County project, environmental, structural and economic data suggests that this use may also be appropriate; and
- While the environmental safety of the use of ash-amended bituminous is clear, additional production and placement of ash-amended bituminous is necessary to better quantify, economic, production, and short-term and long-term structural issues.

[150] Samuel Lucido, "Utilization of MSW Combustor Ash in Bituminous Pavement Construction," Minnesota Solid Waste Seminar, February 24, 2000.
[151] National Renewable Energy Laboratory (NREL), "Why Bury It When You Can Use It?" December 1996.
[152] Samuel Lucido (Wenck Associates, Inc.) and Willard Wilson (Polk County Solid Waste Department), "Bituminous Pavement Constructed with Municipal Solid Waste Combustor Ash: Construction, Performance, and Economic Issues," Summary Paper on the Minnesota Office of Environmental Assistance Market Development Grant Project with Polk County, Minnesota, February 2002.

Although there is strong potential for ash markets, they are not yet developed in the United States and remain burdened by the liability that is associated with the potential classification of ash as a hazardous waste.

6.11 Financial Performance

The Confederation of European Waste to Energy Plants (CEWEP) surveyed its members in 2012, and found that 80% of the members, including operators, manufacturers and suppliers, reported favorable business and market conditions. Operators, in particular noted an increase in commercial waste deliveries, which improved plant utilization. It was noted that although China is growing its WTE capabilities, due to the low standards of facilities being built there it is not considered to be a significant market for established WTE companies[153].

6.11.1 Tax Credits

President Barack Obama in February, 2012, included WTE in his call for a permanent extension of the Section 45 production tax credit for renewable resources. Speaking in Florida, Obama said that this year's rising gasoline prices highlight the need to move to more renewable sources of energy. "If we're going to take control of our energy future; if we're going to avoid these gas price spikes down the line, then we need a sustained, all-of-the-above strategy that develops every available source of American energy - oil, gas, wind, solar, nuclear, biofuels, and more."[154]

6.11.2 Local Effects of WTE on Bond Ratings

The Solid Waste Associate of North America (SWANA) issued a White Paper in January, 2012," Waste-to-Energy Facilities Provide Significant Economic Benefits." Specific examples cited include:

- Lancaster County, PA. The waste-to-energy facility provides a revenue stream from the sale of electricity, producing over $256 million in electric revenue. On average, 500 tons of ferrous metal and 16 tons of non-ferrous metal are removed from the processed waste and recycled each month, offering an additional revenue source. Because of long term operating contracts and a fixed debt payment structure, the waste-to-energy facility offers stable tipping fees for municipal waste. Lancaster County's tipping fee is $62 per ton, is $7 per ton less today than it was when the waste-to-energy facility first opened in 1991.

- York County Resource Recovery Center. In 2010, Standard and Poor's raised its issuer credit rating on the Authority to AA from A+, and Moody's affirmed its A2 rating on the Authority's outstanding bonds. Those agencies cited the Authority's strong liquidity position, key contracts for waste supply, facility operations and electric sales, the Authority's history of strong debt service coverage, and competitive tipping fees as the basis for those ratings.

[153] www.edie.net/news/5/Third-of-EfW-operators-predict-downturn-in-2013.22592/
[154] http://www.wte.org/wte-receive-permanent-benefit-under-obama-a3072

- Pinellas County, FL. Electricity sales and other revenues bring total revenues up to about $80 million against a total operating budget, including allocations, of about $58 million, a significant, positive, revenue stream each year. The solid waste system in Pinellas is a financial contributor to county operations, such that the county board authorized up to $80 million to be borrowed from the solid waste reserve fund to help fund the county capital improvement projects.
- Hillsborough County, FL. The waste-to-energy facility in Hillsborough County underwent a 50 percent expansion in 2009, increasing its capacity to 1,800 tons per day, while generating nearly 47 megawatts of renewable energy. Fitch Ratings has upgraded nearly $150 million worth of Hillsborough solid waste bonds from A-to A+, citing the system's strong financial operations, ample surplus revenues to service debt, above-average reserve levels, and the County's covenant to raise rates at minimum levels as per the series 2006 bond ordinance.

The report concluded that, WTE facilities are economically sound investments that provide multiple financial and environmental benefits to the communities that utilize them. It noted that the majority of the nation's waste-to-energy facilities are owned by local governments that have invested in them to achieve long-term solid waste management solutions. These facilities produce clean, renewable energy while reducing waste volume by 90 percent. SWANA noted that WTE facilities generate revenue through the sale of electricity, tipping fees, and profits from the sale of recovered metals, which allows for the repayment of their municipal bonds, as well as financing of other important aspects of MSW management, such as extensive recycling programs. The economic success of waste-to-energy for several decades throughout the country should provide confidence to other communities considering this economically and environmentally sound technology[155].

6.11.3 Sale of Carbon Offsets: Greenhouse Gas Mitigation

The European Union considers EfW facilities to have potential for greenhouse gas mitigation, by replacing fossil fuel generation of electricity with waste generation of electricity, by displacing virgin steel production due to the recovery of iron and steel scrap at certain WTRE facilities and by avoiding landfill disposal of MSW with subsequent methane production[156]. The Kyoto Protocol provides that EfW facilities can generate tradable credits (Certified Emission Reductions (CERs)) through approved Clean Development Mechanisms. The CERs are a compliance tool for emissions trading in the European Union. EEX has been awarded the role as transitional common auction platform and to auction allowances on behalf of 24 Member States. [157]
In the U.S., the EPA has determined that nearly one ton of CO_2 equivalent emissions are avoided for every ton of municipal solid waste handled by a WTE facility[158].

Energy Income Trust International (EITI) is a Canadian renewable energy company that finances and develops WTE projects. EITI finances its CDM WTE projects by forward selling carbon credit

[155] www.SWANA.org Applied Research Foundation
[156] Ho, Kevin, 2066, "Using the Carbon Credits Earned by the Waste-to-Energy Facility of Wheelabrator Sagus, Inc. to Balance the Carbon Emissions of Columbia University's Morningside Campus
[157] http://www.eex.com/en/Auction
[158] 2010 ERC Directory of Waste-to-Energy Plants, Energy Recovery Council

proxies. EITI sells either it proprietary Income Trust Carbon Displacement Mechanism Units or CERs[159].

One WTE facility in the U.S., Lee County, FL., has been certified by the Voluntary Carbon Standard to market carbon offsets to those entities that wish to purchase carbon credits. Lee County's third facility expansion, of 636 tpd, was the first WTE capacity in the US to market carbon credits. The facility started with 60,000 credits, which they were able to market at approximately $4.00 per credit, they currently are certified for 30,000 credits. Sales of credits vary greatly with economic and political conditions; the Authority currently has 15,000 unsold credits from 2012 remaining on the market, but is expecting to certify and market credits for 2013. The 2012 offering is the first one that did not immediately sell out.

The demand for carbon credits in the US is greatly influenced by legislative activities and "current events," similar to recyclables or stock markets. WTE CER's have a lower "cachet" than hydroelectric or wind farm power generation, but a higher demand than forestry credits. When there is talk of GHG or climate change legislation, including the President's inaugural comments on climate change, there is an influx of inquiries into Lee County credits and subsequent sales of credits.

Lee County has used both an exclusive agreement with national brokerage firms for the sale of CERs and open market type brokering in which they notify brokerage firms of CER availability and they contact the County when they have a client that is interested. Both approaches have been successful. The county's stellar environmental record seems to be the driving factor to those purchasing credits from the county; another factor is that the facility is government owned and has a number of regulatory measures it has to comply with, providing assurance to purchasers.

CERs are sold on a past-date, current date, or forward status. Many companies seek forward sales to hedge protection from future requirements at a relatively low current price. The practice is very similar to contracts for recyclables markets, where spot market price activity is more volatile than long term contracts, but the price risk for better returns must be balanced against actual sales potential. Lee County has found that it is important to be nimble in CER sales. The staff has authority from the Board to negotiate on their behalf, to effectuate sales to take advantage of rapidly changing or ephemeral markets[160].

6.12 Summary

Mass burn and RDF facilities provide the most proven alternative waste processing technologies covered in this report. As the Newport Resource Recovery Facility produces RDF and this report addresses alternatives, Table 6-3 focuses on the advantages and disadvantages of mass burn.

It is a well proven technology capable of handling the entire R/W Counties waste that is not either recycled or composted. Relative to the other waste processing alternative technologies, mass burn is less expensive. Air emissions standards are documented to be met by current air pollution

[159] http://eitiinternational.org/carbonprogram/index.html
[160] Per. Comm. Brigitte Kantor, Solid Waste Coordinator, Lee County Solid Waste Division

control technologies. Nevertheless, past significant public opposition to mass burn facility permitting processes may be expected to make siting and permitting a mass burn facility quite difficult.

WTE facilities continue to provide waste management services in select markets. While no new plants are planned for the U.S., some plants are upgrading and expanding in anticipation of future growth. Emissions from WTE plants are well below EPA standards. Financial performance of WTE plants is known. WTE is a reliable, proven method to convert waste to steam or electricity. However, siting a new WTE plant is anticipated to be difficult. Potential advantages and disadvantages to mass burn WTE facilities are provided in Table 6-3.

Table 6-3
Potential Advantages and Disadvantages of a Mass Burn WTE

Advantages	Disadvantages
♦ Proven technology ♦ Proven capital and operating costs ♦ Capable of processing the entire R/W Counties' waste stream not recycled or composted ♦ Financially stable vendors ♦ Clear regulatory pathway ♦ Compliant air emissions	♦ Public opposition makes siting and permitting a new facility difficult ♦ Capital and operating costs can be high

There are two mass burn facilities in Minnesota that provide excellent touring opportunities for R/W Counties including the HERC facility in Minneapolis and the Olmsted County facility in Rochester.

7 Anaerobic Digestion

Anaerobic digestion (AD) is the process of decomposing the organic portion of MSW in a controlled oxygen-deficient environment. It is widely used to digest sewage sludge and animal manures. Bacteria produce a biogas that consists mainly of methane (CH_4), water vapor, and carbon dioxide (CO_2) through a process called methanogenesis. This is the same process that generates methane naturally in landfills and wetlands. Simplified, the process is common on farms, producing silage, and in wastewater treatment plants to stabilize sludge. While the AD process has historically been applied to food and green waste, agricultural waste, sludge, or other similarly limited segments of the waste stream, more recently, AD has been added to the back end of RDF facilities, or is part of an integrated processing system for MSW. AD can play an important role as a component of organic waste management, avoiding, by more efficient capture and treatment of gasses, the greenhouse gas emissions that are associated with landfill disposal of organics.

The organic portion of MSW in the US represents 70% of the waste composition and consists of non-recyclable paper, garden waste, food waste and other organic waste. The biodegradable fraction (paper and organic material) accounts for 51% of waste composition delivered to Newport (Table 2-4). Therefore, treatment of these wastes is an important component of an integrated solid waste management strategy and reduces both the toxicity and volume of MSW requiring disposal.

Approximately 40 percent of all food generated in the United States is wasted, according to an analysis by the New York-based Natural Resources Defense Council (NRDC), which estimates that Americans are throwing away the equivalent of $165 million in unconsumed food each year.[161] The analysis notes that there has been a 50-percent jump in generation of food waste since the 1970s in the U.S.; food waste is the single largest component of solid waste in U.S. landfills; the average American family throws away an equivalent of up to $2,275 in food annually.[162] The biodegradable fraction of MSW contains anywhere from 15% to 70% water.

The AD-produced biogas can be used directly in engines for Combined Heat and Power (CHP), burned to produce heat, or can be cleaned and used in the same way as natural gas, as a vehicle fuel or in sufficient quantities in a gas turbine to produce electricity. The remaining residue has liquid and solid components. “Whole digestate” is used to describe the un-separated sludge and liquor. The liquid has been used as a fertilizer, especially on non-food crop applications. The solid residue of the AD process is similar, but not identical, to compost. It can be used as a soil conditioner if suitable markets can be identified, however its properties:

- Will depend on the AD feedstock used
- May or may not contain useful levels of nitrate or phosphate
- May be contaminated with heavy metals.

[161] Waste Age, Aug 22, 2012
[162] Ibid

The solid residue can, alternatively, be burned as a fuel, or gasified. In England, provided the requirements of the Anaerobic Digestate Protocol are met, the residual solids are not classified as a waste by the Environment Agency and handling and storage regulations are eased.

7.1 Process

A typical AD process flow diagram is provided in Figure 7-1.

Figure 7-1
Typical AD Process Diagram[163]

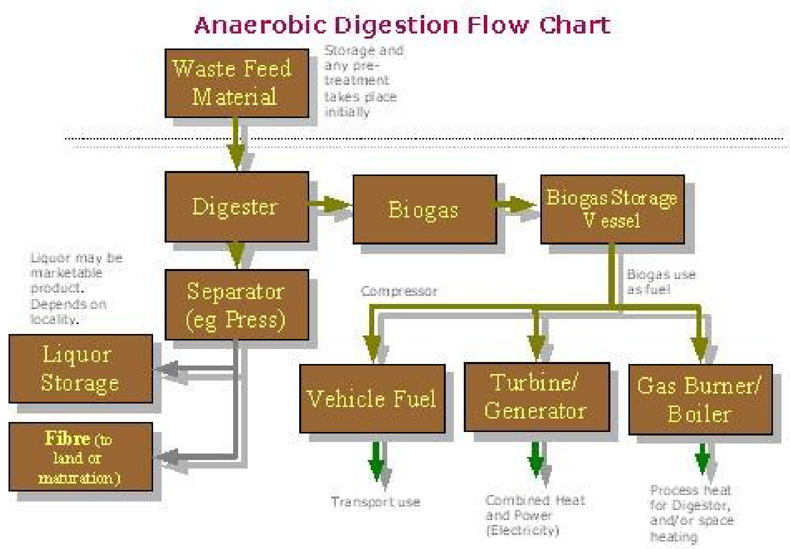


Figure 7-2
Anaerobic Digester in Germany

(Courtesy Linden Hills Power and Light)

[163] www.sswm.info

The commercial AD process is divided into four stages: Pretreatment, waste digestion, gas recovery and residue treatment. Ideally, for simplest operation, the AD feedstock is source separated organic materials. However, anaerobic digestion has recently been used for MSW disposal and in this application waste processing or sorting on the front end is required to provide an effective feedstock. Removal of metals for recycling together with a combination of shredding, screening, and/or air separation has been used to concentrate and separate organic materials from inorganic materials. Mechanical separation can be employed if source separation is not available. The waste is shredded before it is fed into the digester to provide uniform size distribution, and a degree of mixing of the waste components.   Alternatively, an "ultra-wet" separation process has been used by at least one vendor on the front end of an integrated system to use water floatation to separate metals and plastics for recycling.

The digestion process occurs in three stages: hydrolysis/liquefaction, acidogenesis and methanogenesis. In the first stage, microorganisms secrete enzymes, which hydrolyze polymeric materials to monomers such as glucose and amino acids. These are subsequently converted by acetogenic bacteria to more volatile fatty acids, hydrogen and acetic acid. The third group of bacteria, methanogenic bacteria, convert hydrogen, carbon dioxide, and acetate to methane. Anaerobic digestion is typically done in large digesters that are maintained at temperatures ranging from 85°F - 149°F. There are two AD bacterial-specific processes, which take place over different temperature ranges. Mesophilic digestion takes place between 68ºF and 104ºF and can take a month or two to complete. Thermophilic digestion takes place from 122-149ºF and is faster, but the bacteria are more sensitive[164].

Inside the digester, the feed is diluted to achieve the desired solids content and remains in the digester for a designated retention time. For dilution, a varying range of water sources can be used such as clean water, sewage sludge, or re-circulated liquid from the digester effluent. A heat exchanger is usually required to maintain temperature in the digesting vessel. The biogas obtained in AD may be scrubbed to obtain pipeline quality gas. In case of residue treatment, the effluent from the digester is dewatered, and the liquid recycled for use in the dilution of incoming feed. The biosolids are aerobically cured to obtain the compost product.

Commercial AD processes for MSW are also classified according to the total solids (TS) content of the slurry in the digester reactor. Low solids systems (LS) contain less than 10 % solids, medium solids (MS) contain about 15%-20%, and high solids (HS) processes range from 22% to 40%. These categories can be classified further, on the basis of number of reactors used, into single-stage and multi-stage systems. In single stage processes, the three stages of the anaerobic process occur in one reactor and are separated in time (i.e., one stage after the other) while multi-stage processes make use of two or more reactors that separate the acetogenesis and methanogenesis stages in different vessels. Batch reactors are used when the reactor is loaded with feedstock at the beginning of the reaction and products are discharged at the end of a cycle. The other type of reactor used, mostly for low solids slurries, is continuous flow where the feedstock is continuously charged and discharged.

