Appendix F
Description of Conventional Waste-to-Energy (WTE), Material Recovery, and Conversion Technologies (CTs)

1.1 Conventional WTE Technologies

Conventional WTE options include mass burn combustion, refuse-derived fuel (RDF) firing in a conventional, dedicated stoker furnace and Fluidized Bed Combustion.

1.1.1 Production and Combustion of RDF

Technology Description

In refuse-derived fuel (RDF) fired energy systems, the initial step of shredding the waste accomplishes a waste size reduction, which enables further processing involving screening, ferrous metals removal using magnets, sometimes followed by trommel screen processing or air classification. While there are several gradations of RDF, the most common involves shredding and ferrous metals removal. RDF is generally intended to be fired in a dedicated stoker furnace. Processing to a more uniform fuel potentially allows an RDF furnace to be smaller, operated with lower excess air and a higher efficiency, than its mass burn counterpart. RDF is also required for fluidized bed combustion systems that feature good gas/solids mixing at uniform temperatures, which aids the system in ensuring relatively complete burn-out of low-grade fuel.

As fluidized bed combustion requires a relatively homogeneous fuel, which is often difficult to obtain in processing MSW, there are only a few applications of this technology to MSW in Europe and the U.S. One in particular, in LaCrosse, WI, has been operating without major interruption for approximately 25 years. Another, a 600-ton per day (TPD) circulating fluidized bed combustion system, was proposed and designed for the community of Robbins, IL.

Economic Data

Using historical data and adjusting for industry design trends and inflation, it appears that an RDF production and furnace system in the 80-TPD size range would have a capital cost between $5 million and $10 million. It should be noted, however, that this result is extrapolated from historical data and is outside the range of actual data used to perform the regression analysis.

Average total annualized operating and maintenance (O&M) cost including amortization is expected to be somewhat higher than a mass burn plant, due to higher maintenance costs. Historical data averaged over a range of plant sizes (much larger than 80 TPD) would suggest an annual O&M cost including amortization that exceeds $75/ton. O&M cost data are not generally available for such small plant sizes, and the cost would likely be much greater due to the smaller-scale operation and variations in level of processing across historical plants.

Environmental Impacts/ Releases

Similar to a mass burn facility, primary air emissions from an RDF-burning furnace are from the stack and include the residue discharged from the furnace as well as the fly ash from the air pollution control equipment. Wastewater is also generated from equipment washdown and boiler blowdown.

Suitability

The RDF-firing technology alternative represents a significant commitment on the part of the host community, similar in level to the mass burn option. *Aside from public perception and permitting issues, an RDF production/combustion system may not be a cost effective option, given that favorable economies of scale are not available at the 20,000 ton-per-year (weekday average 80 TPD) capacity requirements of Glenn County.*

1.1.2 Mass Burn WTE Technology

Technology Description

The WTE mass burn technology option requires much less in the way of front-end materials separation processing than an RDF system, and is considered more robust, i.e., able to accept non-combustibles. Materials separation technology can be used to remove much of the low-caloric or non-combustible materials from the waste stream.

As is the case with other conventional thermal options, mass burn combustion is dependent on an aggregate heating value in excess of 5,000 British thermal units per pound (Btu/lb) of fuel fired. This would require that all recyclables with significant heating value such as plastics and paper products remain in the waste feed. This would be contrary to some of Glenn County’s current and proposed diversion programs for AB 939 that include removal of newspaper, cardboard, and wood and yard waste for composting[1]. In order to gain diversion credit from a mass burn WTE facility, Glenn County would have to obtain Local Enforcement Agency/California Integrated Waste Management Board (CIWMB) approval of adequate diversion credit from a WTE plant as an alternative to existing and planned diversion programs that remove organic materials needed for a WTE plant. This appears unlikely given current regulations that do not allow diversion credit for new mass burn WTE plants and failures in attempts to obtain diversion credits for new WTE plants.