[164] www.seas.columbia.edu/earth/vermathesis.pdf

7.2 Performance

AD is widely used on a commercial-scale basis for industrial and agricultural wastes, as well as for stabilization of wastewater sludge. AD technology has continued to expand rapidly in Europe on mixed MSW and on a larger scale on source separated organics (SSO) or agricultural-based processes, but there is very limited commercial-scale application in any form in North America. As of June 2012, there were 78 operational AD plants that treat waste and farm feedstocks in the UK.[165]. Two fully on-line commercial-scale plants in North America that are designed specifically for processing SSO are in the Greater Toronto Area; the Dufferin Organic Processing Facility in Toronto and the CCI Energy Facility in Newmarket. There are a number of smaller demonstration facilities in the U.S. operating on either mixed MSW, SSO, or in some cases co-digestion with biosolids and several plants in the planning, construction or start up stages.

AD facilities need to be designed and operated with odor prevention as a primary operations objective. The two main areas where odor can be released in the AD process are in the reception area where food waste is delivered, and from ammonia in the digestate. Anaerobic bacteria are notoriously sensitive to feedstock and environmental parameters; "upsets" of AD facilities can result in odor releases to surrounding properties. Historically, public opposition to siting of AD facilities associated with hog farming or sewage and paper plant facilities were based on odor issues. Recent innovations in AD facility design, including processing in completely enclosed facilities and improved emissions controls, have reduced concerns. European AD facilities, are commonly located adjacent to homes and businesses, although the units are typically of smaller size.

In terms of preventing nuisance to neighbors, the tipping floor and initial processing area must be designed with odor containment and treatment in mind. Most new facilities are completely enclosed for the initial stages of digestions, and are designed along best practice lines, with fast acting doors and air extraction; however as in any industry this needs to be followed by good operation. Ensuring that food waste is introduced into the digestion process as rapidly as possible after delivery and cleaning the tipping area regularly will reduce odor generation and minimize the risk of nuisance for indoor or outdoor facilities. Odor control systems need to be considered central to the operation of plants, and be well maintained. For example biofilters are commonly used, as they have a low operational cost and don't require chemical additions. However unless properly designed and maintained, biofilters can become acidic and generate odor rather than reduce it.

7.3 Vendors

7.3.1 Arrowbio

The Arrowbio process integrates preprocessing and advanced anaerobic digestion to recover recyclables and generate energy via the medium of water. This unique process could be considered an "ultra-wet" AD system. Clean recyclables are recovered from mixed waste via gravitational separation in a water "separation/preparation" vat, and biodegradable organics are converted to biogas. In the front end, physical stage, the water separation system removes grits and other "landfillables," recovers traditional nonbiodegradable recyclables (e.g., plastic soda bottles and

[165] DEFRA http://www.defra.gov.uk/environment/waste/business/anaerobic-digestion/

milk jugs) and other secondary materials, and isolates and prepares the biodegradables for digestion at the backend. The water separation of recyclables and grits is claimed to be more energy efficient than air separation, due to the unique physical properties of specific gravity and solubility of compounds in water; there are also "incidental" benefits of tipping into water including suppression of dust, and the neutralization of odors. Vat water is continuously pumped to the backend enclosed digesters and because the system is watery throughout, any input surges are evened out, contributing to the system's overall resiliency.[166]

7.3.2 Greenfinch

Greenfinch had a pilot project in Ludlow, South Shropshire, GB, which has been in operation since 2007. The Biocycle Ludlow Digester project uses the anaerobic digestion process to treat source separated organic waste. The facility was originally built as a UK Government funded/ Defra Demonstrator Project.

7.3.3 Biogen

Biogen[167], which was established by Bedfordia in 2005, bought Greenfinch in 2008. Biogen bills itself as the UK market leader in anaerobic digestion providing a total solution to the problem of commercial and household food waste disposal. Biogen has two commercial AD plants. Westwood, the second generation facility, opened in June 2009. Westwood can process 49,000 tons per year of food waste each year producing 2.6 MW of renewable electricity. It also produces 35,000 tons of liquid biofertiliser, which is applied to 1,750 acres of growing crop. Twinwoods in Milton Ernest, Bedfordshire which opened in 2005 processes 47,000 tons per year of waste which generates 2.1 MW of green electricity and produces 33,000 tons of a biofertiliser. BIOGEN and partner Alauna Renewable Energy have signed a deal with the City of Edinburgh and Midlothian Councils for the design and build of a new food waste recycling plant near Millerhill, in Midlothian. The 30,000 tons per year plant will process household food waste collected by the local authorities alongside food waste from commercial sources in the region to generate around 1.4 MW of renewable energy. Work on site is planned to begin in February 2014 with the AD plant expected to produce electricity by the autumn of 2015 and finally being handed over to Alauna Renewable Energy (ARE) by December 31, 2015. Biogen has also started construction on an 11,000 tonne AD plant in Caernarfon, is about to start work on a 22,500 tonne plant in Denbighshire and a 45,000 tonne per year plant in Hertfordshire.

> **NOTE:** There is also a gasification company, Biogen, which is located in the US and the Dominican Republic[168]. They do NOT run AD systems. "Biogen Gasification systems achieve the unique ability to gasify difficult fuels successfully by a combination of specialized downdraft reactor design and exclusive closed-loop gas cooling and gas cleaning systems. They use waste heat effectively in an exclusive closed-loop heat recovery biomass drying process. They report their systems also supply substantial thermal energy as a true Combined Heat and Power, or CHP process"

[166] Proceedings of SWANA's 11th Annual Landfill Symposium and Conference June 2006
[167] http://www.biogen.co.uk/
[168] http://biogendr.com/app/en/frontpage.aspx

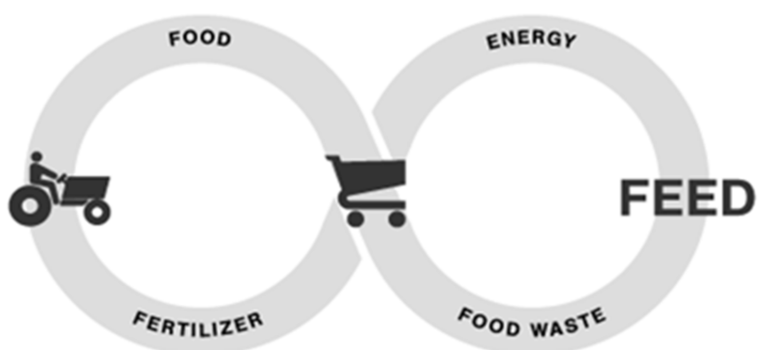
7.3.4 Ecocorp

Ecocorp[169] provides AD plants for the composting of green waste, food waste and paper in combination with dewatered sewage sludge, animal manures and industrial and construction wastes. They use European technology, and have designed plants of between 20,000 and 100,000 tpy. A 50,000 tpy facility is designed to fit on an acre of land, and be fully contained on that property. Ecocorp designs a front end "MRF," that removes OCC, plastics, metals, and non-recyclable plastics from commercial waste streams. The company has a website made from "100% recycled electrons," but does not list completed projects nor have e-mail or telephone enquiries for further information.

7.3.5 FEED Resource Recovery, Inc.

Founded in Boston, Mass. in 2007, Feed Resource Recovery concentrates on Food industry applications that leverage customers' existing transportation and distribution systems to, as stated by the company, "generate clean, sustainable power for onsite operations, reduce emissions and save millions of dollars on waste removal costs." The company is a strong proponent of the Zero Waste movement, and promotes their R2S (Resource Recovery System) model as similar to a natural system with a closed loop life cycle. FEED uses a back-haul system, similar to many grocery recycling programs for OCC and film plastic, to bring food wastes from supermarkets to an AD facility in the trucks that delivered fresh produce to the markets. The system front end waste sorting equipment is capable of removing yogurt containers, egg cartons, sausage wrappers and other grocery packaging. The AD technology produces methane biogas, water effluent for plan processes or irrigation, and a compost/fertilizer component. FEED gas utilization modules include options for use of biogas as fuel for onsite boilers, natural gas trucks, or combined heat & power units. The units can be remotely controlled, such that minimal on-site personnel are needed for plant operation. FEED has a project with Ralph's/Food-for-Less and parent company Kroger at a grocery distribution center in Compton, CA, near Los Angeles.

Figure 7-3
Diagram of FEED Closed Loop System[170]



[169] http://ecocorp.com/
[170] www.feedresource.com

7.3.6 Organic Recycling Systems, PVT., LTD. (ORS)

ORS[171] states that, "We are committed to meet needs of our clients for scientific disposal of municipal solid waste ensuring GHG reductions while recovering Energy & Compost through the proprietary DRYAD(TM) process. The Technology was developed by ORS in consultation with Waste Works, Ireland for mixed urban waste. DRYAD(TM) has been developed after a thorough R&D effort considering the characterization of municipal solid waste in India and validation of operational data through a 12 TPD Pilot Plant on mixed MSW.

The flexibility of the DRYAD(TM) technology allows the treatment of a wide range of different feed materials. The Bio-gas generated from the process is used to generate energy & the digested residue is stabilized aerobically to provide a fertilizer/soil enhancement. The DRYAD(TM) process is stated to have multiple potential revenue streams from the sale of renewable energy, bio-fertiliser and CERs Credit generated through processing of MSW. The Organic Recycling System facilities, to date, are proposed or under construction in Mandur and Solapur, India; there are no U.S. facilities.

> **Note:** Dryad Recycling LLC, in Tonganoxie, KS 66086-3027 is a recycler of packaging material, flexible packaging material, dry laminate, and film laminate, and has no relation to the AD company.

7.3.7 Organic Waste Systems (OWS), Inc.

OWS[172] is a company, in business for 25 years, which designs biogas facilities that are adapted to the type of feedstock the facility will use. Most of the facilities are in Europe, a handful of facilities are in Korea. The facilities that use MSW as a feedstock use the DRANCO (DRy ANaerobic Composting) technology which was developed by OWS to optimize the digestion parameters of the "dry" and "static" anaerobic digestion that takes place in a landfill. The patented DRANCO process is unique because of the vertical design, high-solids concentration and the absence of mixing inside the digester. The patented DRANCO process is a unique process because of the vertical design, high-solids concentration and the absence of mixing inside the digester. All OWS designs follow the "first in – first out" principal.

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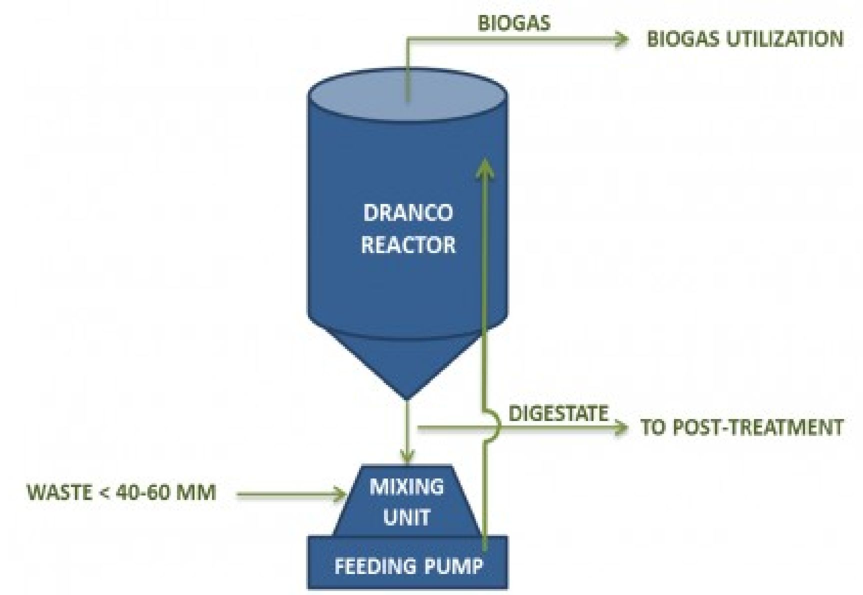
[171] http://organicrecycling.co.in/services.html
[172] http://www.ows.be/

Figure 7-4
DRANCO Process



The MSW plants operate at a dry matter content in the digester of up to 40 %. In source separated organics and yard / food waste facilities, the waste is treated at a dry matter content of 20 to 35%. The company considers the strengths of the DRANCO process to include:

- Vertical fermenter: feeding at the top and extraction through a conical outlet at the bottom
- Single-phase digestion with intensive recycling of the digestate
- Thermophilic or mesophilic operation
- Compact, well-insulated digesters with minimal heating requirements
- High-rate dry digestion (very high loading rates and biogas productivities can be achieved)

OWS has also developed the SORDISEP (SORting, DIgestion and SEParation) process, a "Back end" mechanical treatment for mixed waste that occurs after digestion, facilitating wet separation and removal of inerts and sand. These inert "remainders" are washed to achieve high market value of the components. End products include clean sand, compost, inerts (glass), and a light fraction (plastics). The Sordisep process is applied in the DRANCO installation in Bourg-en-Bresse, France, treating 66,000 tons of MSW per year.

OWS has also developed the BES-Plugflow digestion technology; a horizontal plug-flow digester constructed in concrete. The BES-Pluflow technology works at a lower total solids-content than the DRANCO-FARM technology, has a lower retention time for semi-solid feedstocks, low electricity consumption and a shorter construction time than the DRANCO system..

7.3.8 PurposeEnergy

PurposeEnergy builds patented anaerobic digesters specifically for the food and beverage industry. The company developed the Tribrid-Bioreactors™ which they consider to be different from all other bioreactors available. The multi-chambered design reduces volatile solids into soluble sugars and acids prior to introduction to the high rate reactor chamber. PurposeEnergy states that this provides unique advantages for food and beverage manufacturers:

- Engineered to process liquid, slurry, and solid byproducts (low and high strength waste water and spent grains)
- Disruptive combination of treatment efficiency and solids destruction rate
- Lower installed cost and operating cost compared to alternative solutions
- Robust design is ideal for challenging industrial settings

Operating under the mantra "Saving the Earth, one beer at a time," PurposeEnergy has the financial backing of Vermont's Clean Energy Development Fund and Green Mountain Power[173].

7.3.9 Solutions4CO2

Solutions4CO2 (Toronto, Canada) has developed what it calls the Integrated Biogas RefineryTM (IBR) platform. In the process, AD is coupled with an algae growing system to obtain added products and value. According to the company the system can reduce the payback for AD projects to less than three years with the production of high value Nutraceutical and Pharmaceutical co-products such as Omega-3 and Astaxanthin. Dil Vashi, manager of corporate development at Solutions4CO2, states that at the heart of the system lays the company's own proprietary Biogas Purifier and Infusion SystemTM (BPIS). "The BPIS essentially infuses and completely dissolves CO_2 and Hydrogen Sulphide (H_2S) into water as soluble gases. The methane (CH_4), which isn't soluble, passes through the water and flashes off. The CO_2 and H2S are captured in the water and the methane stream is captured through off gassing. Instead of the typical a biogas stream which is typically 60% methane, 39% CO_2 and less than 1% H_2S, the IBR biogas is over 90% methane and the CO_2 and H_2S are reduced by 85% – 95%."

Solutions4CO2 states "The significance of our system is that when you grow algae in that CO_2 and H_2S infused water, it gives you an increase in your algae growth yield of over two to three times. What we do then, is take that algae and harvest it, dewater it, dry the biomass and then extract certain high value oils – primarily Omega-3 and Astaxanthin – and then sell them into the nutraceutical and pharmaceutical industries," To infuse the CO_2 and H_2S into the water, Vashi says that the company's BPIS differs from more common fine bubble sparging techniques, which operate under pressure with very small bubbles, by displacing other molecules present in the water such as oxygen and nitrogen. Infusing the CO_2 and H_2S at a molecular level results in a bubble-less solution, which makes it considerably easier for the algae to consume the infused gases. Cultivated in an Algae Cultivation System (ACS) that is comprised of an LED lit tank, or photo bioreactor, the algae consume the CO_2 and H_2S as nutrients, and essentially processes them into high value compounds such as Omega-3 and other long chain carbon compounds. To harvest the algae, every couple of days around 50% of it is scooped from the top of the photo bioreactor by the Harvesting

[173] http://www.biocycle.net/2010/07/regional-roundup-80/

and Extraction System (HES), which dewaters and dries it, and then extracts the high value oil. The remaining 50% remains in the bioreactor as an inoculum to get the next batch of algae started. According to the company, its IBR is a closed loop system which utilizes all of the outputs of the AD system as inputs to the co-product platform. Power, CO_2, H_2S, clean methane, water and digestate from the AD are utilized as inputs to the co-product platform, with all residual co-products sold to generate additional revenue. The resulting revenue enhancement effectively reduces project paybacks to less than three years.

The company is currently completing its first commercial IBR facility in Canada at an existing AD installation which processes a mixture of dairy waste and commercial food waste into biogas for power generation. The IBR will be integrated with the AD and will process live biogas from the AD as an input for the IBR to produce algae biomass containing high value nutraceutical and pharmaceutical co-products.

7.3.10 Urbaser S.A.

Urbaser S.A.[174] build sorting and composting treatment plants. The ACS (Activities of Construction and Services) group, through its environmental URBASER Company believes it is a leader in the management and treatment of waste, globally. It is active in street cleaning, and transportation of waste, treatment and recycling of urban waste, management of water and urban gardening and green space management. URBASER covers the whole chain of value in the provision of these services, from design and conception, realization of the project, construction and financing through operation. URBASER states it is also active in the field of renewable energy sources to reduce the negative impacts of greenhouse gas, and is developing processes for alternative sources of energy from biomass from energy crops, residual forest biomass, and agricultural and industrial wastes that are biodegradable. The company, based in Spain, has facilities in Portugal, Spain, Mexico, France and UAE, among others. URBASER SA was short listed for the Santa Barbara, California Conversion Technology Project in December, 2009, their first US venture. URBASER has 27,020 employees world-wide, with an annual 1,200 million euro turnover and 2 billion euro of current orders today. Urbaser is a subsidiary of the Spanish group ACS, which is a shareholder of the group DRAGADOS

7.3.11 Valorga

Valorga[175] is a subsidiary of Urbaser. Valorga states it was in the forefront of the treatment of household waste by anaerobic digestion in the 80's. Valorga constructed and operates 19 methanization treatment plants, with capacities of 10,000 to 300,000 tons a year. Most of their plants are in Europe, but facilities were also built and operated in China. A typical facility is one the company built in 1987 for the processing of 55,000 TPY of MSW from the City of Amiens, France. In 1996, the treatment capacity was extended to 85,000 TPY by the supply of waste from other Amiens' districts' municipalities with the construction of an additional digester. A mechanical sorting unit allows for the separation of the organic fraction from MSW. VALORGA INTERNATIONAL was purchased by URBASER SA in 2005.

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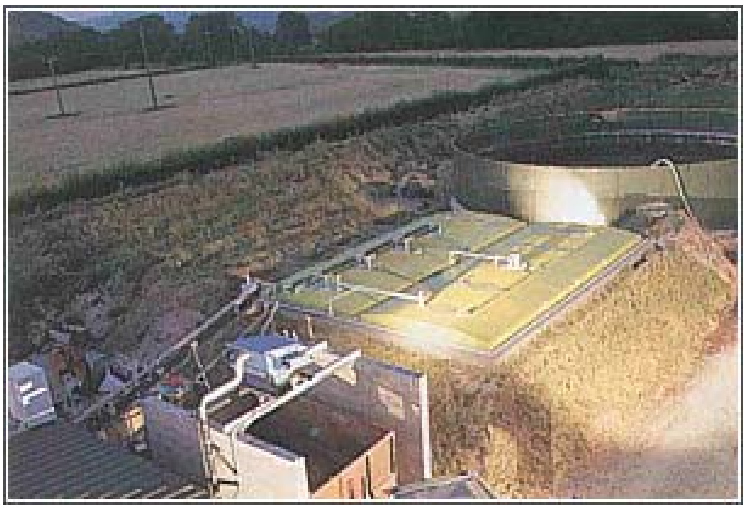
[174] http://www.urbaser.es/
[175] http://www.valorgainternational.fr/en/index.xml

7.3.12 Waste Works

Waste Works[176] of Co. Kerry, Ireland designs AD plants and related services, reedbeds, and compost plants. Their primary experience has been in wastewater treatment, but they also note experience with livestock and ag wastes, grass and crops, MSW, and catering wastes and food industry wastes. They provide in-vessel technology for composting, using a semi-permeable flexible cover similar to an ag-bag that is waterproof, retains odors, bio-aerosols and moisture to enclose the waste processing. They have 135 plants worldwide ranging from 1,500 to 160,000 tpy. Their anaerobic digester systems, noted to be installed in five countries, are capable of high solids AD.

Figure 7-5
Waste Works Facility[177]



Courtesy, WasteWorks

7.3.13 Xergi [178]

Xergi is a Danish company that specializes in biogas generation. They offer turnkey services including design, engineering, specification of equipment, and construction management. They have partnered with the Faculty of Agricultural Sciences, University of Aarhus world's largest test facility for biogas for

7.3.14 ZeroWaste/ KOMPOFERM Dry Fermentation AD (ZME)

ZWE[179] uses technology developed by the German company SMARTFERM, to process organic waste such as food scraps and generate electricity and compost for agriculture use. The KOMPOFERM technology is a "dry" process. Zero Waste Energy's patented KOMPOFERM "dry anaerobic digestion system", contains unique features, according to the company, that make it a cost-effective and productive AD system available. Pre-processing is not required. Dry solids can

176 http://www.wasteworks.ie/
177 http://zerowasteenergy.com/content/dry-anaerobic-digestion
178 http://www.xergi.com/en/homepage.html
179 www.zerowasteenergy.com

be in excess of 50% of the input. The 21 day batch average cycle time compares favorably (up to 25% more productive) than other systems. They report:

- Digesters are biologically self-heated through the air system and re-circulation of the liquid percolate through the material, effectively optimizing energy usage.
- The liquid percolate contains the necessary biological constituents to negate the use of previously digested material needing to be used to start subsequent batches.
- Plants require a smaller footprint than traditional systems, creating opportunities for urban applications, and lowering infrastructure and operating costs.
- Odor is controlled through the injection of oxygen into the digester at the end of the process, which helps to strip odors and results in a superior product.
- The "digestate" emerging at the end of the process contains the lowest moisture content of any available system, making it easier to compost through our patented In-Vessel Composting ("IVC') system.

ZWE also developed a modular system, SMARTFERM, which uses the Kompoferm technology. According to the company, the Smartferm 21 day batch process diverts over 99% of organic waste, reduces greenhouse gases, reduces reliance on landfills and produces a clean, green energy. The technology is semi-mobile, prefabricated, and scalable up to 30,000 tons (27,200 tonnes) of waste per year, which is claimed to enable the customer to reduce installation time and costs when compared to other AD technologies. In addition to the Ventura County, California installation, the company has said that it has three more projects in the construction stages in California alone. The SMARTFERM technology will be manufactured in the US by a ZWE partner: waste industry equipment manufacturer, Dover ESG.

7.4 Projects

Projects handling organics from MSW are beginning to be developed in the United States.

7.4.1 San Jose-based Zero Waste Energy LLC

San Jose-based Zero Waste Energy LLC has several projects in California using the Smartferm and Kompoferm technologies.

In Ventura County, California near the community of Oxnard, the yard waste processing facility, operated by Agromin using Zero Waste technology, will be expanded to process up to 150,000 tons per year of source separated yard waste and food waste collected in the local communities by Harrison Industries. The site is owned by Limoneira which is the potential end user of the green energy for their citrus operation[180].

The Monterey Regional Waste Management District (MRWMD) is a Joint Powers District formed by Monterey County, Pebble Beach Community Services District and the Cities of Carmel, Seaside, Del Rey Oaks, Sand City, Monterey, Pacific Grove, and Marina, California. MRWMD has

[180] http://zerowasteenergy.com/content/agromin-limoneira

partnered with ZeroWaste on an anaerobic digestion operation in Marina, Calif. It is the first U.S. facility to use the **SmartFerm** dry anaerobic digestion system, according to company information. The project will convert 5,000 tons per year of organic waste into electricity and features four anaerobic digesters. The facility is scheduled to open in March, 2013.[181, 182]

The City of Napa, together with Napa Recycling & Waste Services, LLC are proposing a project that will compost a 50/50 blend of 20,000 tons per year of combined source separated municipal food waste and yard waste. ZWE will use Dry Anaerobic Digestion (AD) to produce approximately 111,891 diesel gallon equivalents (DGE), which would provide enough CNG to fuel 14 solid wastes and recycling collection vehicles per day. In addition, 8,882 tons per year of finished compost will be produced along with 160 KW of power that will be used in the process. The project has filed for a CEC grant under the CalRecycle program and is in the initial stage of design and development[183].

The City of San Jose has developed a project to process all of the City's commercial organics from the new, city-wide collection system. San Jose is partnering with Zero Waste Energy Development, comprised of the companies GreenWaste Recovery, Zanker Resource Recovery and Zero Waste Energy for the dry fermentation anaerobic digestion and in-vessel composting ("IVC") facility utilizing KompoFerm technology. The KompoFerm dry AD system and IVC is licensed exclusively to ZWE[184]. GreenWaste owns and operates the GreenWaste MRF located in the City of San Jose. The GreenWaste MRF is a 2,000 ton per day (tpd) MRF that is permitted to handle MSW, food wastes, single stream recyclables, yard waste and C&D debris[185].

When the three phase project is complete, the facility will be processing over 270,000 tons per year of organic waste that would otherwise be disposed in a landfill. The compost produced will be used to enrich soils, while the renewable biogas will be sold as energy for the utility power grid, and used to fuel local plants and facilities.

In South San Francisco, Blue Line Transfer, Inc. proposes to produce compressed natural gas (CNG) for transportation fuel from the bio methane generated by the ZWE anaerobic digestion (AD) of food waste and green waste portion of municipal solid waste (MSW) from the cities of South San Francisco, Brisbane, Millbrae and the County of San Mateo. The AD facility will convert 9,000 tons per year of food waste and green waste into bio methane that would be cleaned and compressed to produce CNG for the South San Francisco Scavenger Co., Inc. CNG refuse and recycling collection vehicle fleet. The project will convert food waste and green waste into CNG fuel for the collection vehicle fleet that collects organic MSW[186].

7.4.2 American River Packaging / Clean World Partners

American River Packaging has contracted with Clean World Partners and has opened a 25 tpd high solids anaerobic digestion (AD) system, which will be expanded next year to be the largest of its type in the U.S. Located in Sacramento, CA, the high-solid anaerobic digestion system will provide

[181] http://zerowasteenergy.com/content/monterey-regional-waste-management-district
[182] http://www.energymanagertoday.com/waste-district-trials-dry-anaerobic-digestion-088623/
[183] http://zerowasteenergy.com/content/city-napa-and-napa-recycling- waste-services-llc)
[184] http://zerowasteenergy.com/content/city-napa-and-napa- recycling-waste-services-llc
[185] http://zerowasteenergy.com/content/san-jose-msw
[186] http://zerowasteenergy.com/content/south-san-francisco-scavengers-blueline

American River Packaging with 1/3 of its electrical needs. Clean World said in a news release that the Sacramento Biodigester will convert 25 tons of food waste per day from area food processing companies (Campbell Soups), restaurants and supermarkets into renewable natural gas, electricity and soil-amendment products.

The site also will feature California's first anaerobic digestion-based renewable natural gas fueling station. The station is being developed by Atlas Disposal Industries of Sacramento and is expected to open in the spring. The system will fuel Atlas' clean fuel trucks, as well as other vehicles. In 2013 the operation will expand processing capacity to 100 tons of waste per day. Construction began in June. The operation will employ 13. At full capacity, the system will divert nearly 37,000 tons of waste annually from landfills. It also will produce organic fertilizers and soil amendment products for distribution to area farms. CleanWorld's proprietary systems are based on AD technology originally developed at UC Davis to convert food waste, agricultural residue and other organic waste with up to 60% solid content into renewable energy, fertilizer and soil enhancements without adding water. The company said that this reduces the systems' size and cost, and enables use in a wide range of settings. [187]

7.4.3 Kroger/Raphs's/Food for Less, Compton, CA

Kroger (NYSE: KR), a major grocery retailer, has opened a 55,000 ton per year anaerobic digestion food waste to biogas facility to help power its Ralphs/Food 4 Less distribution center in Compton, California. According to the company the facility will produce enough energy annually to power the over 650,000 square feet of its distribution center. The Kroger Recovery System utilizes the FEED anaerobic digestion technology to transform organic food waste that cannot be sold or donated, as well as onsite food-processing effluent to generate power for onsite operations. The company does not have to transport 150 tons of food waste per day to a composting operation in Bakersfield, California. The company said that the plant will also reduce area truck trips by more than 500,000 miles each year.

The plant is expected to produce enough biogas to offset more than 20% of the energy demand of the Ralphs/Food 4 Less distribution center. Combining the use of renewable energy power with more than 150 zero emission fuel cell fork lifts, the Ralphs/Food4Less distribution center, Korger claims that the facility is now one of the greenest and most efficient of its kind.[188] The AD facility is contained within the footprint of the Distribution center The facility is projected to provide power to the distribution center, produce biogas that will replace 95% of the center's natural gas consumption, supply 20 per cent of the distribution center's electrical needs, heat and repurpose waste water from an adjacent creamery for use in plant processes, additionally purify water for discharge to the environment and produce nutrient-rich fertilizers. Kroger is projecting a 18.5% return on the plant investment.[189] Project partners also include CalRecycle and CalEPA, the City of Compton, and the SCAQMD.

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[187] Waste Management World, December 17, 2012. http://waste360.com/commercial/clean-world-opens-anaerobic-digestion-operation-food-waste Waste Management World, December 17, 2012) (http://www.waste-management-world.com/articles/2013/02/video-update-100tpd-biogas-ad-plant-in-sacramento.html

[188] Waste Management World, May 17, 2013

[189] Video at http://vimeo.com/user18325931/review/66288741/820bd1e0df

Figure 7-6
FEED AD Digester
in the Kroger Grocery Distribution Center
Compton, California[190]

7.4.4 The City of Santa Barbara, CA

The City of Santa Barbara, CA convened a Community Advisory Council which was tasked with identifying an alternative to the proposed Tajiguas Landfill expansion. A RFP for waste management was issued, with the goals of:

- Pre-processing or converting MSW into beneficial products
- Reduce environmental impacts of landfilling MSW
- Cost-competitive tipping fee
- Production of clean green energy
- Provide a humane work environment
- Result in a long-term waste management plan
- Identified a campus of infrastructure to manage MSW

Mustang Renewable Power Ventures was selected to build a campus at the existing landfill with a MRF, followed by an anaerobic digester. The MRF will have an 800 TPD (250,000 TPY) mixed MSW line, a 130 TPD (40,000 TPY) Single Stream line, a 200 TPD (75,000 TPY) MSW & SS Organics AD Facility on a 6 acre site (140,000 SF of structures) and 4-6 acres additional compost finishing area on the landfill area. The project was announced in July 2011; the CEQA was begun in April 2012 and is expected to take 18+ months. Construction is anticipated in 2014 with operations beginning in 2016. The Tip Fees are estimated to be $60-77 per ton[191].

In reporting the facility announcement, the Santa Barbara Independent stated that, "The company hired, Mustang, is run by San Luis Obispo real estate moguls John Dewey and Rob Rossi of the Rossi Group. While the principals involved have no landfill experience — let alone background with seemingly futuristic technologies — they are experienced business operators and have

[190] http://feedresource.com/
[191] www.calrecycle.ca.gov/Organics/Conversion/Events/Digesting12

reportedly teamed up with subcontractors who've installed three to six such facilities in the United States[192]." Side note, the name "Mustang Ventures" appears to be derived from the Cal Poly Mustangs, alma mater of the principals

7.4.5 Gary, IN

Discussions are under way to establish a partnership that would bring a waste-to-energy plant to the city, according to J. Forest Hayes, Director of Commerce with the Gary Economic Development Corp. Organic Solutions Management is an Indiana company with decades of experience managing waste disposal facility throughout the country, said Chelsea Whittington, Gary spokeswoman. The company would manage the Gary Renewable Energy Plant. A location for the plant is still in the discussion phase, Hayes said.

Food waste from food manufacturing plants throughout the area would fuel the plant. Those include manufacturers of bread, beer, and other items, Hayes said. "This is a value-added solution for the Gary Sanitary District," Hayes said. The city facilitated the award of a $14 million volume cap award from the Indiana Finance Authority as a contribution to the partnership, he said. A project must obtain an award of volume cap before it can have tax-exempt bonds issued. The city will work to issue $14 million in economic development bonds on behalf of the developer. However, the bonds will be payable solely from the revenue of the renewable energy facility, which is the responsibility of the developer, Hayes said.[193]

7.4.6 South Burlington, VT

The Magic Hat Brewing Company, a Vermont-based craft brewer, installed an anaerobic digester to process the spent hops, barley and yeast left over from the brewing process into natural gas fuel. It also treats the facility's wastewater. The system was designed by Waltham, Mass.-based PurposeEnergy. Since firing up last summer, the 42-foot tall, $4-million digester has been providing enough natural gas to power the Magic Hat brewery, slashing the facility's power and waste treatment bills and creating a closed-loop system[194].

Once the digester is fully operational, PurposeEnergy will begin selling biogas back to the brewery – with Green Mountain Power as a middleman in order to avoid being regulated as a public utility – which will power all systems traditionally run on natural gas. Biogas will be piped to the brewery's boilers, so "instead of buying imported natural gas from Canada, they'll be using "homebrew" from their own backyard," says Fitch. The system will also be harvesting 1.3 million Btus of power from the exhaust, engine coolant and engine oil in order to heat the digester and preheat water going into the brewery's boilers. Any excess power will be sold back to the grid[195] and be powered by the waste stream. Tenants will have access to recyclable by-products made from waste at the facility.