Economic Data

The range of capital costs for a WTE mass burn system can vary widely, depending on the technological basis of design, scope of supply, ancillaries, and type of air pollution control equipment, as well as other factors. One regression analysis suggests that the capital costs including cost of capital for an 80-TPD mass burn system could be in excess of $14 million. However, as in the case of the RDF cost analysis, the 80-TPD solid waste capacity at Glenn County is well below the plant size range used for predicting capital costs. Also, it is generally recognized that conventional combustion systems do not present economies of scale for such a low capacity requirement.

Average total annualized O&M cost including amortization can be on the order of $75/ton of waste processed, based on a 500-TPD plant. Again, the analysis is for order-of-magnitude estimating purposes only and is not a reliable predictor of O&M costs for an 80-TPD facility size. It is reasonable to assume that the unit cost for an 80-TPD facility would be much higher (double or more) due to basic capital facility and operating requirements and economies of scale.

Environmental Impacts / Releases

Primary air emissions from mass burning of MSW are from the stack and include the residue discharged from the furnace as well as the fly ash from the air pollution control equipment. Unburned solid waste and ash residue are discharged from the furnace and, along with the fly ash from the air pollution control equipment, typically require land disposal. Wastewater is also generated from equipment washdown and boiler blowdown.

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[1] Final Summary Plan of the Glenn County Integrated Waste Management Plan, March 1998, includes existing and planned programs for newspaper and cardboard recycling, and wood and yard waste composting.

Suitability

Based on the CIWMB's application of general waste composition data for California to Glenn County, but assuming *no recycling* and ignoring obvious economies of scale issues presented above, the waste stream can theoretically support a conventional combustion option at 5,345 Btu/lb of waste fuel, as presented in Table 2-2. However, Glenn County has a drop-off center program and will be encouraging additional recycling in the near future to help meet its waste diversion target under AB 939. *As a result, the necessary heat content of the fuel stream will likely not support any conventional combustion option for Glenn County. It should also be noted that permitting and public perception issues in California would likely make siting a conventional WTE plant in Glenn County extremely difficult.*

1.2 Materials Recovery/Reuse

This section presents a materials recovery or recycling technology alternative that could either be included in the transfer station option discussed in Section 2.2.2, or precede a combustion facility (if conventional combustion were feasible for Glenn County), a composting operation, or next generation conversion technology such as anaerobic digestion. The purpose of a materials recovery facility (MRF) is to recover components of the waste stream that may have value as recycled/reprocessed products. After valued materials are removed, the residuals can be landfilled.

In addition to marketing the plastics, glass and ferrous metals for example, much of the kitchen and yard waste materials may be diverted to a composting facility. Alternatively, the organic materials along with cellulose or paper products could also be diverted to an in-vessel bioreactor to produce biogas, although separation of these components from a mixed municipal solid waste (MSW) waste stream at the level needed an in-vessel bioreactor can be challenging and costly. That fact underscores the importance of designing a MRF that will reliably produce high quality ("clean") by products for any WTE/CT facility.

1.2.1 Separation of Recyclables from MSW

Technology Description

A typical MRF process will consist of both hand picking and mechanical processing. Labor sorting serves as a quality check to remove the obvious oversized bulky waste and large pieces of construction and demolition waste from the waste pile for separate processing and/or disposal. The bulk of the waste is then subjected to various levels of screening and classification, using trommel screens, air classifiers, and ferrous metal magnets to effect separation and recovery of commodities to be recycled and inert materials to be disposed of. The level of separation depends on whether processing is to precede a combustion system or a bioconversion system, such as anaerobic digestion. In that case, organic matter is prized, and the non-organic, non-compostable constituents are to be removed as recyclables and marketed, while inert materials will be disposed of in a landfill.

A more equipment-intensive mixed MSW MRF will consist of parallel processing lines featuring shredders to size reduce the waste and screens to separate larger items not removed by pickers on the sorting floor. This would be followed by robust trommel screens and ferrous metal magnets. Most magnetic separators cannot produce a salable ferrous metal product from MSW without substantial added processing to remove trash and contamination.