[192] http://www.independent.com/news/2011/oct/31/vendor-picked-gas-trash-scheme/?print
[193] The Times of Northwest Indiana (NWI.com), Feb 28, 2013
[194] Waste 360, Feb. 25, 2011
[195] http://www.biocycle.net/2010/07/regional-roundup-80/

7.4.7 The Solid Waste Authority of Central Ohio (SWACO)

SWACO will add a landfill receiving facility (LRF) and a material recovery facility (MRF) in Grove City, Ohio. Team Gemini, a sustainable project design company in Orlando, Fla., will build the facilities, according to a news release. Columbus area-based SWACO will own and operate the LRF, while Team Gemini will own and operate the MRF. The buildings will cover a combined area of more than 185,000 square feet. Team Gemini is investing up to $300 million in the project, which will create up to 300 jobs. The facilities should be online in two years, although total construction could take up to four years. SWACO and Gemini said the agreement will allow for SWACO to reduce its use of landfills and eventually eliminate the need, as the LRF works with the waste stream recovery and recycling facility, which is being called the Center for Resource Recovery and Recycling.

Municipal solid waste (MSW) will be delivered to the receiving facility, where it will be directed to either the MRF or the landfill, which will allow haulers to remain on pavement and not climb the hill, therefore reducing carbon dioxide emissions and power needs. The MRF will be able to process up to 2,000 tons per day, with plans to process the entire waste stream in the future. Organic waste will be preprocessed for use in anaerobic digesters and other sustainable energy generation technologies. Gemini also signed a lease with SWACO to develop an industrial and research park nearby.

7.4.8 Turtle Lake, Wisconsin

Biogas developer, GreenWhey Energy has secured $28.5 million of long term financing to construct and operate a wastewater anaerobic digestion facility which will treat food waste carried in wastewater from local food companies. When completed in summer 2013, the project is expected to be one of the largest facilities of its kind in the U.S., processing some 500,000 gallons of wastewater from the local dairy and soy food industries. The 3.2 MW of electricity produced by the project will be sold to Xcel Energy and according to the developer will be enough to power 3,000 average Wisconsin households. The heat produced will be sold back to local factories reducing the amount of natural gas needed to run industrial processes, the digestate will be turned into organic fertilizer, offered to area farmers.

The project is believed to be the first privately owned wastewater treatment and AD facility in Wisconsin to bring together the organic waste from multiple food producers – mostly cheese and dairy - into a central facility.[196] The company has secured $28.5 million of funding from renewable energy investor, Geo Investors. GreenWhey Energy is owned by its management team and is supported by key partner investors, including the Geo Investors Fund[197]. Project investment was arranged by Baker Tilly Capital, LLC, financial advisor to GreenWhey. The financing included senior loan financing from Caterpillar Financial Services as well as New Markets Tax Credit financing from CAP Services, Inc. The project will also qualify for a federal grant upon completion of construction[198]. The GreenWhey plant is under construction. They expect to go online in June of 2013[199]

[196] 22 February 2013 By Ben Messenger, Waste Management World
[197] http://www.wisconsintechnologycouncil.com/newsroom/?ID=1961
[198] http://www.wisbusiness.com/index.iml?Article=290365
[199] Engineering.com April 7, 2013

Figure 7-7
Greenway Construction

7.4.9 Hometown BioEnergy Facility[200]

The Hometown BioEnergy Facility will be located in Le Sueur, Minnesota and is an AD project that will process 45,000 dry tons per year of agricultural and food processing residue into biogas, liquids and a solid renewable fuel. The biogas is used in reciprocating engine/gensets to produce 8 MW of electricity.

The AD process was designed by Xergi A/S. Xergi A/S has researched, installed, and operated about 40 similar plants. The plant is located in an abandon gravel pit in Le Sueur County.

The AD Process consists of five basic steps:

- ♦ Feedstock unloading and pretreatment.
- ♦ Anaerobic digestion.
- ♦ Biogas conditioning and storage.
- ♦ Electrical generation and heat recovery.
- ♦ By-product production and use.

The plant is currently under construction and is expected to be completed in 2013 or 2014.

[200] Minnesota Pollution Control Agency, Citizens Advisory Board Decision on the Need for an Environmental Impact Statement for the Proposed Hometown BioEnergy Facility. April 25, 2012.

7.4.10 UW Oshkosh

In 2011, UW Oshkosh began operation of their dry fermentation anaerobic digestion system. The facility, located on the campus of UW-Oshkosh, accepts agricultural plant waste, City of Oshkosh yard waste and campus generated food waste to produce methane.

The AD system used is a BIOFerm Energy systems unit with a total electrical output of 370 kW. BIOFerm Energy designs and builds biogas plants with over 330 installations worldwide. Their North American headquarters are in Madison, Wisconsin. The UW Oshkosh plant is designed for 8,000 tpy of agricultural wastes and source separated organics. There are four fermenters used to convert the organic materials into methane. Each chamber is 70' x 23' x 15' with a 28 day retention time. Food waste accounts for approximately 15% of the feedstock with the remainder coming from agricultural suppliers and City of Oshkosh waste.

Biogas created in the AD process is stored in bags before being used in the engine/gensets to produce electricity and heat. Odors are controlled using biofilters composed of lava rock and biological media.[201]

7.4.11 Gaylord, Minnesota

The city of Gaylord, Minn., has received a $7,550 grant from the West Central Region Clean Energy Resource Team to study the feasibility of building an anaerobic digester to convert local and regional organic waste into methane biogas. Short Elliott Hendrickson Inc., an engineering firm based in St. Paul, Minn., has been contracted to determine the availability of feedstock, as well as regional interest for the digester and biogas, according to Mark Broses, an engineer for the firm.[202]

7.4.12 Becker, MN

In Becker, MN, the Saint Paul Port Authority (SPPA) broke ground on a $15 million AD facility in April 2012 as part of an urban-rural partnership with Liberty Paper and the City of Becker. The anaerobic digestion plant is the largest single investment Liberty made since it broke ground on the Becker plant in 1994. Since that time, the plant outgrew the wastewater treatment plant capability of the City of Becker. About 500,000 gallons of water a day is used in the plant's paper-recycling operations. The wastewater is trucked to Saint Paul to be treated because Becker cannot handle the volume. The wastewater now will be treated on site by the anaerobic digester. The spin-off benefit to the plant is the generation of about 4 megawatts of electricity to power the entire plant. Partners in this effort included the City of Becker, the Port Authority, the Initiative Foundation, Xcel Energy, and the Minnesota Department of Commerce. Commerce Deputy Commissioner Bill Grant said the project was made possible by an earlier state grant, administered by the Port, to be used to help the Rock-Tenn paper recycling plant develop an alternative fuel source to power the Saint Paul operation. The Rock-Tenn study recommended that the biofuel produced by anaerobic digestion be used as an offset to the cost of natural gas. Liberty Paper is the first of eight projects throughout the state to develop anaerobic digestion as an alternative and sustainable fuel source throughout the Xcel Energy service area[203].

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[201] BIOFerm presentation by Christine McKiernan. June 20, 2012. Anaerobic Digestion for Organic Wastes, Albany, New York.
[202] http://biomassmagazine.com/articles/2060/anaerobic-digestion-projects-move-forward
[203] Report. The Newsletter of the Saint Paul Port Authority APR. 2012, Executive report from feasibility study.

7.4.13 Sanimax

Sanimax, a North American rendering company recently announced a partnership with Green Energy Partners that is planning to build a $30 million anaerobic digestion facility in South St. Paul, MN with construction beginning in the fall of 2013. According to the partnership, the facility will utilize organic waste from local food processing facilities, local schools, grocery stores, and area municipalities and will generate electricity and organic fertilizer.

7.5 Economics

There has been little government funding for AD facilities in North America. Factors that have been listed as hindering AD development include the lack of landfill diversion regulations for organic wastes, either undeveloped or strict environmental regulations for air and water quality, particularly rules relating to the release of hydrogen sulfide, lengthy and/or costly permit processes, the lack of robust carbon-offset markets and recently, the arrival of cheap and plentiful shale gas.

Due to these factors AD developers in North America rely heavily on tipping fees, and expect paybacks typically in the five to seven year range. While there has been some government backing through loan guarantees and Renewable Energy Certificates in the U.S., for years the biogas market in North America has struggled to attract the investment required to really take off. "The main reason is quite simply the lack of subsidies. Power purchase agreements and so forth," explains Vashi, of Solutions for CO_2.

An aversion of debt investors to 'technology risks', combined with public reticence to provide capital or financial guarantees is holding up development of AD projects in the U.S. The key to attract equity investors looking for substantial returns is identifying those projects or technologies that will be "transformative", and Anaerobic Digestion (AD) is not perceived as a "high return generator"[204]. Harvey Gershman, president of Gershman, Brickner & Bratton, a consulting firm specializing in solid waste management believes that "the public is reticent about providing capital, or guarantees, until the technologies are more proven". He goes on to add that companies should focus on developing their demonstration facilities to prove the technology and mitigate the risk from moving to commercial scale plants. Such facilities should be operating at a minimum of between 100 and 200 tons per day. "We don't have a disposal crisis here in the US, so it's hard to make a case for new technologies. It's not something that waste management people necessarily need. Landfill provides about two-thirds of our disposal capacity, and there is plenty of capacity. To change from what we have now, you have to convince people the technology works better," adds Gershman.

One state, California, has significantly invested startup capital to AD facilities, to support compliance with California Clean Air Act rules. A number of waste to renewable transport fuel companies are to benefit from over $17 million of funding from the California Energy Commission. According to the Energy Commission chair, Robert B. Weisenmiller the awards, totaling $17,223,593 will help support the expansion of alternative fuels and zero-emission vehicles in California. The program is paid for through surcharges on vehicle and boating registrations, and

[204] http://www.waste-management-world.com/articles/2011/09/waste-to-energy-must-prove-itself-to-take-off-in-u-s-.html

smog check and license plate fees, and the state's investments in these projects are safeguarded by matching fund requirements for awardees, and by making payments on a reimbursement basis after invoices are submitted[205].

Profiled projects that received funding include:

- **Blue Line Transfer**
  $2,590,929 to build an anaerobic digestion facility in South San Francisco to convert 9,000 tons (8160 tons) per year food and plant waste into biogas which will be used to produce compressed natural gas for a fleet of five refuse and recycling collection vehicles.
- **Sacramento Municipal Utility District**
  $1,819,166 to facilitate the completion of a project to demonstrate a patented process developed at the Argonne National Laboratory to optimize the production of biomethane and reduce carbon dioxide from anaerobic digestion. (American River Packaging project)
- **Aerovironment**
  $2,150,000 for the purchase and installation of electric vehicle charging equipment.

Paul Relis, senior vice president at CR&R, an Orange County-based waste management company feels that the biggest challenge for companies looking to commercialize is securing long term feedstock supplies. "We're relying on a $4.52 million grant from the California Energy Commission," says Relis. "This grant is very important to the feasibility of the project. We believe if we achieve scale at 450 tons per day or greater (ours is 150 tpd) an AD project could compete in the marketplace within 5 years. But that depends on the policies California adopts…" In evaluating traditional "flow control" financing options, Michele Young, organics manager for the City of San Jose, California has stated that "municipalities have the ability to direct feedstock, and assure the rates paid by generators support the processing plans to reach diversion goals. What we hear from the vendors is that they are anxious to work with municipalities that already have political buy-in for innovative technology projects. Without such support, there are examples of projects that "fall apart".

Solutions4CO2 has pursued an alternative financial enhancement measure: the production of "platform" or "designer" chemicals in the AD process. According to the company their system can reduce the payback for AD projects to less than three years with the production of high value Nutraceutical and Pharmaceutical co-products such as Omega-3 and Astaxanthin. According to Dil Vashi, manager of corporate development at Solutions4CO2, at the heart of their system lays the company's own proprietary Biogas Purifier and Infusion SystemTM (BPIS).

Their system is not dependent on subsidies, but adds value to the AD process through production of specialized commodities in the AD process. "If AD is to become a more attractive prospect to investors in the region it will be necessary to increase the revenue generating potential for such facilities." Several vendors are customizing AD facilities to produce commercially marketed CO_2, specialty gasses or other co-products.

205 Waste Management World, Feb 19, 2013

As an example of the value of co-produced materials, Solutions4CO2 cites the example of a typical AD plant producing around 300 cubic feet (8.5 cubic meters) of biogas per minute and generating around 6 million kWh of electricity each year. The power consumption of the ancilar facilities consumes around 1 million kWh per year – with the AD's parasitic load consuming around another 1 million kWh per year, leaving 4 million kWh per year for export to the grid. Solutions4CO2 sees a more significant monetary return in the sale of the recovered high value co-products. According to food industry market research company, Packaged Facts, consumer spending on products fortified with Docosahexaenoic Acid (DHA) and Eicosapentaenoic Acid (EPA) from Omega-3 will grow from $25.4 billion in 2011 to $34.7 billion by 2016. Meanwhile the market for Astaxanthin - a natural nutritional component which can also be used as a food supplement and is considered an 'E' number in the European Union - is currently estimated at a more modest $60 million, but is expected to grow rapidly to $200 million by 2015. While traditionally Omega-3 oil has been sourced from fish oil, interestingly, the fish themselves don't actually produce Omega-3, it's the algae they eat which produce it and it builds up in the bodies of the fish that typically cannot process it – which the human body can. Solutions4CO2 is currently completing its first commercial IBR facility in Canada at an existing AD installation which processes a mixture of dairy waste and commercial food waste into biogas for power generation. The IBR will be integrated with the AD and will process live biogas from the AD as an input for the IBR to produce algae biomass containing high value nutraceutical and pharmaceutical co-products[206].

7.6 Environmental/Permitting Considerations

Federal air quality permits for AD facilities are required only if a combustion device is present and operating above federal thresholds. AD systems processing only manure have no federal solid waste permitting requirements. The agency's approach to permitting AD systems which process manure and other organic waste is to include the solid waste requirements in an individual permit that also includes the water permit information. For the water permits, if the AD system processes only manure, it must meet the requirements of a CAFO permit or a general state disposal system permit. If the AD system includes other organic wastes, it requires an individual permit.[207]

As noted in the Introduction to AD Technology, the primary environmental downside of AD facilities is the potential for unpleasant odor emissions. Rigorous control of feed stocks, proper design of the intake facility or tipping area, and best management operations will minimize these impacts.

AD or Biomass facilities have been marketed as an alternative for waste management when a landfill or mass burn facility has been proposed in a community. Where conventional MSW landfills tend to provoke a predictable and negative reaction, AD facilities can be met with widespread support and also passionate opposition.[208] When proposals are made to construct an AD facility on a site, the AD facility can become a locally unacceptable land use.

[206] http://www.waste-management-world.com/articles/print/volume-14/issue-1/wmw-special-biowaste-focus/is-algae-the-answer-for-biogas-in-north-america.html
[207] http://www.epa.gov/agstar/tools/permitting.html#mn
[208] Waste 360, 2/6/2013

There is a lack of understanding about the environmental benefits of biomass facilities. Organics-processing plants frequently encounter environmental opposition when these facilities could be a key tool in reducing dependence on fossil fuels and reducing the perceived “toxic emissions” of other waste management alternatives. Educating the public about practical waste management alternatives and what the plant will use as feed stocks, promoting the environmental benefits of the facility and agreeing to citizen “monitoring” of the facility, its inbound loads and emissions data, are important actions that can assist the permitting process.

7.7 Application of Current Waste Stream – Organic Fraction

AD processes could be implemented on RDF as a method to produce methane. In a 2009 study, Foth collected rejects from the RDF process at Newport and Elk River and conducted a biochemical methane assay on the materials. Two samples were collected by Foth and sent to the University of Florida for testing. Test results indicated a lower than expected methane yield for the rejects. Foth also completed a study in 2009 on the feasibility of a source separated organic materials AD facility in St. Paul. The 2009 AD study concluded that AD would be a good conversion technology for the organic waste stream in R/W Counties. For a 100,000 tpy facility, estimated tipping fees would range from $55 to $60 per ton.

To capture organic materials from the current waste stream from R/W Counties would require either a source separated (SSOM) collection program or installation of material sorting equipment (mixed waste processing) ahead of the RDF process to target organics removal from the current waste stream. Organics could then be sent to an AD process for conversion to methane for electrical generation or steam. Residuals from the process (solids and liquid) could be managed via composting and existing waste water treatment plants.

7.8 Outputs

Typical outputs from an AD process include methane, solids and liquids. Methane from an AD process can be cleaned and injected into a natural gas pipeline; burned in an engine/generator set to produce electricity; burned in a boiler to produce steam for district heating or to be used in a steam turbine to generate electricity.

For R/W Counties, Foth estimated potential energy from AD of RDF and residuals would be 350,000 MM Btu’s per year. This could be converted to electrical energy using engines or turbines. Depending on the system, electrical generation is estimated to be 5-8 megawatts.

7.9 Financial Performance

Financial performance for AD facilities is somewhat well documented. In the Foth 2009 AD study for SSOM in the seven county metro area, estimated tip fees for an AD facility were $55-$60 per ton. If R/W Counties installed a mixed waste processing facility ahead of the RDF process to extract organics prior to making RDF, a small AD plant could be constructed. Estimated tipping fees to separated organics range from $35 to $50 per ton and a small AD facility is anticipated to be $50-$60 per ton.

7.10 Summary

While AD technology is commonly used for the organic fraction of MSW in Europe and for manures and sewage treatment in the U.S., it has not yet been widely used for MSW in the U.S. Even so, the number of proposed and new facilities has been increasing recently. AD can produce readily marketable types of energy such as methane or electricity along with potentially marketable digestate as compost, and perhaps a liquid fertilizer. Currently, the price of natural gas is affected by the increased production of gas reducing the revenue potential for methane produced by an AD facility.

There is adequate overall experience with AD that it could be considered a proven technology. But it is limited in its application to only the organic fraction of MSW and requires separation of the organics either via source separation or processing of MSW. Both of these increase the overall costs of an AD system.

Odor control can cause environmental and nuisance problems due to the anaerobic nature of the process. There are measures available to control the odors during the process. Table 7-7 provides a summary of the advantages and disadvantages of AD.

Table 7-7
Advantages/Disadvantages of Anaerobic Digestion

Advantages	Disadvantages
♦ AD is a well understood process similar to sewage sludge digestion. Most people do not associate AD with toxic gasses (including dioxin) or ash, such that AD may be "preferable" to mass burn or RDF.	♦ While fairly common in Europe, AD is not widely proven for MSW in the U.S. Even so, several new facilities are being developed.
♦ Can be used in combination with other technologies to target organic wastes.	♦ Requires either source separation and collection of food and other organic wastes or processing MSW to separate organics. Both increase system costs.
♦ The end product of AD can be potentially saleable: biogas, electricity, soil conditioner and a liquid fertilizer.	♦ AD bacteria have specific environmental and chemical requirements, and may need a consistent feed stock, not a wide range of different organic materials.
♦ Anaerobic digestion contributes to reducing greenhouse gases by reducing demand for alternate fossil fuels.	♦ The digestate from an AD process may require further treatment to control odors.

There are a number of AD facilities in California that could be considered for a tour. There are also some fairly recently announced projects in Minnesota (in Le Sueur, Becker, and South St. Paul) that may provide opportunities to tour when they become operational.

8 Mixed Waste Processing

Mixed waste processing technology has taken many different forms and meant different things over time. Essentially the purpose of a mixed waste processing (MWP) facility is to separate and remove recyclable materials from incoming mixed waste (i.e., divert the recyclable materials from the waste stream). The MWP facility can be a stand-alone facility or it can be part of a front-end separation process at a WTE facility (either mass burn or RDF), anaerobic digestion (AD) facility, composting facility, transfer station, C&D waste processing facility, balefill, sanitary landfill, or even as part of a recycling facility handling source-separated recyclables. In each case, the MWP facility is tailored to the specific waste streams and goals for the project. Therefore, there are several different approaches to facility design, materials targeted for recovery, and costs.

Recently announced waste processing projects appear to be including some type of front-end separation or mixed waste processing technologies.

8.1 Process

MWP facilities may be developed with either relatively low-tech approaches using primarily manual sorting or more high-tech approaches using some mechanical, automated processes combined with relatively less manual labor.

8.1.1 Low-Technology MWP Facilities

The simplest type of MWP facility may be referred to as a "dump and pick" operation. Waste materials are delivered on the tipping floor and recyclable materials are manually pulled from the waste. There may be some equipment such as a grapple, which can separate and lift heavy objects such as white goods, wood, scrap metal, etc. A front-end loader may be used to help move materials around the tipping floor to help separate larger items. This simple approach is sometimes used at a transfer station.

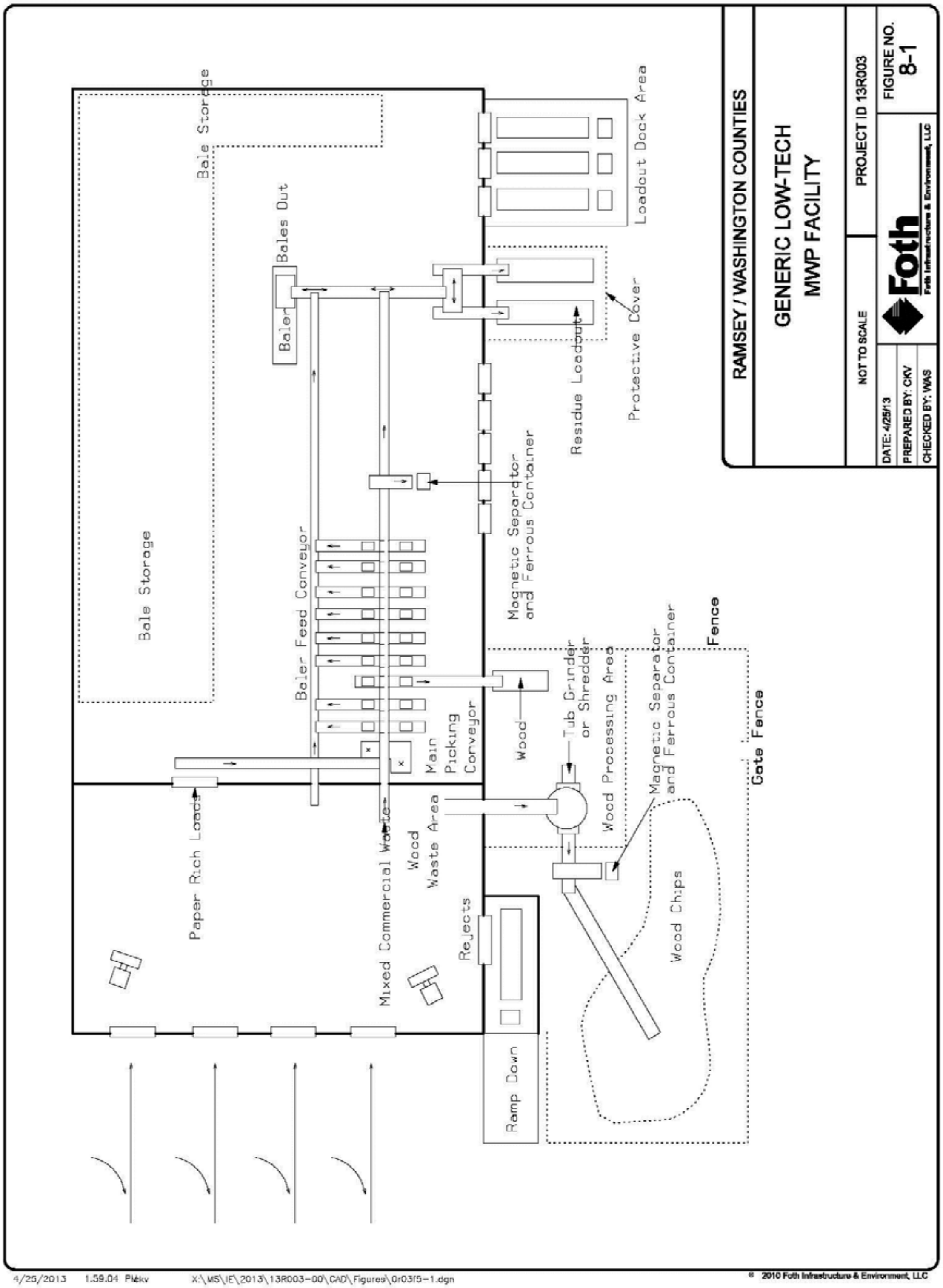
The next step up in relatively low-technology approaches incorporates a conveyor system with manual sorting stations. The mixed waste stream is conveyed up an incline conveyor to an elevated sorting platform, which may be enclosed in a separate room. Sorters pick the targeted recyclables out of the waste stream, deposit the recyclables through chutes into dedicated bunkers, bins, or roll-off containers for each material. The remaining waste materials discharge off the sorting conveyor to be handled via whatever the next technology may be (landfill, balefill, WTE facility, etc.). The sorted recyclables are typically densified (baled, crushed, etc.) for transport to the end markets.

MWP facilities may limit the types of wastes they receive in order to target certain materials. For example, a MWP facility may target wastes from commercial businesses that tend to have higher concentrations of corrugated cardboard, high-grade paper, wood, or other recyclables. By targeting certain types of waste deliveries, the MWP facility is able to recover a higher percentage of the wastes and the recovered materials may have less contamination.

Another approach is to separate materials during collection into a wet or dry collection system. One bin collects "dry" items like plastics, cans, bottles, recyclable paper, etc. while the "wet" collection container has food, other organic wastes, soiled paper, etc. Keeping high moisture solid wastes separate from dry improves the eventual recovery of both types of material streams. Separate wet/dry collection approaches can be used in both low and high-tech systems.

Figure 8-1 provides a schematic of a generic, low-technology MWP facility.

Figure 8-1
General Low-Tech MWP Facility



8.1.2 High-Technology MWP Facilities

High-technology MWP facilities are more elaborate than low-technology operations, but still incorporate some manual sorting. Sorting of the different recyclables has not evolved to the point that sorting is fully automated although some systems have made improvements recently. Also, as with the low-technology facilities, the extent of automation can vary widely depending on the specific waste stream handled and the project goals.

A high-technology MWP facility may include metered infeed, manual pre-sort, automated debaggers, shredders, finger screens, trommel screens, disc screens, air classifiers or other density separation systems, magnetic separators, eddy current separators, optical sorters, pneumatic conveyors, balers, or tub grinders to separate and densify the recyclable materials.

Metered infeed equipment controls the flow of materials to a steady flow entering the processing lines. The pre-sort stations manually remove large items that could damage processing equipment further down the line. Debaggers open and remove wastes from plastic bags. Shredders such as slow-speed, shear shredders help open bags and can size reduce materials.

Different types of screens (finger, trommel, and disc) are used to size-separate the materials, often times into three or more sizes: (1) fines, which may be residue or material too small to be recyclable; (2) middlings, which may contain recyclable containers; and (3) overs, which may contain recyclable paper or wood.

Air classifiers separate materials by weight into lighter and heavier fractions. For example, aluminum and plastic containers are lighter than glass containers. A magnetic separator removes ferrous items from the rest of the materials. An eddy current system separates aluminum and non-ferrous metals.

Optical sorters can automatically sort out different types of materials with a combination infrared light beam and air pulses at relatively high speeds and through puts. Optical sorters are used for plastics, glass, and even fibers.

Typically the materials are conveyed through the process from one piece of equipment to another on belt conveyors. Pneumatic conveyors have been used to move lightweight sorted recyclables such as film plastic or aluminum cans from a sorting station to a bunker or bin to await baling.

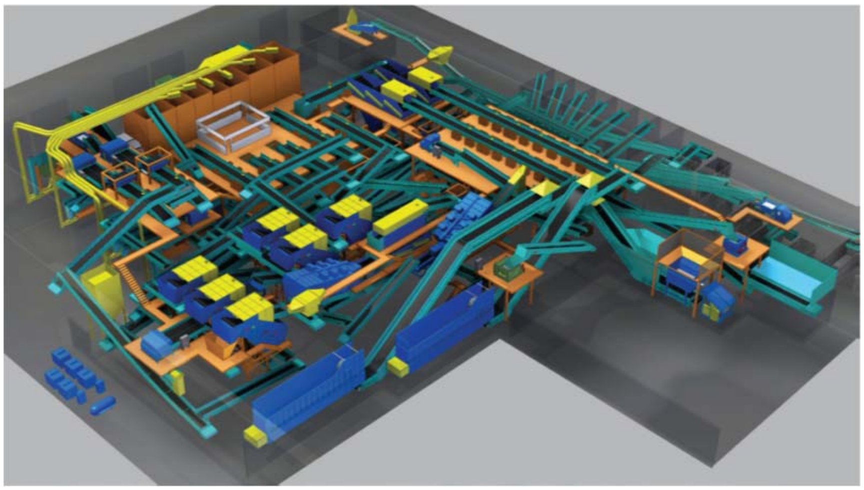
There is typically still some manual sorting of various recyclables such as various grades of paper (newsprint, office paper, magazines, etc.) or different plastic resins for recycling markets or the recently emerging plastics-to-oil technology.

The extent of manual sorting depends on several factors such as the actual type of waste delivered (select commercial loads versus mixed residential wastes); the market specifications (mixed paper versus a #8 news), and the follow-up technology and overall project goals.

Some type of densification such as baling, crushing, or shredding occurs to minimize hauling costs to market

Figure 8-2 provides a schematic of a high-technology MWP facility.

Figure 8-2
Current High-Tech MWP Facility
Newby Island Resource Recovery Park, San Jose, California



8.1.3 Comparison and Typical Applications

Low-technology and high-technology approaches each have their advantages and disadvantages and are used for specific applications.

The low-technology dump and pick approach is quite limited in effectiveness and the application may only be suitable for low-volume transfer stations or to target a limited type of bulky recyclable on a tipping floor (such as bulky metal objects). The low-technology approaches that incorporate sorting conveyors and balers have broader applications such as at the City of Red Wing, MN Material Recovery Facility. Red Wing has a MWP sorting system ahead of their mass burn waste-to-energy facility.

The major advantage of low-technology facilities is that equipment requirements are low, minimizing capital, fuel, and maintenance expense. Equipment downtime is not a significant factor in the rate of waste flow through the facility.

The disadvantages of low-technology facilities include worker safety issues (i.e., bending, repetitive motions, danger from sharp and protruding objects, and general exposure to hazardous materials). The amount of material recovered is highly dependent on the adequate bag breaking equipment, number of laborers, the speed of the conveyors, and the extent of contamination (especially moisture). Hand sorting is most efficient on dry, well sorted wastes.

A low-technology hand-sorting operation may be applicable for the dry fraction of a two-stream wet/dry collection program; select commercial waste, which contains minimal amounts of wet contamination; removing blue bags with organics from the MSW waste stream; or construction waste and light demolition debris. Relatively high labor costs versus the quantity of material recovered would make it more difficult to address mixed waste streams such as residential waste unless limited to a low throughput or removing only select materials such as blue bags and low recovery rates of recyclables.

Some construction and demolition processing facilities have incorporated mechanical screens (commonly finger screens) and hammer mills into the manual sorting process. The fines from the screens are mixed with the non-sorted materials entering the hammer mill. The resulting product is a material used as "alternative daily cover" (ADC) at sanitary landfills.

The advantages of high-technology facilities may include higher recovery rates of recyclables, as well as higher throughputs of waste per worker, which reduces labor cost per ton.

The disadvantages of high-technology facilities include the increased capital and maintenance costs for equipment and potential equipment related downtime. Contamination may still be a problem.

The high-technology approach can be applied to more types of waste streams and process a larger daily volume. Typically, the high technology approach will haul the highest recovery rates for recyclables. These rates can increase if clean, dry levels are received.

8.2 Typical Markets

The material products that typically can be recovered by a MWP facility include corrugated cardboard, office paper, mixed paper, newsprint, containers (aluminum, glass, tin cans, plastic, etc.), organics, wood and ferrous metals. The mix of products depends on the incoming waste stream. As noted, a MWP facility can be a stand-alone facility or on the front-end of other processing technologies. These other processing technologies (many covered elsewhere in the report) can recover other materials such as energy or compost. This section only addresses the recyclable materials recovered from a MWP.

The markets for the recyclables include the standard markets utilized by source-separated recycling programs. These include paper mills, insulation manufacturers, aluminum mills, glass manufacturing, metal mills, and plastic recyclers. Wood markets include mulch and wood fuels.

It should be noted that recyclables recovered via MWP facilities have a higher likelihood of contamination. Depending on market specifications and economic conditions, marketing recyclables from MWP facilities may be more difficult than from source-separated programs.

8.3 Residual Material

An MWP facility is used to remove the targeted recyclable material from the mixed waste stream delivered. The residue will include the rest of the waste stream, which may be largely unchanged from the state it was delivered (as opposed to ash from a WTE facility or screenings from a compost facility).

The recovery rate in a MWP facility will vary significantly depending on the composition of the waste stream delivered. For facilities handling the entire waste stream, less than 10 percent is likely to be recovered leaving over 90 percent to be disposed or otherwise processed. For facilities targeting commercial wastes with high recyclable content and relatively dry, recovery rates may be at or above 40 percent leaving approximately 60 percent of the incoming wastes for disposal.

8.4 Environmental Concerns/Permitting Issues

MWP facilities have similar potential environmental impacts as transfer stations and source-separated recyclables processing facilities (commonly referred to as MRFs). In particular, dust and particulate matter may be created from the processing operations, especially from any wood grinding equipment. The dust and particulate matter will be minimal and controlled by air handling and filtering equipment if necessary.