As described above, facilities that recover recyclables directly from mixed municipal solid waste (sometimes historically termed "dirty MRFs"), are integral to the success of the selected MSW thermal, biological or chemical treatment technology. Also defined as MRFs are materials recycling facilities that sort individual recyclables from commingled recyclables, which can be collected at curbside or deposited at a drop-off center or buy-back center. The primary reference to MRFs in this appendix involves mechanized removal of recyclables and inert materials from mixed MSW.

Economic Data

For a MRF that achieves separation of a co-mingled recyclable stream at a plant capacity of 60 TPD to 80 TPD, the adjusted capital cost will generally be in the $1 million to $2 million range. However, MRFs that separate recyclables from mixed municipal solid waste, including significant mechanized sorting equipment, will easily cost 2 to 3 times that amount or greater. This is due to the fact that sorting recyclables from MSW requires more extensive and robust equipment than from sorting commingled recyclables, as mentioned above. The operating cost for such a MRF is also higher.

Integration with Other Technologies

As mentioned earlier, the importance of pre-processing of MSW and materials recycling has been demonstrated for WTE combustion technologies. It is also often applied as an integral part of other MSW management strategies such as composting and landfilling. Composting also requires materials separation to remove non-compostable inorganics, consisting of both recyclables as well as inert materials. The landfill life can be extended when recyclables are removed.

Suitability

Separation of recyclables, or other unsuitable materials, from MSW will need to be undertaken at some degree at the front end of the other WTE/CT facilities described in this appendix. However, separation of recycles from MSW received at the GCLF site could also be undertaken as a distinct strategy by Glenn County as part of the transfer station option discussed in this report, Option II. This can be done at a relatively economic level using limited manual or wheel-loader separation on the tipping floor. If additional diversion is required, the County could enlarge the transfer station and add mechanized equipment and labor for sorting in a MRF process. *Both load-tech floor recovery and higher levels of labor and mechanized equipment in a MRF facility would be suitable, proven technologies for Glenn County and would receive full AB 939 diversion credit.*

1.2.2 Conventional MSW Composting

An alternative to landfilling organics or attempting to burn them in a conventional mass burn or RDF combustion system is to design and install a conventional composting facility for MSW. In addition to the requirement of having sufficient organic and yard waste to support a composting operation, such a project must provide sufficient processing to promote aerobic decomposition. There must also be a demand for the compost product, likely from agricultural and landscaping sectors of the local economy.

Technology Description

Several generic forms of composting, in the context of MSW composting, are defined below:

- Turned windrow: Most MSW composting facilities in the US have utilized the turned windrow method, which consists of piled compostable MSW, typically in rows at least 5 feet high. A variety of manual and machine techniques can be employed to periodically mix compost to assure that sufficient oxygen is available to support aerobic biological activity.
- Static Pile with Forced Aeration: While more commonly used in sludge composting, this method of creating a static pile of compostable MSW has been

used. While air can be forced into the pile, heterogeneous material such as MSW will often not receive enough oxygen, causing the pile to become anaerobic, with attendant odors.

- In-Vessel: This conventional method is broadly defined as decomposition taking place in any container where the material to be composted is aerated and mixed by mechanical means. A next generation technology of this type, namely anaerobic digestion, features highly controlled biological decomposition in-vessel, often involving temperature and pressure control to accelerate gas production and organic decomposition. [Anaerobic digestion is presented in Section 2.2.3.4]
- Hybrid: The most commonly found hybrid approach to composting is the use of a conventional in-vessel system followed by a static pile or windrow composting.

Composting of MSW has seen resurgence around the world in the past two decades; for the U.S. that trend was more noticeable in the 1980s into the early 1990s. During that period, increased interest in the US in composting paralleled the closure of smaller landfills, the increased cost and time in permitting larger landfills that complied with Resource Conservation and Recovery Act (RCRA) Subtitle D regulations, a downturn in public support for combustion facilities burning MSW and increased interest in recycling. Mixed waste composting, however, began to experience technical and odor problems with increasing costs to maintain product quality. Like recycling in many states, composting has also suffered from state and local budget cuts. As a result, interest in implementing composting operations has waned in many states. In California, turned windrow or open composting of MSW would likely be difficult to permit and perceived negatively by the public due to air emissions and the potential for odor problems.