Wash water or moisture from loads must be handled via the municipal waste water treatment system.

Noise, litter, and odors could be problems but are easily controlled by fully enclosing receiving and processing areas. An MWP facility would be regulated by the Minnesota Pollution Control Agency (MPCA) and county environmental departments.

8.5 Applicability to Ramsey/Washington Counties Waste Stream

In general, MWP facilities appear to be used more commonly as a front-end separation process for newer waste processing technologies. That is the application considered in this report using a high-technology system targeting recovery of scrap metals, bulk plastics, corrugated cardboard, mixed paper, PETE (# 1) containers, HDPE (# 2) containers, mixed plastics, ferrous metals, aluminum, and potentially organics rich fines. All other solid wastes would either be residue or sent to another recovery technology such as mass burn, RDF, anaerobic digestion, gasification, etc.

The processing line equipment is anticipated to include:

- Metered infeed – to provide an even, steady flow of material.
- MSW Shredder – using a slow-speed, shear shredder to reduce particle size to less than 18 inches and open bags, removing material from the bags to provide access for the sorting equipment.
- Manual Pre-sort – to remove large, bulky items that might cause problems downstream.
- Disc Screens – to provide initial material sizing including separation of larger, corrugated cardboard for recovery and removal of 2” minus so that it does not contaminate the remaining products. The 2” minus could end up as residue or possibly further organics recovery, depending on the composition.

- Density Separation – to separate the light or low-density material which contains the vast majority of recoverable commodities such as paper, plastics, aluminum, and ferrous cans. The other fraction, high-density material contains mostly organics, inert materials, soiled paper, textiles, and non-recyclable materials.
- Disc screens – to separate materials by shape including 2D materials such as fiber and plastic film from 3D materials which is mostly plastic, aluminum and ferrous containers. At this point, any remaining fines (< 2”) fall through the openings in the disc screen.
- Final sorting of 2D and 3D Fractions – the 2D materials are transferred to another disc screen to separate out non-recyclable materials such as diapers and other contaminants. The rejected paper continues to an optical sort where compressed air sorts out the desired fiber onto another manual sorting conveyor for removal of contaminants such as soiled fiber, film, and residue. The 3D materials (container stream) passes through a combination of automatic and manual sort stations including:
    - A magnet to remove ferrous materials
    - Manual sorting of Natural HDPE
    - Manual sorting of Colored HDPE
    - Eddy current separator to remove aluminum
    - Optical sorter for PET
    - Optical sorter for Mixed Plastics
- Quality control stations to remove contaminants
- Storage in bunkers or silos prior to baling
- Baling prior to shipping to market.

The recovery percentages will depend on the recyclable material composition of the incoming materials. Some system vendors may quote a recovery rate of up to 75% of the incoming targeted recyclable materials with the overall recovery percentage dependent on the overall percentage of available recyclable materials in the mixed waste stream.

8.6 Current Status[209]

More than half the MWP facilities are located in the West (mainly California) where they handle yard debris and C&D debris, which count toward their waste reduction goal. MWP facilities have been added to some Minnesota waste-to-energy facilities (Polk County, City of Red Wing, and Pope-Douglas counties) as front-end separation processes to remove recyclable cardboard, metals, and glass. This may improve the overall fuel quality and reduce the size of the combustion facility required (saving some capital costs while increasing operating costs).

Rational Energies recently contracted with Hennepin County to install and operate a mixed waste processing facility at the Brooklyn Park Transfer Station. The original intent of this facility was to recover various plastics and metals with the plastics brought to the recently developed Rational Energies Plastics-to-Oil facility.

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[209] Brenyi, E.B., “Whether MRF-based Recycling?”, *Resource Recycling*, April 1999; and “State of MRF’s: 2001,” *Resource Recycling*, January 2001.

Republic Services recently opened a new mixed waste processing facility at its Newby Island Resource Recovery Park located in San Jose, CA. This facility has the ability to sort 110 tons per hour and recover high percentages of recyclables. There are four processing lines designed to process 400,000 tons per year.

The facility processes all the commercial waste generated in San Jose. Republic has a contract with San Jose to collect and process all commercial material produced in San Jose. Materials are collected mixed as either wet or dry streams. The facility recovers recyclables and organic matter as feedstock for further waste-to-energy processing. The system incorporates advanced screening, optical, and air separation technologies. Several mixed waste MRFs are currently operating in California. Table 8-1 [210] highlights these facilities; capital costs were stated from $10 to $45 million.

Table 8-1
California MRF Summary

MRF Facility	Location	Processing Lines	Processing (tpy)	Type	Wet or Dry	Capital Cost ($M)	Upgrade Cost ($M)
Green Waste Recovery*	San Jose, CA	2	132,000	MSW, single stream	W	-	-
CVT Regional MRF	Anaheim CA	4	720,000	residential, commercial	W	-	-
Athens Services	Industry, CA	3	576,000	MSW	W	9	12
Western Placer WMA	Lincoln, CA	8	240,000	MSW, single stream	D	22	26
Sunyvale SMaRT Station	Sunnyvale, CA	2	240,000	MSW, dual stream	W	-	15
Puente Hills	Whittier, CA	1	120,000	MSW	W	45	-
Victor Valley MRF	Victorville, CA	-	36,000	single stream	D	7	3

* This facility employs the Bulk Handling Systems (BHS) unit
- Information not provided

The City of Houston TX was recently awarded $1 million from Bloomberg Philanthropies for its plan to dump separate waste and recycling collections in favor of a system to collect all items in one bin, in an effort to boost recycling rates from 14% to 75%.

8.7 Site Needs

An MWP facility in the range of 250 to 500 tpd would require approximately 7 to 10 acres for the entire facility. Typical utility needs would include three-phase electrical service, natural gas, water, and sewer. As with all the processing facilities, adequate truck access, access to major highways and zoning for heavy commercial or light industrial is recommended.

8.8 Typical Capital Costs

Using a shredder on the front end to open bags, size material, and control the flow with up to three optical sorters for fiber, film plastic, PET, and mixed plastics at 30 tons per hour (TPH) would cost in the range of $8 to $10.5 million for just the processing equipment. Adding building and site development costs could double the total cost to approximately $20 million. A larger system with two 30 TPH lines would be estimated at $14 to $16 million for the equipment and approximately $26

[210] Kessler Consulting, Inc. 2009. Innovative Waste Reduction & Recycling Grant IG8-06, MRFing Our Way to Diversion: Capturing the Commercial Waste Stream. Materials Recovery Facility Technology Review. Prepared for Pinellas County, Department of Solid Waste Operations, St. Petersburg FL

million for the total project cost. For a facility capable of handling 110 TPH similar to the capacity of Newby Island, the equipment costs may range from $25 million to $30 million. Total for equipment, land, building, site development, and permitting could approach $45 million.

8.9 Typical Break-even Cost Per Ton Update

Operating costs will be dependent on several factors, with labor and residue disposal being the largest. Another factor affecting a break-even cost will be the revenues received from the recyclables. At this conceptual stage, a facility capable of handling 110,000 TPY (~50 TPH) with an assumed recovery rate of recyclables at 20%, organics recovery at 30% (with 20% of that being residue), and disposing of the remaining 50% at a landfill could be expected to have a net cost per ton of $45 to $55.

8.10 Implementation Needs/Timelines

Construction of an MWP facility could be completed in approximately a year. Permitting is not anticipated to be as difficult as other technologies such as mass burn, RDF, or waste-to-ethanol. Depending on the procurement approach and financing method, a stand-alone MWP facility could be operational within two to three years of a decision to utilize the technology. As a front-end separation add-on to a different technology, the MWP permit would likely be simpler than the primary technology.

8.11 Advantages/Disadvantages

Table 8-1 provides a summary of potential advantages and disadvantages to an MWP facility. These are in use in Minnesota, primarily to target recyclables ahead of the modular mass burn facilities in the state. Newer applications are occurring in California. As a “stand alone” facility, MWP would be of limited value to R/W Counties. However, as part of a “resource recovery park” the technology could be used to target recovery of recyclables, separate organics for AD or potentially composting, separate plastics for a plastics to fuel facility, with the remaining wastes either converted to RDF for combustion or to process with the gasification technology.

Table 8-2
Potential Advantages and Disadvantages of Mixed Waste Processing

Advantages	Disadvantages
♦ Can be added to the front-end of other technologies	♦ Not appropriate for the entire waste stream
♦ Lower capital and operating costs than other major processing facilities	♦ A stand-alone facility diverts only 10 to 15 percent of total R/W waste stream.
♦ Can be flexible to adapt to material market changes	♦ Quality of recyclables recovered may be lower than source-separated programs
♦ Can focus in on specific waste streams with high recyclable content and achieve a higher percent recovery of the targeted waste stream	
♦ May eliminate the need for separate collection systems for targeted waste generators	

There are several mixed waste processing facilities in California that could provide tours for R/W Counties. The Newby Island Resource Recovery Park would provide an example of a higher tech facility targeting recovery of a significant percentage of materials as well as the combination of wet/dry collection systems and targeting recyclables rich commercial loads.

9 Plastics to Fuel

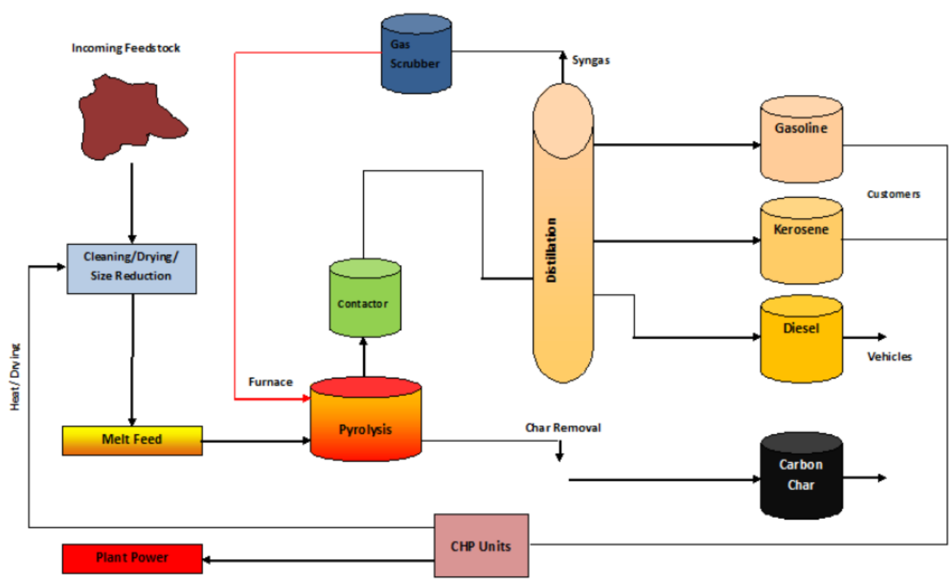
9.1 Process

Plastics to fuel (PTF) systems use a pyrolitic process coupled with depolymerization/distillation components to convert recovered plastics into oil[211]. Due to well established markets for numbers 1 and 2 plastics, numbers 2, 4, and 5 plastics are considered the best feedstock for plastic to oil production. Process technologies vary from vendor to vendor with each having unique features and performance claims, but most share the same basic processes including;

- Some level of pretreatment –this could be as minor as size reduction or as involved as cleaning and moisture removal.
- Conversion – pyrolytic processes are used to convert the plastic to a syngas.
- Distillation – the syngas is converted to liquid form
- Acid removal process – removal of acids that form in the breakdown of some scrap plastics. These acids require removal because they can be corrosive to the PTF systems as well as the engines that will consume the fuel.
- Separation/refining/final blending - the final steps required to make this product consumer ready can either be done on site or by a third party, depending on the system design.

Figure 9-1 is a general schematic of the plastics to fuel process:

Figure 9-1
Plastics To Fuel Flow Schematic



9.2 Performance

Theoretical performance data compiled in various reports from PTF vendors include[212];

[211] 4R Sustainability Inc. 2011. Conversion Technology: A Complement to Plastic Recycling, Prepared for American Chemistry Council Washington D.C.
[212] HDR. 2013. Alternative Disposal Feasibility, Final Report, Prepared for Metro Waste Authority Iowa

- 10,000 tons per year throughput, capital cost estimates $1 to $7million
- 8 to 11 pounds of plastic to produce 1 gallon of oil, representing a conversion rate of 70% to 85%
- Natural gas 8 to 12% of output; representing 30% to 100% of the gas required for heating
- Residuals (metals and char) represent 10% to 20% of the output for a clean feedstock; higher if mixed

9.3 Vendors

A number of vendors, and research organizations, are in various stages of development and research inside and outside of the United States. Currently there are three vendors in the United States who have constructed or constructed and operating full scale facilities in New York, Ohio, and Oregon. Several vendors are identified in the Table 9-1[213].

Table 9-1
Plastics To Fuel Vendors Inside The United States

Company Name	Location	Pilot (P) Scale, Full (F) Scale, Neither (N)
Green EnviroTech	California	P
Natural State Research	Connecticut	N
Northeastern University	Massachusetts	N
Rational Energies	Minnesota	F
Plasstics2Oil (JBI)	New York	F
Polyflow	Ohio	P
Vadxx	Ohio	F
Agilyx	Oregon	F
Agri-Plas	Oregon	P
Recarbon Corp.	Pennsylvania	P
Climax Global Energy	South Carolina	P
Envion	Washington D.C	P

9.4 Projects

Several vendors have pilot scale or research and development (R&D) facilities in operation. There are a few commercial scale facilities in the United States that are in varying levels of construction, permitting, or less than full-scale operation. The pilot scale, approximately 1/5th of full-scale, typically takes 3-5 years to develop. In most cases PTF facilities have remained in pilot scale, conducting improvements and developing new generation pilot scale facilities over the last decade or more. Outside of the United States three systems are in full-scale operation including two systems in Thailand and one in India. The map below provides locations of PTF projects being

[213] Resource Recycling Magazine. 2012. Plastics to Fuel Grows-Up, Carson Maxted and Dylan De Thomas.

pursued in the United States[214]. The first commercially operated PTF facility in the United States is the Rational Energies facility in Plymouth, Minnesota.

Figure 9-2
PTF Projects Being Pursued In The United States

9.5 Environmental Considerations

The pyrolysis process can be considered a net energy producer (i.e., the energy produced is larger than the energy consumed) with some variation in the amount of energy produced according to the data obtained from the different vendors and the literature.

9.5.1 Air Emissions

Air emissions can result from process-related activities or fuel-related activities. Process emissions are those that are emitted during a processing step, but not as a result of fuel combustion. The emissions reported in Table 9-2 are the quantities that reach the environment (air, water, and land) after pollution control measures have been taken. Atmospheric emissions include substances released to the air that are regulated or classified as pollutants. Emissions are reported as pounds of pollutant per annual tonnage of waste managed. CO_2 emissions are labeled as being from either fossil or non-fossil fuels. Pyrolysis of plastics results in GHG emission savings, which are mostly due to emission savings from the replacement of conventional energy (petroleum) products. However, the emissions data obtained for pyrolysis exhibits a wide range of variation.

9.5.2 Waterborne Pollutants

Waterborne wastes are produced from both process activities and fuel-production activities. Similar to air emissions, the waterborne pollutants include substances released to the surface and groundwater that are regulated or classified as pollutants. The values reported in Table 9-2 are the

[214] RTI International. 2012. Environmental and Economic Analysis of Emerging Plastics Conversion Technologies, Final Project Report, Prepared for American Chemistry Council Washington D.C.)

average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters.

9.6 Financial Performance

Table 9-2 provides an estimate of cost for the Plastics2Oil (JBI) facility[215].

Table 9-2
Plastics 2011 (JBI) Facility Performance Summary

Process				JBI[1]
Inputs	Percentage of plastics captured from raw after processing[2]			
	Post-processed annual plastic load	-	dtpy	10,585
	Post-processed daily plastic load	-	dtpd	29
	Power consumption/parasitic load	-	KWh/dry ton	480
	Other inputs (e.g., water, oxygen, etc.)	Water	gal/dry ton	216
	Supplemental fuel use	Natural Gas	MMBtu/dry ton	0.03
Outputs[3]	Energy product (e.g., syngas,ethanol, hydrogen, electricity, steam)	Syngas	MMBtu/dry ton	0.2
		Synthetic crude oil	lb/dry ton	39
		Light fraction (liquid)	lb/dry ton	400
		Gas fraction	lb/dry ton	500
		Gasoline	lb/dry ton	23
		Diesel	lb/dry ton	1,711
	Residuals (e.g., ash, char, slag, etc.)	Char	lb/dry ton	160
		Solid Residues	lb/dry ton	160
		Inorganic Sludge	lb/dry ton	300
		Non-hazardous solid waste	lb/dry ton	5
	Water Loses	-	gal/dry ton	25
	Air Emissions Data			
	PM		lb/dry ton	15
	Fossil Carbon Dioxide (CO2 Fossil)		lb/dry ton	962
	Methane (CH4)		lb/dry ton	65
	HCl		lb/dry ton	3.00E-04
	Hydrocarbons		lb/dry ton	8
	Nitrous Oxide (N2O)		lb/dry ton	2
	NOx expressed as NO2		lb/dry ton	91
	Carbon monoxide (CO)		lb/dry ton	9
	Lead		lb/dry ton	0.02
	VOC		lb/dry ton	2
Cost Data[4]				
	Cost per design capacity		$/dtpd	280,699
	Total cost		$M	*8.14*
	Other Cost Comparisons			
	Cost per design capacity (27 dtpd)[5]		$/dtpd	146,039
	Total cost		$M	*3.94*
	Cost per design capacity (30 dtpd)[6]		$/dtpd	1,327,140
	Total cost		$M	*39.81*

1 - RTI International. 2012. Environmental and Economic Analysis of Emerging Plastics Conversion Technologies, Final Project Report, Prepared for American Chemistry Council Washington D.C.
2 - Assumed 25% to 50% of the Ramsey-Washington plastics stream (135,336 tpy) would be useable for a PTF facility
3 - Output data for Ramsey-Washington calculated as linearly proportional to the JBI facility
4 - Cost data for Ramsey-Washington calculated from the JBI facility used a scaling factor (25% and 50%) to account for additional equipment capital and operation costs.
5 - 4R Sustainability Inc. 2011. Conversion Technology: A Complement to Plastic Recycling, Prepared for American Chemistry Council Washington D.C.
6 - HDR. 2013. Alternative Disposal Feasibility, Final Report, Prepared for Metro Waste Authority Iowa

9.7 Summary

Plastics to fuel is a relatively new emerging technology and is lacking the history that the other technologies covered in this report have.

215 RTI International. 2012. Environmental and Economic Analysis of Emerging Plastics Conversion Technologies, Final Project Report, Prepared for American Chemistry Council Washington D.C.)

The following are insights regarding plastics conversion technologies[216];

- **Conversion technologies do present another option for managing non-recoverable plastics.**

  At present, there are very few commercially operating facilities in North America. A number of "first generation" demonstration facilities are built and operating in North America, with the first commercial operation by Rational Energies, located in Plymouth, Minnesota. This conversion technology cannot immediately address landfill diversion needs but may be capable of addressing them in the near future. The capability of conversion technologies to meet landfill diversion goals will depend heavily on the success of these first-generation facilities. The average size of a current plastics-to-oil facility is in the range of 10-30 tons per day.

- **Pyrolysis appears to offer environmental benefits as compared to landfill disposal.**

  Pyrolysis of waste plastics saves 1.8–3.6 MM Btu per ton as compared to landfill disposal. Pyrolysis of waste plastics saves 0.15–0.25 tons of carbon equitant (TCE) emissions per ton as compared to landfill disposal.

- **Different technology vendors/facilities have specific variations on the process to enhance conversion efficiency and/or to tailor the end product to local markets.**

  The primary objective of the conversion technologies is to convert waste into useful energy products, which can include synthesis gas, petroleum products, and/or commodity chemicals. Syngas can be used directly in industrial boilers or in an ICE gen-set to produce electrical energy. Petroleum products and commodity chemicals are typically tailored to specific end-users (e.g., petroleum wax for cosmetics manufacturers). Each end product has different life-cycle offsets that can affect the overall environmental impact of the process.

- **There are a number of vendors for pyrolysis - although most are currently in the demonstration stage of development.**

  Plastics to Fuel pyrolysis technologies are generally further along than MSW-based technologies (typically gasification), in part because of the decreased variability of the incoming feedstock.

- **Estimates provided by vendors indicate cost/ton is comparable to other MSW options, such as recycling and landfilling.**

  Vendors estimate that the cost to process the waste via pyrolysis is approximately $50 per ton which is generally related to the cost of electricity or fuel required to run the process.

[216] RTI International. 2012. Environmental and Economic Analysis of Emerging Plastics Conversion Technologies, Final Project Report, Prepared for American Chemistry Council Washington D.C.

U.S. averages for landfill disposal and recycling, for comparison, range from $30-75/ton depending on region.

- **There is a high level of uncertainty associated with the environmental and cost data associated with pyrolysis.**

  Because most conversion facilities are demonstration plants, they are operating in batch-test mode and not as continuous mode commercial plants. Until there are more commercially operating facilities there will not be good real-world data to characterize the environmental aspects and costs for PTF technology.

Rational Energies has a commercially operating facility in Plymouth, Minnesota, that provides a good opportunity for R/W Counties to tour and learn more about this technology.

10 Overall Summary

This overall summary section provides a brief description of each technology along with its perceived advantages/ disadvantages and observations on its applicability to R/W Counties.

10.1 Gasification

Gasification converts waste to gases, liquids, and char. The gasification process allows a small amount of air, steam or oxygen into the conversion process depending on the desired outputs. Outputs are gases, liquids, and char. The gases consist of carbon monoxide, hydrogen, nitrogen, and carbon dioxide. The liquid portion tends to be in the form of tars. Finally, the char is the ash that is formed since the gasification process includes some air which causes materials to burn and form ash.

Outputs marketed from a gasification process are typically electricity and/or chemicals. Current plants appear to be focused on chemical production. Primarily, ethanol and methanol are being proposed to be produced at MSW gasification plants. There are higher margins available from producing chemicals and fuel versus electricity.

Gasification is not yet a proven technology for processing MSW but appears to be a promising technology that could be effective in converting waste materials into fuels and chemicals. The key developments for this technology are the new plants under construction in Edmonton, Alberta, McCarren, Nevada, and operating in Vero Beach, Florida. If these plants can be shown to be effective at a reasonable tipping fee, further plants may be developed.

Gasification faces challenges in expanding technology beyond the plants mentioned, including:

- **Cost.** Given the current plants appear to create fuels; cost volatility may be a challenge for investment into a waste gasification to fuels process. Additionally, waste jurisdictions that have low tipping fees (<$100/ton) may find this technology not economically viable. More study of commercial scale plants is needed to better understand costs for gasification.
- **Scale Up.** Many vendors of gasification systems point to pilot scale plants as demonstration of the technology. However, scale up of pilot plants creates significant challenges. Typically, scale ups greater than three (3) are considered risky.
- **Permitting.** Most states do not have an appropriate regulatory framework to permit gasification facilities using waste as a feedstock.

Table 10-1 shows the advantages and disadvantages for an MSW gasification system.

Table 10-1
Potential Advantages and Disadvantages of Gasification

Advantages	Disadvantages
♦ Not incineration ♦ Efficient energy production through combustion of gases ♦ High temperatures can make the process flexible to other waste streams ♦ Recycling can be enhanced by up-front separation ♦ Fuels production may be economically superior to electrical generation.	♦ Most systems require MSW pre-treatment to remove non-organic waste and homogenize the material (similar to RDF production) ♦ Unproven on a commercial scale for MSW in the United States ♦ Permitting – no clear path. ♦ System can be sensitive to non-organic feedstock

Successful conversion of the MSW to biofuels would be considered a "game changer" to MSW management. However, the application of the gasification technology to any specific location in the U.S. may face considerable challenges.

The Enerkem Waste-to-Biofuels Project in Edmonton, Canada may be a worthwhile tour when it becomes fully operational in 2014. Additionally, the Fulcrum Bioenergy plant in McCarron, Nevada is anticipated to be operational in 2015 and may be a plant that would be good to tour.

10.2 Pyrolysis

Pyrolysis is a thermal breakdown process of carbon based materials in an oxygen-deficient atmosphere using heat to produce syngas. The process does not allow air to enter the process so there is no direct burning of the waste material. Based on descriptions of several United States based projects at the pilot level, managing MSW through pyrolysis requires several steps:

- Pre-processing, this typically includes a bag opener, a sorting or screening system to separate non-organic recyclables, and a shredding or size reduction process.
- Drying, this involves evaporation of moisture from the waste feedstock. This typically occurs through heating the feedstock before it enters the pyrolysis system.
- Recovery and refinement of oils, gases, and solids from the pyrolysis process.
- Power generation or gas combustion, typically to support on-site processes.

The result of these processes is intended to be the transformation of MSW into pre-separated recyclable materials and three process components; gas, liquid, and solid (sometimes referred to as "char."). The outputs are very similar to gasification plants.

Several attempts to commercialize large-scale MSW pyrolysis systems in the U.S. in the 1980's failed. There have been some commercial-scale pyrolysis facilities in operation in Europe (e.g. Germany) on select waste streams. Vendors claim that the activated carbon byproduct from the pyrolysis is marketable, but this has not been demonstrated.

The use of pyrolysis systems to process MSW has occurred mostly in Japan, where landfill space and resources are limited. In examining the three largest suppliers in Japan, the plant capacities represent more than two million tons of material each year, with additional plants planned. Much of this capacity has been installed in the past five (5) years. Japan is the leader in the use of pyrolysis systems for MSW.

With the lack of plants in North America, no published economic studies are known. Recent published information on pyrolysis plants with MSW feedstock indicated tipping fees for new facilities would be in the range of $100-$300 per ton with capital costs approximated as $275,000 per design ton per day. Since most plants that have operated in the past experienced significant problems, the cost for a pyrolysis plant could be excessive.

There are no pyrolysis facilities in commercial operation in the U.S. with minimal current development activities. The most recent plant proposed in Green Bay, Wisconsin is no longer being pursued. Much of the data on pyrolysis plants is over 30 years old and should not be relied upon as representative of current technology. Extensive, in-depth investigation would be required if pyrolysis is pursued as an alternative MSW technology for R/W Counties.

No potential advantages and disadvantages are noted due to the limited documented information with the technology handling MSW. There are no operating plants to tour in North America.

10.3 Plasma Arc

Plasma arc technology uses very high temperatures to break down the feedstock into elemental byproducts. Plasma arc technology uses carbon electrodes to produce a very-high-temperature arc ranging between 5,000 to 13,000 degrees Fahrenheit that "vaporizes" the feedstock. The high-energy electric arc that is struck between the two carbon electrodes creates a high temperature ionized gas (or "plasma"). The intense heat of the plasma breaks the MSW fed to the reaction chamber into basic elemental compounds.

The inorganic fractions (glass, metals, etc.) of the MSW stream are melted to form a liquid slag material which when cooled and hardened encapsulates toxic metals. The ash material forms an inert glass-like slag material that may be marketable as a construction aggregate. Metals can be recovered from both feedstock pre-processing and from the post-processing slag material. The organic fraction is converted to a syngas that can be converted to steam, electricity, or chemicals.

A significant requirement for the plasma arc gasification process is that the MSW must be preprocessed before being fed into the plasma arc gasifier. In addition, the process may require the use of supplemental fuels to moderate and control the process.

Based on a review of commercial facility operating data, as well as recent studies and technology procurements, there appears to be three areas of concern regarding the technical viability of MSW plasma arc gasification in North America.

- **Ability to Process North American MSW** – The sole commercially operating MSW plasma arc gasification facility in Japan does not process traditional MSW but shredded paper and plastics from the Japanese MSW stream. A key technical concern is how processing North American MSW will impact the performance and costs of plasma arc gasification technologies in North America.
- **Preprocessing Requirements and Costs** – The Plasco Energy Demonstration Plant being developed in Ottawa, Canada requires wastes to be shredded to a nominal two inches in size. This can increase costs for operations of a plasma system.
- **Scale Up and Demonstration on a Commercial Basis** –Scale up from the currently existing 200 TPD plasma facility to a larger facility (such as 800 TPD) can cause significant problems in the process.

At this time, it is difficult to obtain data on the plasma arc process. The major plasma facilities are in Japan and limited cost and performance data is available to determine the applicability of plasma arc to the R/W Counties. Table 10-2 provides a summary of plasma arc advantages and disadvantages.

Table 10-2
Potential Advantages and Disadvantages of Plasma Arc Systems

Advantages	Disadvantages
♦ Superior thermal destruction ♦ Limited pollution ♦ Beneficial use possibilities for gas and ash produced from plasma destruction ♦ Potential to expand waste stream to include other non-MSW streams	♦ High initial investment ♦ High power requirements ♦ Unknown Performance ♦ May require waste pre-shredding to fit into plasma reactor ♦ Not a proven technology handling U.S. MSW

The Plasco Energy facility in Ottawa, Canada may provide a touring opportunity sometime in 2015 when it is projected to be fully operational.

10.4 Mass Burn Waste-To-Energy

There are two basic types of WTE facilities; refuse derived fuel (RDF) and mass burn. Hybrids of these two types are also in existence. RDF facilities typically presort recyclables-rich loads, shredding the non-recyclable and highly mixed wastes which are then combusted in on or off-site incineration facilities.

Mass burn facilities are fed directly from the tipping floor or stockpile, through a feed chute or conveyor into the combustion chamber without pre-sorting or processing. Of the mass burn facilities, there are two types: mass burn waterwall, and modular mass burn. Mass burn waterwall facilities, which are more common, incinerate MSW in a single chamber under non-pressurized conditions. Modular facilities are smaller, have two chambers, and can be developed as modules for expandability.

There are seven RDF facilities in the U.S., of which three are privately owned facilities and four are publicly owned facilities. All but two of these facilities process MSW. Two facilities, Great River Energy Elk River Processing Facility and Newport Resource Recovery Facility are in Minnesota. The published MSW tipping fees, nationally, are \$50 - \$ 84 per ton; the two Minnesota facilities' published tipping fees are \$68 and \$84 per ton, respectively.

There are 99 mass burn WTE facilities in the nation. Of these, fifty six (56) are publicly owned facilities and forty three (43) are privately owned facilities. Nineteen of the facilities burn only MSW, thirteen burn no MSW, and the remainder burn MSW in conjunction with scrap metals, wood, tires, dry industrial material, recyclables, asbestos, sludge or other combustibles.

Nationally published tipping fees for MSW range from \$35 to \$240 per ton. Six of the mass burn facilities are in Minnesota.

In either mass burn or RDF incineration facilities, energy from combustion is captured to heat water to produce superheated steam. The steam can be used to power a turbine to generate electricity, to heat or cool buildings in a local "energy district" or to supply energy for industrial processes. WTE facilities that generate electricity and sell steam for other purposes are termed co-generation (co-gen) facilities, because of the dual use of the recovered energy.

Air pollution control equipment for WTE facilities have been greatly improved since the original facilities in the 1980's. The 1990 Clean Air Act, with the 1995 Maximum Achievable Control Technology (MACT) standards have resulted in WTE facilities that are cleaner in operation than coal or oil-fired electrical generating facilities, and rival emissions of natural gas combustion plants. Of particular interest, dioxin/furan emissions were reduced by more than 99% and mercury emissions were reduced by more than 96%.

Currently, most of the available MSW in R/W Counties is delivered to the Newport facility and processed into RDF. A mass burn facility could also handle all of the available R/W Counties MSW. WTE facilities can market steam, electricity, or both. Although steam is more efficient and economical, it is more difficult to find convenient steam markets. Electricity is more flexible and easier to market. Although the ash has been beneficially used in some areas, most of the ash produced is disposed in sanitary landfills.

Mass burn and RDF facilities provide the most proven waste processing technologies covered in this report. As the Newport Resource Recovery Facility produces RDF and this report addresses alternatives, Table ES-3 focuses on the advantages and disadvantages of mass burn.

WTE is a well proven technology capable of handling the entire R/W Counties waste that is not recycled or composted. Relative to the other waste processing technologies, mass burn is less expensive. Air emissions standards are documented to be met by current air pollution control technologies. Nevertheless, past significant public opposition to mass burn facility permitting processes may be expected to make siting and permitting a mass burn facility quite difficult.

WTE facilities continue to provide waste management services in select markets. While no new plants are planned for the U.S., some plants are upgrading and expanding in anticipation of future growth. Potential advantages and disadvantages are provided in Table 10-3.

Table 10-3
Potential Advantages and Disadvantages of a Mass Burn WTE

Advantages	Disadvantages
♦ Proven technology ♦ Proven capital and operating costs ♦ Capable of processing the entire R/W Counties' waste stream not recycled or composted ♦ Financially stable vendors ♦ Clear regulatory pathway ♦ Compliant air emissions	♦ Public opposition makes siting and permitting a new facility difficult ♦ Capital and operating costs can be high

There are two facilities in Minnesota that provide excellent touring opportunities including the HERC facility in Minneapolis and the Olmsted County facility in Rochester.

10.5 Anaerobic Digestion

Anaerobic digestion (AD) is the process of decomposing the organic portion of MSW in a controlled oxygen-deficient environment. It is widely used to digest sewage sludge and animal manures. Bacteria produce a biogas that consists mainly of methane (CH_4), water vapor, and carbon dioxide (CO_2) through a process called methanogenesis. This is the same process that generates methane naturally in landfills and wetlands. Simplified, the process is common on farms and in wastewater treatment plants to stabilize sludge.