Economics

In order to achieve aerobic decomposition, it is essential that MSW be size-reduced to maximize surface area thereby allowing micro-organisms to consume the organic materials. This step is most commonly accomplished with shredding and grinding equipment, as well as rotating drums that pulverize waste. However, size reduction equipment is the most capital (as well as O&M) intensive part of a composting system, often exceeding $1 million, installed for a shredder. Capital costs for the more commonly found MSW windrow systems can range from $20,000/ton to $60,000/ton per day. O&M costs typically range from $20/ton to $40/ton for operations, but would likely be higher for a small operation that would be undertaken for Glenn County.

Energy

Composting systems are net energy consumers. The type of composting system and the amount of waste processed will determine energy usage at MSW composting facilities. The largest single energy use is size reduction, making up approximately 50 percent to 70 percent of the total. Other large energy users are blowers for forced aeration, air classifiers, and trommel screens.

Environmental Releases / Impacts

Odor issues can be a nuisance factor, especially when inefficient composting systems are used, such as the low-cost static pile where anaerobic conditions can sometimes exist. These odors can be minimized by proper agitation of the pile, as is the case with windrows.

Integration with Other Technologies

While composting can be achieved for a relatively low cost compared to other thermal and more sophisticated biological systems, its effectiveness depends on the availability of size-reduction equipment and other compatible technologies with which it will be used. It has been most effective in the U.S. when limited to homogeneous waste streams (yard wastes) that can be effectively managed using low-cost methods. As mentioned earlier, odor nuisance problems are generally more prevalent with compostable MSW compared to the route-separated yard wastes.

Suitability

Based on the small waste stream of 20,000 tons per year for Glenn County, assumed to be roughly 50 percent organic material, a MSW composting operation would be more expensive than a landfilling operation for Glenn County. This is because incoming MSW needs to be processed to remove inorganics and many of the materials removed would have to be landfilled. Although the diversion rate would be higher than the landfill and transfer station options (a much larger portion of the roughly 50 percent organic fraction of the waste stream), the potential for odor problems, from operations other than in-vessel composting, would be higher than for the landfill or transfer station options.

1.3 Potential "Next Generation" Technologies

Next generation MSW conversion technologies (or CTs) use advanced thermal, biological, or chemical processes to convert the carbon-based portion of a MSW stream into a synthetic gas. This gas, or "syngas," is then used to produce electricity, chemical and/or fertilizer products.

Some CTs have been used in industrial applications for a number of years. These include pyrolysis, gasification and anaerobic digestion, which have successfully converted such feedstocks as coal, wood and wood waste, petroleum coke, sewage sludge, and biomass. *MSW, however, is a new application, which requires significant front-end processing to make MSW more of a homogeneous feedstock.*

1.3.1 Thermal Conversion Technologies

Thermal CTs include pyrolysis, gasification (alone or in combination with pyrolysis), plasma gasification and syngas-to-ethanol using a catalyst. Of these, pyrolysis/gasification has several decades of industrial experience, while plasma gasification probably the least. Gasification/ pyrolysis applied to MSW has been investigated on a pilot-scale basis, with very limited larger scale experience. It is the most promising in concept of those mentioned above, and therefore discussed further, below.

Gasification / Pyrolysis

Pyrolysis is defined as a chemical change resulting from the addition of heat in the absence of oxygen. More broadly, it encompasses all thermal degradation processes without combustion, either proceeding without oxygen (pure pyrolysis) or under partial oxidation (gasification). Products from this sort of degradation include solid char, a liquid tar and a gas, which are considered high-energy-density fuels that store and transport easily and therefore may be substituted for conventional fuels. Pyrolysis has had a long history of industrial applications with varying feedstocks, but not as non-homogeneous as MSW.

It has been suggested that particulate emissions and heavy metals pyrolyze in the char, potentially reducing environmental emissions. Also, pyrolysis off-gas can be recycled. Less positive is the fact that it is difficult to control reactions in this process. The lower quality of MSW/RDF fuel, namely the high moisture and ash levels, is expected to produce lower quality char and gas.