While the AD process has historically been applied to food and green waste, agricultural waste, sludge, or other similarly limited segments of the waste stream, more recently, AD is becoming part of an integrated processing system for the organic portion of MSW. AD can play an important role for organic waste management, avoiding, by efficient capture and treatment of gasses, the greenhouse gas emissions that are associated with landfilling organics.

The AD-produced biogas can be used directly in engines for Combined Heat and Power (CHP), burned to produce heat, or can be cleaned and used the same way as natural gas, as a vehicle fuel or in a gas turbine to produce electricity. The remaining residue has liquid and solid components. "Whole digestate" is used to describe the un-separated sludge and liquor. The liquid has been used as a fertilizer, especially on non-food crop applications. The solid residue of the AD process is similar, but not identical, to compost. It can be used as a soil conditioner if suitable markets can be identified.

The commercial AD process is divided into four stages: Pretreatment, waste digestion, gas recovery and residue treatment. Ideally, for simplest operation, the AD feedstock is source separated organic materials. However, anaerobic digestion has been used for MSW disposal with waste processing or sorting on the front end required to provide an effective feedstock. Removal of metals for recycling together with a combination of shredding, screening, and/or air separation has been used to concentrate and separate organic materials from inorganic materials. Mechanical separation can be employed if source separation is not available.

AD is widely used on a commercial-scale basis for industrial and agricultural wastes, as well as for stabilizing wastewater sludge. AD technology has continued to expand rapidly in Europe on mixed MSW and on a larger scale on source separated organics (SSO) or agricultural-based processes, but there is starting to be limited commercial-scale application in North America.

AD facilities must be designed and operated with odor prevention as a primary objective. The two main areas where odor can be released in the AD process are in the reception area where food waste is delivered, and from ammonia in the digestate. Anaerobic bacteria are sensitive to feedstock and environmental parameters; "upsets" of AD facilities can result in odor releases.

Historically, public opposition to siting of AD facilities associated with hog farming or sewage and paper plant facilities were based on odor issues. Recent innovations in AD facility design, including processing in completely enclosed facilities and improved emissions controls, have reduced concerns.

Table 10-4 provides a summary of the advantages and disadvantages of AD. While AD technology is commonly used for the organic fraction of MSW in Europe and for manures and sewage treatment in the U.S., it has not yet been widely used for MSW in the U.S. Even so, the number of proposed and new facilities has been increasing recently. AD can produce readily marketable types of energy such as methane or electricity along with potentially marketable digestate as compost, and perhaps a liquid fertilizer. Currently, the price of natural gas is affected by the increased production of gas reducing the revenue potential for methane produced by an AD facility.

There is adequate overall experience with AD that it could be considered a proven technology. But it is limited in its application to only the organic fraction of MSW and requires separation of the organics either via source separation or processing of MSW. Both of these increase the overall costs of an AD system.

Odor control can cause environmental and nuisance problems due to the anaerobic nature of the process. There are measures available to control the odors during the process.

Table 10-4
Advantages/Disadvantages of Anaerobic Digestion

Advantages	Disadvantages
♦ AD is a well understood process similar to sewage sludge digestion. Most people do not associate AD with toxic gasses (including dioxin) or ash, such that AD may be "preferable" to mass burn or RDF.	♦ While fairly common in Europe, AD is not widely proven for MSW in the U.S. Even so, several new facilities are being developed.
♦ Can be used in combination with other technologies to target organic wastes.	♦ Requires either source separation and collection of food and other organic wastes or processing MSW to separate organics. Both increase system costs.
♦ The end product of AD can be potentially saleable: biogas, electricity, soil conditioner and a liquid fertilizer.	♦ AD bacteria have specific environmental and chemical requirements, and may need a consistent feed stock, not a wide range of different organic materials.
♦ Anaerobic digestion contributes to reducing greenhouse gases by reducing demand for alternate fossil fuels.	♦ The digestate from an AD process may require further treatment to control odors.

There are a number of AD facilities in California that could be considered for a tour. There are also some fairly recently announced projects in Minnesota (in Le Sueur, Becker, and South St. Paul) that may provide opportunities to tour when they become operational.

10.6 Mixed Waste Processing (Front-end Separation)

Mixed waste processing technology can take many different forms. Essentially the purpose of a mixed waste processing (MWP) facility is to separate and remove recyclable materials from incoming mixed waste (i.e., divert the recyclable materials from the waste stream). The MWP facility can be a standalone facility or it can be part of a front-end separation process at a WTE facility, composting facility, transfer station, C&D waste processing facility, sanitary landfill, or even as part of a recycling facility handling source-separated recyclables.

In each case, the MWP facility is tailored to the specific waste streams and goals for the project. There are several approaches to facility design, materials targeted for recovery and costs. Approaches potentially applicable for R/W counties could be a facility targeting commercial waste loads with a high percentage of recyclables or as a front-end to a WTE facility.

MWP facilities may be developed with either relatively low-tech approaches using primarily manual sorting or more high-tech approaches using some mechanical, automated processes combined with relatively less manual labor.

The material products that typically can be recovered by a MWP facility include corrugated cardboard, office paper, mixed paper, newsprint, containers (aluminum, glass, tin cans, plastic, etc.), organics, wood and ferrous metals. Some recent projects have included a MWP component as the front-end of a "resource recovery park."

The markets for the recyclables include the standard markets utilized by source-separated programs. These include paper mills, insulation manufacturers, aluminum mills, glass manufacturing, metal mills, and plastic recyclers. Wood markets include mulch and wood fuels. Organics could go to an AD facility or potentially a compost facility if the materials are clean.

It should be noted that recyclables recovered via MWP facilities have a higher likelihood of contamination. Depending on market specifications and economic conditions, marketing recyclables from MWP facilities may be more difficult than from source-separated programs.

The recovery rate in a MWP facility will vary significantly depending on the composition of the waste stream delivered. For facilities handling the entire waste stream, less than 10 percent may be recovered leaving over 90 percent to be disposed or otherwise processed. For facilities targeting dry commercial wastes with high recyclable content, recovery rates may be at or above 40 percent leaving approximately 60 percent of the incoming wastes for disposal.

More than half the MWP facilities are located in the West (mainly California) where they handle yard debris and C&D debris, which count toward their waste reduction goal. MWP facilities have been added to some Minnesota waste-to-energy facilities (Polk County, City of Red Wing, and Pope-Douglas counties) as front-end separation processes to remove recyclable cardboard, metals, and glass. This may improve the overall fuel quality and reduce the size of the combustion facility required (saving some capital costs while increasing operating costs).

Rational Energies recently contracted with Hennepin County to install and operate a mixed waste processing facility at the Brooklyn Park Transfer Station. The original intent of this facility was to recover various plastics and metals with the plastics brought to the recently developed Rational Energies Plastics-to-Oil facility.

Republic Services recently opened a new mixed waste processing facility at its Newby Island Resource Recovery Park located in San Jose, CA. This facility has the ability to sort 110 tons per hour and recover high percentages of recyclables. There are four processing lines designed to process 400,000 tons per year. The facility processes all the commercial waste generated in San Jose. Republic has a contract with San Jose to collect and process all commercial material produced in San Jose. Materials are collected as either wet or dry streams. The facility recovers recyclables and organic matter as feedstock for further waste-to-energy processing. The system incorporates advanced screening, optical, and air separation technologies.

Table 10-5 provides a summary of potential advantages and disadvantages to an MWP facility.

As a “stand alone” facility, MWP would be of limited value to R/W Counties. However, as part of a “resource recovery park” the technology could be used to target recovery of recyclables, separate organics for AD or potentially composting, separate plastics for a plastics to fuel facility, with the remaining wastes either converted to RDF for combustion or to process with the gasification technology.

Table 10-5
Potential Advantages and Disadvantages of Mixed Waste Processing

Advantages	Disadvantages
♦ Can be added to the front-end of other technologies.	♦ Not appropriate for the entire waste stream
♦ Lower capital and operating costs than other major processing facilities.	♦ A stand-alone facility may divert only 10 percent of total R/W waste stream.
♦ Can be flexible to adapt to material market changes.	♦ Quality of recyclables recovered may be lower than source-separated programs.
♦ Can focus on specific waste streams with high recyclable content to increase recovery.	
♦ May eliminate the need for separate collection systems for generators.	

There are several mixed waste processing facilities in California that could provide tours for R/W Counties. The Newby Island Resource Recovery Park would provide an example of a higher tech facility targeting recovery of a significant percentage of materials as well as the combination of wet/dry collection systems and targeting recyclables rich commercial loads.

10.7 Plastics to Fuel

Plastics to fuel (PTF) systems use a pyrolysis process coupled with depolymerization/distillation components to convert recovered plastics into fuel (oil). Due to well established markets for numbers 1 and 2 plastics, numbers 2, 4, and 5 plastics are considered the best feedstock for plastic to fuel production. Process technologies vary from vendor to vendor with each having unique features and performance claims, but most use the same basic processes including;

- Some level of pretreatment – this could be as minor as size reduction or as involved as cleaning and moisture removal.
- Conversion – pyrolytic processes are used to convert the plastic to a syngas.
- Distillation – the syngas is converted to liquid form
- Acid removal process – removal of acids that form in the breakdown of some plastics.
- Separation/refining/final blending – the final steps required to make this product consumer ready can either be done on site or by a third party, depending on the design.

Plastics to fuel is a relatively new, emerging technology and is lacking the history of other technologies covered in this report. A list of advantages and disadvantages was not provided at this early stage in the technology, although it is promising from a waste management standpoint.

The following are insights regarding plastics conversion technologies;

- **Conversion technologies present another option for managing non-recoverable plastics.**

  At present, there are very few commercially operating facilities in North America. A number of "first generation" demonstration facilities are built and operating in North America, with the first commercial operation by Rational Energies, located in Plymouth, Minnesota. The average size of a current plastics-to-oil facility is in the range of 10-30 tons per day.

- **Different technology vendors/facilities have specific variations on the process to enhance conversion efficiency and/or to tailor the end product to local markets.**

  The primary objective of the conversion technologies is to convert waste into useful energy products, which can include synthesis gas, petroleum products, and/or commodity chemicals.

- **Estimates provided by vendors indicate a cost/ton is comparable to other MSW options, such as recycling and landfilling.**

  Vendors estimate that the cost to process the waste via pyrolysis is approximately $50 per ton which is generally related to the cost of electricity or fuel required to run the process. U.S. averages for landfill disposal and recycling, for comparison, range from $30-75/ton depending on region.

- **There is a high level of uncertainty associated with the environmental and cost data associated with pyrolysis.**

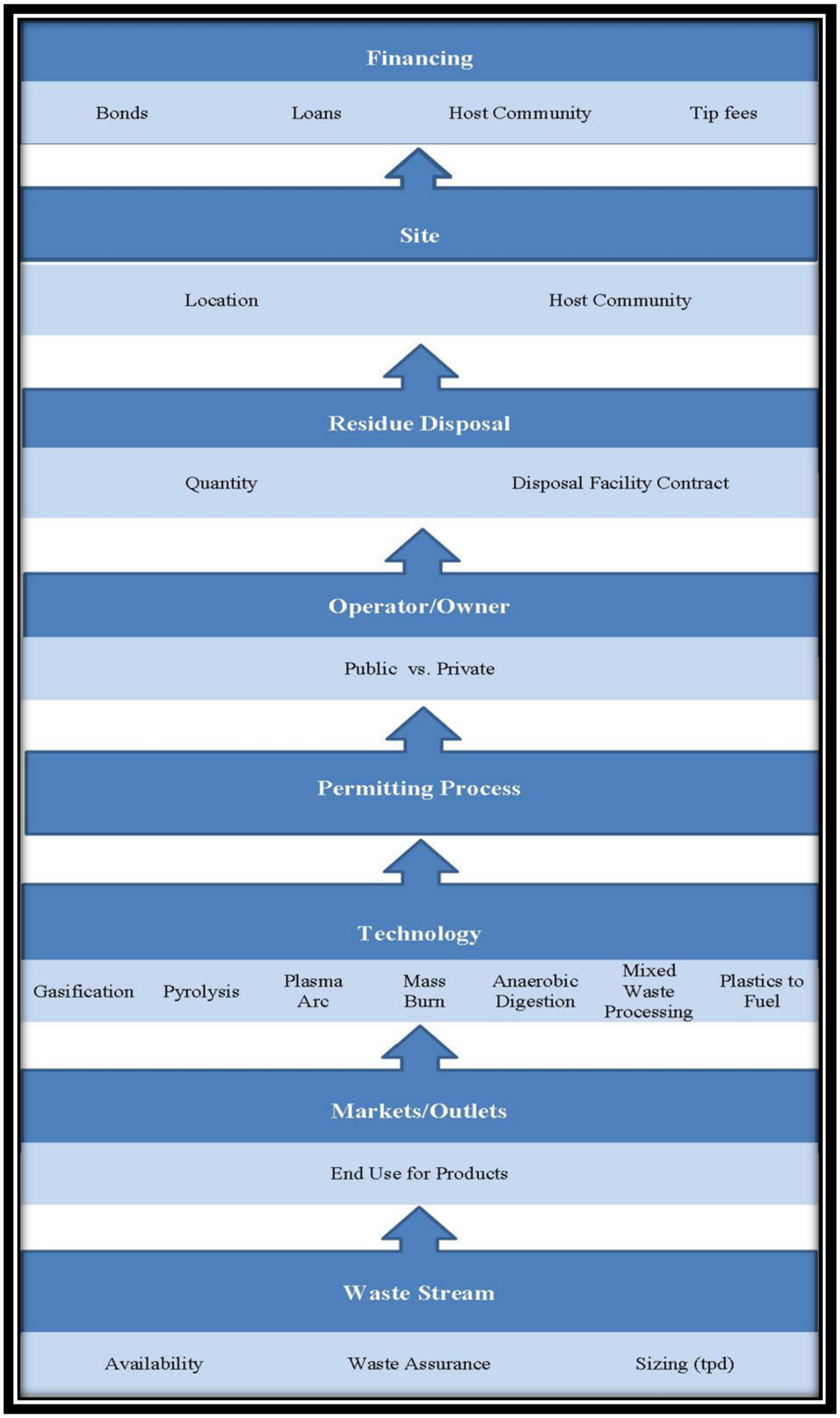
  Because most facilities are demonstration plants, they are operating in batch-test mode and not as continuous mode commercial plants. Until there are more commercially operating facilities there will not be good real-world data to characterize the environmental aspects and costs for PTF technology.

Rational Energies has a commercially operating facility in Plymouth, Minnesota, that provides a good opportunity for R/W Counties to tour and learn more about this technology.

10.8 Project Building Blocks for a Major Waste Management Facility

Consideration of a major waste management processing facility can be quite complex. One convenient way to organize the components and the associated issues is to think of the various components as building blocks to complete the project. Figure 10-1 shows the key components in a building block approach.

Figure 10-1
Project Building Blocks for a Major Waste Management Facility



The purpose of the facility is to manage solid wastes produced by our society; therefore, waste stream issues provide the base or foundation of the project. What wastes need to be managed or are available for a facility? Can the waste stream be controlled to assure it will be delivered? What type of wastes should be targeted? How much waste needs to be managed and what are the future projections for quantities? Resolution of these questions/issues is the first step in building a major waste management facility.

Selection of the technology and the markets for the technology somewhat go hand-in-hand. Without secure markets for the processing facilities end-products, the waste processing facility will not be successful (i.e., “no market, no project”). The selected technology must be capable of meeting the specifications of the targeted markets. This is a key consideration for whether the technology can be considered as a proven technology.

The facility cannot be built without all the required permits. To gain the permits requires meeting all the regulatory requirements and somehow gaining public acceptance. Solid waste facilities are typically locally unacceptable land uses (LULUs). Opposition from site neighbors and organized environmental groups is common. Securing this Project Building Block is typically the most difficult step in the process.

Somewhere in the process, a decision must be made as to who will own the facility and who will operate. Each of the options has advantages and disadvantages. The first basic decision is between public and private. Currently, flow control appears available for publicly owned and operated facilities. Procurement processes vary depending on owner/operator preferences. Selecting the preferred contractor and negotiating a contract also requires careful consideration.

The site selection is critical to the permitting process. Certain technologies require larger site sizes. Existing solid waste facilities are typically easier to expand than establishing new green field sites. The use of a Host Community Benefit Package is quite common.

All of the technologies have a residue waste stream. The quantities vary along with the characteristics. Arrangements must be made to assure long-term access to a disposal facility.

Financing is the building block that brings all the other project building blocks together. Financing the capital cost may require bond feasibility studies to address the feasibility of success for each building block. Ongoing revenue generation via tipping fees, market revenues, service charges, or tax support is fundamental to long-term success.

While this explanation of the steps to implement a major processing facility seems simple, the actual process is often times very complicated. It is very difficult to entirely resolve any one building block issue before moving on to another. Typically, waste stream issues are never fully resolved. Market conditions change with a global economy. New vendors try to enter the process even after a specific vendor is selected. Site selection, the permitting process, and community reaction are all complicated by the adverse image of solid waste facilities.