Suitability

In addition to no established markets being available for its products, pyrolysis remains unproven on a large scale, at least for the MSW application. Therefore, while it has been studied for over 30 years, is not being recommended to Glenn County.

1.3.2 Biological and Chemical CTs

Biological and chemical CTs include anaerobic digestion, fermentation to ethanol, syngas-to-ethanol using engineered bacteria, thermal depolymerization, catalytic cracking, and acid hydrolysis. Of these, anaerobic digestion has considerable application experience in managing sewage biosolids, farm wastes and, to a lesser degree, the organic portion of MSW that might otherwise end up in a landfill. Several full-scale systems in Europe have achieved successful operation on organic waste streams. While there is every indication that anaerobic digestion will prove successful on mixed MSW coupled with a high-efficiency front-end processing system, experience to date for this application is very limited, even in Europe. Because of it considerable application to biosolids and promise for application to MSW, anaerobic digestion applied to MSW is discussed further, below, as a potential CT application to Glenn County.

1.3.2.1 Anaerobic Digestion Applied to MSW

Much of the biodegradable organic matter in MSW, namely paper, food waste and yard waste can be bio-converted anaerobically to methane and carbon dioxide, which provides a measurable, renewable energy resource potential. Removal of carbon dioxide and water can further produce a suitable pipeline quality gas. In addition to this fuel value, bioconversion processes have the potential for producing a stabilized solid product that may be suitable as a fuel for combustion or used as a compost soil amendment.

Bioreactors include in-vessel anaerobic digesters of MSW that produce methane for use as a fuel substitute for natural gas or to power an energy plant. While their use in reducing sewage sludge and farm waste is well known and its application to MSW has potential, there are only a few operating systems based on organic solid waste streams in Europe at this time. In the U.S., the Edom Hill project planned in Palm Desert, CA will be accepting “route-separated” or (“bio”) wastes, i.e., dedicated kitchen and garden wastes from restaurants and supermarkets. While not a mixed MSW application, that project has generated considerable interest. It is expected to begin operating in 2007.

Technology Description and Background

While conventional (in-vessel) anaerobic digestion processes have been used since the mid-1800s to stabilize settled sewage solids, productive use of biogas from MSW in a controlled environment (in-vessel) is not in widespread practice in the US or around the world. The only large-scale MSW facility developed in the US was at the Pompano Beach, FL Solid Waste Reduction Center site (RefCom), which was operated from 1978 to 1985.

Interest in biomass to energy conversion, including MSW, has developed over the past 50 years primarily on a pilot-scale basis in the U.S. and France. Much of the anaerobic digester activity in the past 10 to 15 years has taken place in Europe, particularly Denmark and Germany, According to the German Technical Co-operation Agency, as of 1999, there were nearly 400 commercial anaerobic digestion plants worldwide, treating portions of MSW as well as industrial wastes. This progress, principally on farm waste, suggests to developers the applicability to other high-organic waste treatment, namely mixed MSW. Companies such as Valorga, DRAINCO and others have been actively pursuing MSW applications. As indicated, the Edom Hill, Palm Desert, CA project will be accepting route-separated organic wastes when it begins operating in 2007.

Economic Data and Diversion Levels

Anaerobic digestion of wastes, in particular route-separated organic wastes, has the potential to divert 70 percent to 80 percent or more of these wastes from landfills. In the case of route-separated waste, only minimal labor processing is needed to assure a “clean” feedstock for the anaerobic digesters. However, the diversion potential is expected to be lower when processing and separating organic and cellulose materials from mixed MSW, due to increased mechanical processing and labor effort required and the increased residual.

Costs for a fully turnkey system will include equipment capital investment for the digesters and engine plant, financing, return on equity and operating costs for a 20-year system with “put or pay” contracts in place. The aggregate unit cost will depend heavily on the initial quality of the source material feedstock, degree of mechanical and labor processing required, and availability of key infrastructure (such as trash transfer station building or other appropriate structure, as well as land). The typical aggregate unit cost range may be $50/ton to over $100/ton of material processed through the anaerobic digesters. This is the cost range expected for operations <u>greater than 100 TPD or for</u>

processing and digestion of source-separated waste streams. For Glenn County, the economies of scale will be far less attractive considering that only a portion of the 60 TPD to 80 TPD waste stream would be processed in digesters and a good deal of pre-processing would be required. It is expected that the cost for processing the Glenn County waste stream, due to it composition and size, is expected to be $100/ton to $200/ton or higher.

Suitability

Attachment F-1 contains a system schematic description for the RefCom project, scaled to the current GCLF waste stream. This is termed a "benchmark" facility because it is a known application of anaerobic digestion technology to MSW. *Based on this proof-of-concept, anaerobic digestion in considered the CT with the highest potential for application to Glenn County compared to other WTE/CT discussed, above. The current designs in Europe and planned in the U.S., applied to only route-separated organic waste streams, may help to further development of overall MSW stream applications. However, this technology still needs to be proven in full-scale applications using MSW.*

Attachment F-1

BENCHMARK CONVENTIONAL ANAEROBIC DIGESTION SYSTEM

With the uncertainties surrounding application of anaerobic digestion systems to MSW, Shaw presents the following analysis of a conventional system operated many years ago. It attempted to establish a proof-of-concept for MSW applications.

One of the difficulties in recommending anaerobic digestion is that while its potential application to MSW is considerable, hard data are lacking. The most complete data available come from the proof-of-concept project experience of the RefCom project. This benchmark project has great instructional value in that a very robust (RDF fluff-like) materials recovery process will be required to assure high quality feedstock for the digester. The RefCom project also depended on a significant amount of primary sewage sludge to accelerate the digestion process.

The current Valorga designs in Europe and future applications in Europe and the U.S. relating to MSW are likely to improve upon the technologies used at RefCom. However, effective front-end processing and tailored nutrient/sludge loadings will need to be proved in full-scale applications using MSW.

RefCom Anaerobic Digestion System Concept

A general flow diagram for a conventional MSW anaerobic digestion system is illustrated in **Figure A**. The overall process can be divided into: (i) feedstock preparation (involving both size reduction and a series of screening/separation steps); (ii) feed dilution and (anaerobic) digestion, (iii) gas recovery; and (iv) residue treatment.

The as-received MSW feedstock must be size-reduced using a primary shredder or a flail mill, or both in combination, to increase feedstock homogeneity, an essential first step. After ferrous metals removal and trommel screening, a secondary shredder may be employed to assure a maximum surface–to-mass ratio and thereby accelerate digestion. Additional separation technologies, such as screening, air classification, and cyclone separation of materials based on density will be used to further remove inorganics. In particular, textile and plastic “stringer” materials must be removed, as they will foul the digester stirring mechanism. The recovered constituents will either be disposed of in the landfill or marketed as recyclables.

The preparation or pre-processing steps closely resemble those required to produce fluff RDF, which is slightly more refined than typical RDF due to the additional processing required to remove contaminants that will impede anaerobic digestion. The fluff RDF is then mixed with dilution consisting of a nutrient loading and primary sewage sludge to promote digestion. This process produces off-gas, which is then scrubbed to remove carbon dioxide and water, resulting in methane. Available methane may be sufficient for combustion in a gas-fired engine to ultimately produce electricity for on-site use. If the substation and line costs can be justified based on the quantity of methane recovered, the sale of electricity to the grid may be possible. In addition, some of the methane produced may be used to fire the boiler to generate steam for the anaerobic digestion process.

The digestion residue stream is dewatered, with most (or all) of the liquid returning to dilute the new batch of RDF fluff feedstock. The remainder is disposed of. The solid residue from the digestion process can be combusted to produce steam for the anaerobic digestion process. If there is another source of energy to maintain temperature during anaerobic digestion, the resulting solids may have value as compost, depending on the local markets and competing compost quality.

INSERT PDF OF FIGURE A HERE